DOI: 10.21608/pajn.2025.330847.1157

Original Article

Different Techniques of Atlantoaxial Posterior Screw Fixation with Special Attention to High Riding Vertebral Artery

Nabil Amin Nasef,[1] Ahmed Sherin Hamdy,[2] Mohamed Elsayed Abdel-Bary[2]
[1]Department of Neurosurgery, Faculty of Medicine, Kafr Elsheikh University, Kafr Elsheikh, EGYPT
[2]Department of Neurosurgery, Faculty of Medicine, Alexandria University, Alexandria, EGYPT

Received: 23 October 2024 / **Accepted:** 18 January 2025 / **Published online:** 15 June 2025

BACKGROUND: Posterior atlantoaxial fixation (AAF) is a standard surgical procedure for atlantoaxial instability (AAI). Cervical 1 (C 1) lateral mass-C2 pedicle screw fixation is the most common adopted technique by many surgeons affording solid fusion, potential reducibility, with minimal risk of vertebral artery (VA) injury, yet achieving favorable clinical outcome. In the setting of a high-riding vertebral artery (HRVA), the placement of screws remains a challenge due to narrow C2 pedicle increasing the risk of VA injury mandating proper preoperative evaluation for effective safe fusion.

OBJECTIVE: To evaluate posterior AAF for patients with AAI assessing clinical, functional and radiological outcomes, and complications with special consideration for HRVA.

METHODS: Retrospective study of 58 patients with AAI, aged 11-68 years old who underwent posterior AAF between March 2011 and July 2023 with a minimal follow up period of 1 year. Patients' demographics, clinical presentation, HRVA incidence, laterality, type of screw fixation, diagnosis, operative data, clinical, functional, radiological outcomes and complications were tabulated and analyzed.

RESULTS: Fifty-eight patients underwent AAF. Forty-eight (82.8%) patients without HRVA underwent C1 lateral mass-C2 pedicle screw fixation. HRVA was noted in 10 (17.2%) patients. Four (40%) patients had bilateral HRVA, and 6 (60%) patients had unilateral HRVA. In cases with bilateral HRVA, 3 (30%) cases had bilateral C2 laminar screws, and 1 (10%) case had bilateral C2 pars screws. In cases with unilateral HRVA, 3 (30%) patients had unilateral pars screws, 2 (20%) patients had unilateral laminar screws, and one (10%) patient had unilateral C2 pedicle clamp. Postoperatively, there were statistically significant clinical and functional improvements. Fusion was achieved in 98.3%. Only 1 screw severely violated transverse foramen. Complications were venous bleeding in 6 (10.3%) patients, infection in 1 (1.7%) case, irritation of the C2 root in 1 (1.7%) patient. Vertebral artery injury occurred in 1 (1.7%) case.

CONCLUSION: Careful preoperative radiological studies are crucial for identifying HRVA. Different techniques of atlantoaxial posterior screw fixation are used to reduce VA injury risk. The selection of screw fixation techniques in the presence of HRVA must be individualized based on the patient's specific anatomical challenges. Unilateral pars screw fixation is commonly used due to its balance between safety and efficacy. Bilateral laminar fixation provides robust stabilization when feasible, while unilateral trans-laminar and bilateral pars fixation serve specialized roles. Using a unilateral C2 pedicle clamp offers a valuable alternative in high-risk cases.

KEYWORDS: Atlantoaxial instability, C2 pedicle screw, High riding vertebral artery, Posterior atlantoaxial screw fixation.

INTRODUCTION

The atlantoaxial joint functions as a highly mobile hinge joint and it is mainly responsible for axial rotation with a little role in flexion/extension and lateral bending.[1] Atlantoaxial instability (AAI) is defined as an atlantodental interval (ADI) greater than 5 mm. AAI can be a result of trauma, infection, congenital, tumour or rheumatological diseases. Traumatic instability results from forced neck displacement, disrupting the transverse ligament, with or without the alar and apical ligaments. Congenital conditions such as Down syndrome, and Os odontoideum predispose to AAI by ligamentous laxity and osseous abnormalities. Inflammatory causes like chronic rheumatoid arthritis can lead to instability due to chronic synovitis and ligamentous laxity.[2]

Correspondence:
Ahmed Sherin Hamdy
Department of Neurosurgery, Alexandria University, Alexandria, EGYPT
Email: ahmed.sherin@alexmed.edu.eg

Internal fixation remains the primary treatment approach for stabilizing the atlantoaxial joint.[3] Initially, steel wire and laminar clamps were employed for fixation, but they proved inadequate in providing sufficient strength. Even with external fixation, the atlantoaxial fixation failure rate remained relatively high.[4] However, advancements in fixation techniques have led to significant improvements in instrumentation, with multiple methods being reported and applied in surgery.[5]

The most used methods for atlantoaxial fixation include the Magerl technique, which involves the use of transarticular screws, and the Harms technique, which combines atlantal lateral mass screws with axial pedicle screws.[6] Both techniques have been shown to provide rigid fixation and achieve high fusion rates and satisfactory clinical outcome.[7]

Posterior AAF is a common surgical technique to treat AAI. Posterior atlantoaxial fusion procedure involves various posterior screw fixation options, including transarticular, pedicle, pars, and translaminar screws.[8] However, posterior screw fixation of the upper cervical spine using C1 lateral mass screws (C1LM) and C2 pedicle screws (C2PS) is a challenging task due to the complex anatomy of the atlantoaxial vertebral complex, its proximity to vital vascular and neural structures, and the requirement for high accuracy to avoid complications such as vertebral artery (VA) injury, nerve root injury, and spinal cord injury.[9]

The course and dominance of vertebral artery and the width of the C2 pedicle greatly affects the type of C2 screw in the setting of decreasing the risk of vertebral artery injury and achieving effective reduction and stout fixation. The width of C2 pedicle less than 4.5 mm carries a high risk of breaching the transverse foramen and VA injury using the transpedicular fixation. Also, the vertebral artery after passing through the C2 transverse foramen may have a variable anatomic course making the preoperative radiological evaluation a must for successful surgery. The regular course of vertebral artery is to bend posterolaterally in a horizontal orientation just after exiting the transverse foramen. But in a non-negligible percentage of cases vertebral artery may have a variable course. One of the common anatomical variations of the course of vertebral artery is high riding vertebral artery (HRVA).[9,10]

HRVA is defined as isthmic height ≤ 5 mm or internal height ≤ 2 mm measured at 3 mm from the outer border of the spinal canal. HRVA is either too medial, too high or too posterior, making it in the path of the C2 pedicle screw or C1-C2 transarticular screw. Studies have reported a prevalence of HRVA and narrow C2-pedicle diameter, affecting 8-61.49% of cases.[9,10]

This work aimed to compare different options of posterior atlantoaxial screw fixation with care to HRVA.

PATIENTS AND METHODS

This retrospective study was performed on 58 patients with AAI who presented to a single tertiary referral center for AAF between March 2011 and July 2023 with a minimal follow up period of 1 year. Of the treated 58 patients with AAF, 10 patients had HRVA (4 patients had bilateral HRVA, and 6 patients had unilateral HRVA).

Exclusion criteria included patients who had previously undergone surgery in the occipito-cervical region, those with previously failed AAF and patients with incomplete medical records or follow-up period less than 12 months.

In the current study, none of the treated cases had transarticular fixation due to lack of available navigation which is mandatory for insertion of C1-C2 transarticular screws. The standard procedure was C1 lateral mass - C2 pedicle screw fixation as this technique provides rigid fixation and allow reduction. In patients with HRVA whether unilateral or bilateral, the width of C2 pedicle was measured by 3 dimensional (3D) computerized tomography (CT) and when proved too narrow (≤4.5 mm) the use of standard C2 pedicle screw was precluded and was replaced by either pars or laminar screw based on surgeon decision.

For all enrolled patients, the preoperative assessment included patients' demographics, body mass index (BMI), diagnosis, clinical presentation and follow up period. Radiological imaging was employed to obtain detailed anatomical knowledge of the atlas and axis vertebrae. X-rays, including extension and flexion views, were used to confirm the instability and reducibility of the C1-C2 complex. Computerized tomography (CT) scans with 1 mm slices were utilized to evaluate potential pathways for C1LM and C2PS and to assess the width of C2 pedicle, the internal height and isthmus height to identify cases with HRVA. Additionally, CT angiography was performed to visualize the course of the VA in the C1-C2 region, enabling the identification of any anomalies and minimizing the risk of VA injury and to identify the dominant vertebral artery. Magnetic resonance imaging (MRI) was also employed to assess possible cord compression. **(Fig. 1)** represents dynamic X ray of the cervical spine assessing reducibility in extension lateral view.

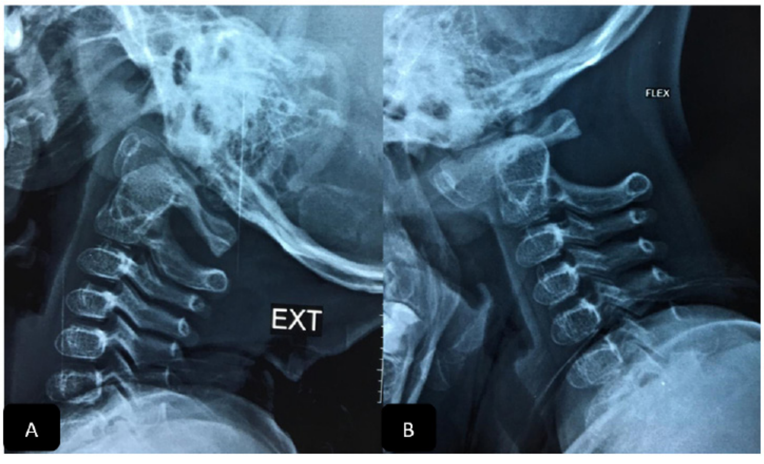

Fig 1: Dynamic X ray cervical spine assessing reducibility of atlantoaxial instability in extension lateral view. A. Extension View. B. Flexion view.

Revised operative data included operative time, operative blood loss, length of hospital stays and perioperative complications.

Assessing the treatment outcome, the clinical evaluation was assessed using pain numeric rating scale (NRS). Functional outcome was evaluated using American spinal injury association (ASIA) scale. Radiological outcomes included assessment of proper screw positioning and successful fusion. Proper screw insertion was defined as presence of all screw serrations within the bone, while minimal violation was defined as less than 50% of screw diameter violating the surrounding cortex. Severe violation was defined as more than half diameter of screw violating the cortex. This was assessed by plain X-ray and 3 D CT with reconstruction done in day 1 postoperatively. Assessment of fusion was done using dynamic X-ray and CT done after 12 months follow up and was considered proper if there was ≤ 2 mm translation between C1 and C2 on dynamic X-ray and CT assessment.

Operative technique

Antibiotic prophylaxis was given 30 minutes before skin incision. Patients were placed in prone position over a radiolucent operative table to permit intraoperative fluoroscopy. Intubation was conducted using fiberoptic technique. The head was fixed with a three-pin MAYFIELD® skull clamp (Integra Life Sciences Corporation, Cincinnati, OH). A lateral view X-ray was obtained before skin incision to ensure proper reducibility of C1-C2. Traction was applied if there was no spontaneous reducibility. Skin incision was done in midline exposing from inion to C3 preserving C2-C3, C3-C4 facets. Dissection was done exposing the posterior arch of C1 reaching the medial edge of vertebral artery groove and the inferior surface of the posterior arch exposing the lateral mass of C1. Exposure of C1-C2 joint was avoided to prevent unjustifiable bleeding from the nearby venous plexus around C2 nerve root which was retracted inferiorly, and a starting point was created on the mid-point of C1 lateral mass using a high-speed drill. Screw pathways were created with a medial trajectory 0-10 degrees from the midline and directed anteriorly towards the anterior tubercle of atlas till reaching the posterior border of the anterior arch of C1. The track was tapped . Poly-axial screws (3.5 mm diameter) were inserted into the lateral mass.

Considering C2 pedicle screw insertion, to prevent misplacement of the C2 pedicle screw into the spinal canal, the medial border of the C2 pedicle was identified using small dissector. The transitional corner, located cephalad on the lamina and C2 isthmus, was identified, and an entry point was created 4 mm laterally and caudally. The screw was inserted with a medial (20-30 degrees) and upward orientation towards the base of odontoid process, guided by palpation of the C2 pars interarticularis. This was followed by using a pedicle probe to confirm proper screw pathway, then tapping followed by insertion of poly-axial screws (3.5 mm diameter). After insertion of C2 pedicle screws, reduction of C1-C2 was accomplished using a persuader, monitoring both heat rate and arterial blood pressure as indicative of spinal cord compression.

Considering C1-C2 fusion, cases with unstable odontoid fracture did not need fusion. In cases with congenital and inflammatory conditions of atlantoaxial instability, decortication of posterior arch of C1 and C2 lamina were done, and fusion was accomplished by either using autologous iliac crest bone graft or hydroxyapatite mixed with platelet rich plasma (PRP). This was fixed in position with sutures to either the rods or C1-C2 bone.

For the insertion of C2 pars screws, the entry point was located 3-4 mm superior to the C2-C3 facet joint and in the midpoint of the pars mediolaterally, and the screw was angled 10 degrees inward and 45 degrees upward. Typically, a screw that was 14-18 mm long and 3.5 mm in diameter was used.

For the insertion of the left C2 laminar screw, the point of insertion was situated at the intersection where the right side of the C2 vertebral spinous process met the lamina, near the upper edge. In a comparable fashion, when inserting a right C2 laminar screw, the point of entry was at the convergence of the left side of the C2 spinous process with the lamina adjacent to the lower end. The direction taken for the screw was aligned with the angle of the C2 lamina's exposed surface on the opposite side. From the starting point, a pedicle probe was directed as dorsally as possible avoiding violation of spinal canal. After tapping, the proper screw length was identified, and poly-axial screws were inserted.

Pedicle clamps hooks were used in a single case. Two C2 pedicle screws were inserted. The laminar hooks were placed on the posterior arch of atlas, then the laminar hooks were connected to C2 pedicle screws with rods.

The primary outcome was the incidence of HRVA and type of C1-C2 fixation. The secondary outcomes were screw placement accuracy, fusion rates, clinical, functional outcomes and complications.

Statistical analysis

Data analysis was conducted using statistical package for social science (SPSS) version 26 (IBM Inc., Chicago, IL, USA). Quantitative data were analyzed using descriptive statistics, presenting means and standard deviations. Qualitative data were summarized using frequencies and percentages. Statistical significance was defined as a two-tailed P value less than 0.05.

Ethical Approval

All patients had signed informed consent before surgery and for active participation in this study. The study was revised and approved by the Ethics Committee of the Faculty of Medicine of Alexandria University (Institutional review board (IRB) regarding human subjects).

RESULTS

This retrospective study included 58 patients who underwent atlantoaxial fixation due to atlantoaxial instability between March 2011 and July 2023 in a single tertiary center. There were 10 cases who proved radiologically using 3D CT to have either unilateral or bilateral HRVA.

The mean age at the presentation was 48 years with a range between 11-68 years. There were 40 (69%) males and 18 (31%) females. The mean weight was 82 kg, with a range between 66-110 Kg. The mean BMI was 20.1 kg/m2 with a range between 17-23.4. Kg/m2.

Acute trauma affecting either C1 or C2 was the most common cause for AAI as presented in 27 (46.6%) patients. Chronic atlantoaxial subluxation was present in 13 (22.4%) patients. Rheumatoid arthritis was the causative factor in 10 (17.2%) patients, while congenital etiologies were present in 8 (13.8%) patients.

Twenty-nine (50%) patients had axial neck pain only. 18 (31%) patients had myelopathy only, and 10 (17.2%) patients had neck pain and myelopathy. One (1.7%) patient was asymptomatic at presentation, he had an ADI >10 mm.

HRVA was present in 10 (17.2%) patients; 4 (40%) patients had bilateral HRVA, and 6 (60%) patients had unilateral HRVA. Of the 6 cases with unilateral HRVA, 4 (66.7%) patients had left HRVA, mean while 2 (33.3%) patients had right HRVA.

Cases without HRVA (n= 48 patients) underwent C1LM-C2PS with or without fusion as fusion was not indicated in most cases of acute fracture. In cases with HRVA (n=10), application of C2 pedicle screw entails higher risk of iatrogenic VA injury, therefore alternative choices were adopted to afford higher safety. In the current study, of the 6 cases with unilateral HRVA, 3 (30%) had ipsilateral C2 pars screw insertion, 2 (20%) patients had translaminar screw, and only one (10%) patient had C2 pedicle clamp as this patient had severe bony deformity. Application of C2PS contralaterally was done in all cases with unilateral HRVA. Four patients had bilateral HRVA; 3 (30%) patients had bilateral translaminar screws, and one (10%) patient had bilateral pars screws. The mean follow-up duration was 23.2 months with a range between 12-58 months. Patients' demographics, clinical presentation and characteristic data are illustrated in **(Table 1).**

As regards to the operative data for patients without HRVA, the mean operative time was 130 ±25 minutes with a range between 110-180 minutes. For patients with HRVA, the mean operative time was 150±10 minutes with a range between 140-200 minutes. The mean intraoperative blood loss was 120 ±30 cc with a range between 90-300 cc for non-HRVA patients. In patients with HRVA, the mean blood loss was 160 ± 18 cc with a range between 120-400 cc. The mean postoperative hospital stay for non-HRVA patients was 5.8±2.4 days with a range between 5-12 days. For patients with HRVA, the mean postoperative hospital stay was 5.3±3.1 days with a range between 4-13 days. There was no statistically significant difference between non-HRVA patients and patients with HRVA as regards operative data. The operative data and postoperative hospital stay are illustrated in **(Table 2).**

After one year follow-up, assessment of the pain severity showed that the mean NRS improved significantly from 8.3 ±1.6 to 2.1 ±1.4. Functionally, there was a statistically significant improvement in ASIA impairment scale after 1year follow-up. None of the treated cases had worsening of their preoperative clinical and functional status. These results are illustrated in **(Table 3).**

As regards radiological outcome, complete reducibility was achieved in all cases as proved in postoperative imaging after 2 days. Fifty-seven (98.3%) patients had proper solid bony fusion as proved in imaging one year after surgery. For all cases in the study, C1 lateral mass screw was inserted with proper screw position. Only 3 (5.2%) C2 pedicle screws showed screw spacing,2 (3.4%) of them had mild violation of adjacent cortex and only one (1.7%) case had significant violation of transverse foramen with significant bleeding after removal of the drill which stopped upon screw insertion and patient was not have postoperative neurological complications as it was not the dominant VA side.

Regarding complications, 6 (10.3%) patients had venous bleeding which was managed conservatively, infection occurred in one (1.7%) patient which required wound debridement and systemic antibiotic, irritation of the C2 root occurred in one (1.7%) patient and was managed conservatively, and iatrogenic vertebral artery injury was detected only in one (1.7%) patient as illustrated in axial postoperative CT image of the cervical spine where C2 pedicle screw had severely violated right transverse foramen with right vertebral artery injury in **(Fig. 2).** Fortunately, it was not the dominant vertebral artery, and this did not result in any neurological deficit. **(Table 4)** illustrates the postoperative radiological outcome and complications.

Illustrated case

A 54 years old male patient presented with neck pain increasing with movement. Radiological imaging revealed atlantoaxial subluxation as illustrated in dynamic X-ray **(Figs. 3A,B).** The Sagittal CT view of cervical spine proved atlantoaxial subluxation **(Fig. 3C).** The patient was prepared for C1-C2 fixation and proved to have the right HRVA. The patient underwent fixation with hybrid technique to avoid injury of right vertebral artery. Patient had bilateral C1 lateral mass screws fixation and C2 pedicle screw on left side and right pars screw as illustrated in intraoperative fluoroscopic image with proper reduction of atlantoaxial subluxation **(Fig. 3D).**Pain improved postoperatively.

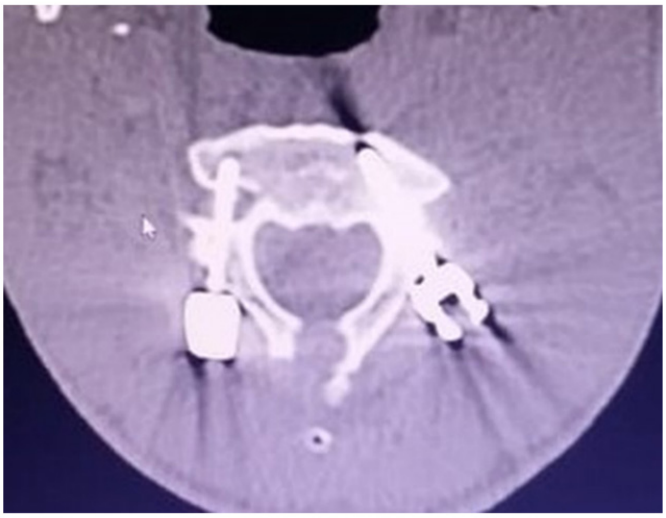

Fig 2: Axial postoperative CT image of the of cervical spine representing C2 pedicle screw had severely violated right transverse foramen with right vertebral artery injury.

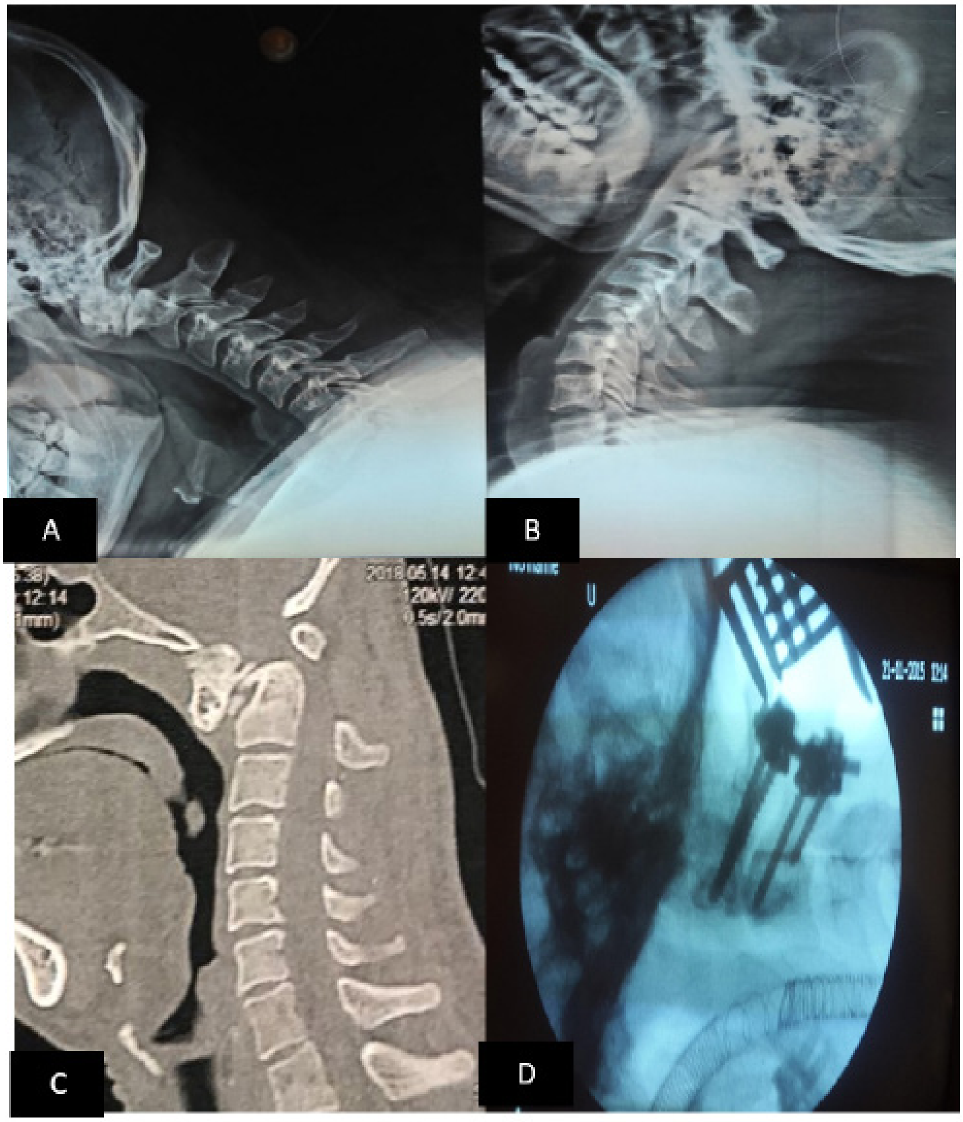

Fig 3: (A,B): Preoperative dynamic X-ray of fifty-four year old male patient with atlantoaxial subluxation. (C): Preoperative sagittal CT of cervical spine proving atlantoaxial subluxation. (D): Intraoperative fluoroscopic image with proper reduction of atlantoaxial subluxation using bilateral C1 lateral mass screws fixation and C2 pedicle screw on left side and right pars screw.

Table 1: Basic demographic and clinical data of the study participants

Variables	Data (n=58)
Age (years), mean, range	48 (11-68)
Gender	
Male	40 (69%)
Female	18 (31%)
Weight (Kg), mean, range	82 (66-110)
BMI (Kg/m²) , mean, range	20.1 (17-23.4)
Diagnosis	
Acute trauma	27 (46.6%)
Chronic atlantoaxial subluxation	13 (22.4%)
Rheumatoid Arthritis	10 (17.2%)
Congenital	8 (13.8%)
Clinical presentation	
Axial neck pain only	29 (50%)
Myelopathic weakness only	18 (31%)
Neck pain and myelopathic weakness	10 (17.2%)
Asymptomatic (ADI > 10 mm)	1 (1.7%)
HRVA	10 (17.2%)
Unilateral	6/10 (60%)
Unilateral pars screw	3/10 (30%)
Unilateral translaminar screw	2/10 (20%)
C2 pedicle clamp	1/10 (10%)
Bilateral	4/10 (40%)
Bilateral translaminar screw	3/10 (30%)
Bilateral pars screw	1/10 (10%)
Follow-up period (Months)	
Mean	23.2
Range	12-58

Abbreviations: n; number, BMI; Body mass index, HRVA; High riding vertebral artery, ADI; atlantodental interval.

Table 2: Operative data of the study participants

Variable	No HRVA	HRVA	P value
Operative time (minutes)			
Mean±SD	130±25	150±10	1.003
Range	110-180	140-200	
Estimated blood loss (cc)			
Mean±SD	120±30	160±18	0.491
Range	90-300	120-400	
Postoperative hospital stays (days)			
Mean±SD	5.8±2.4	5.3±3.1	0.827
Range	5-12	4-13	

Abbreviations: SD; Standard deviation, HRVA; high riding vertebral artery.

* Statistically significant at P value <0.05.

Table 3: Clinical and functional outcomes after C1-C2 fixation of the study participants

Variable	Preoperative	One year follow-up	P-value
NRS (mean ± SD)	8.3±1.6	2.1±1.4	< 0.001*
ASIA Impairment scale			
A	1 (1.7%)	1 (1.7%)	
B	7 (12.1%)	6 (10.3%)	
C	13 (22.4%)	8 (13.8%)	< 0.001*
D	16 (27.6%)	9 (15.5%)	
E	21 (36.2%)	34 (58.6%)	

Abbreviations: NRS; Numerical Rating Scale, ASIA; American spinal injury association, SD; standard deviation.

* Statistically significant at P value <0.05.

Table 4: Radiological outcome and complications of the studied group

Variables	Value (n=174)
Radiological outcome	
Complete reducibility	58 (100%)
Solid fusion	57 (98.3%)
C2 Screw malposition	3 (5.2%)
Mild violation	2 (3.4%)
Severe violation	1 (1.7%)
C1 screw malposition	0
Complications	9 (15.5%)
Venous bleeding	6 (10.3%)
Vertebral artery injury	1 (1.7%)
Infection	1 (1.7%)
Irritation of C2 root	1 (1.7%)
Iatrogenic neurological deficit	0

DISCUSSION

The C2PS fixation is widely recognized as a secure and effective approach for stabilizing the craniovertebral junction.[7] The C2PS fixation approach offers the advantage of more secure stabilization of the atlantoaxial joint and enhanced biomechanical features. It also carries a reduced likelihood of nonunion compared to other techniques, such as pars and laminar screw fixations, which are often considered when the unique anatomy of the VA and pedicles makes the placement of C2PS impractical.[11,12]

In cases where there is a need for high biomechanical stability to maintain vertebral fixation and promote bone fusion, the employment of C2PS is not just preferable but essential within its therapeutic guidelines.[13] Narrow pedicle width, high VA injury rates, and pedicle screw malpositioning are common considerations associated with HRVA.[14,15]

The incidence of HRVA in this study was 17.2%. Higher incidences were reported in several studies. Zhou et al. found that the HRVA incidence was 61.49%.[9] The incidence of HRVA in Xu et al. study was 61.5%.[16] Vaněk et al. stated that the incidence of HRVA was 24.1%.[17] Yamazaki et al. noticed that the HRVA incidence was 31%.[18]

Unilateral HRVA incidence in this study was 60%, and bilateral HRVA was 40%. Lee et al. noted a higher incidence of unilateral HRVA as out of 8 cases with HRVA in the studied sample, 7 patients had unilateral HRVA and only 1 case had bilateral HRVA.[19] However Hue et al. reported lower incidence as 50% of the population had unilateral HRVA.[20] Neo et al. stated that 25.9% had bilateral HRVA which was close to the findings of the current study.[21]

The results of our study highlight the diverse range of surgical techniques employed to address HRVA. The study found that 30% of patients received unilateral pars fixation. Unilateral pars fixation was employed to reduce VA accidental injury risk, mainly in cases where the VA position was atypical.[15]

Thirty percent of HRVA patients underwent bilateral translaminar fixation. Bilateral translaminar fixation offers robust and symmetrical stabilization. In the context of HRVA, bilateral translaminar fixation was used to ensure secure fixation while reducing VA injury risk. The bilateral nature of this technique provides balanced support and may help mitigate the challenges posed by HRVA during screw placement.[22]

Twenty percent of patients with HRVA received unilateral translaminar fixation and 10% of HRVA had bilateral pars screw. Unilateral translaminar fixation may offer targeted support on one side of the vertebra, potentially allowing for careful maneuvering around the VA. On the other hand, bilateral pars fixation provides stability by engaging both sides of the vertebra, requiring precision to avoid the VA in cases of HRVA.[23]

Notably, one patient required a unilateral C2 pedicle clamp. Using a pedicle clamp in the presence of HRVA may indicate a cautious approach to avoid the VA and ensure secure fixation in challenging anatomical scenarios.[24]

In cases of HRVA, the pars and translaminar screws can provide a safer alternative to pedicle screws, as they avoid the region where the VA is located.[25] Studies have showed that pars and translaminar screws can provide comparable biomechanical stability compared to pedicle screws in certain spinal pathologies.[26,27] The use of pars and translaminar screws allow for the preservation of the pedicle, which can be beneficial in revision surgeries or in cases where the pedicle is compromised.[28,29]

The placement of pars and translaminar screws demands a thorough understanding of the complex spinal anatomy. Pars and translaminar screws may have a lower pullout strength compared to pedicle screws, which can be a concern in cases where strong fixation is required.[29,30]

There were no statistically significant differences as regards operative data between HRVA group and non-HRVA group. The same insignificance was as regards the postoperative hospital stay. There were statistically significant clinical and functional improvement postoperatively as confirmed by change in NRS and ASIA impairment scale reflecting the feasibility of posterior C1-C2 fusion.

Radiologically, in the current study, the fusion rate after 1-year (98.3%) was comparable to fusion rate achieved by Rajinda et al. in-screw rod construct (SRC) (96.7 %) and transarticular screw (TAS) (95.6 %) groups. Also, there was similarity as regards incidence of improper screw positioning between current study (5.2%) and SRC (3.3%) group. In the current study, screw malposition was related to C2, meanwhile, Rajinda has screw malposition related to C1 lateral mass screw. This low incidence can reflect proper decision making selecting proper screw type.[31]

Regarding complications, there was venous bleeding in 6 (10.3%) patients, vertebral artery injury in 1 (1.7%) patient,infection in 1 (1.7%) patient, and irritation of the C2 root in 1 (1.7%) patient.

Several strategies were employed to mitigate the risk of venous bleeding, including using an armored tube to secure the airway, maintaining normal intrathoracic pressure with peak end-expiratory pressure of less than 20, and elevating the head above the heart. Subperiosteal dissection at the C1 lateral mass was also performed to minimize bleeding. Hemostatic agents such as Gelfoam® (Pfizer, USA) or Surgicel®(Ethicon , Johnson and Johnson, Somerville, NJ, USA). soaked in thrombin and fibrin glue were used to control bleeding. Bipolar cautery was found to be less effective in this context. Apart from venous bleeding, there were 3 (5.2%) patients who suffered from complications, and this again matched Rajinda's results.[31]

Limitations

The findings' generalization to other patient populations may be restricted by the fact that the study population was mainly composed of adult patients, and the study excluded patients with previous surgery on the occipitocervical region, and those requiring revision surgery, which may limit the applicability of the findings to these patient populations. The study was conducted at a single center, and the study's retrospective nature limited the results' generalizability. Some patients were followed up for only one year, which may not be sufficient to assess long-term outcomes, such as long-term complications.

CONCLUSIONS

Careful preoperative radiological studies using dynamic plain X-ray and 3D are crucial for identifying HRVA. Different techniques of atlantoaxial posterior screw fixation are used to reduce VA injury risk. The selection of screw fixation techniques in the presence of HRVA must be individualized based on the patient's specific anatomical challenges. Unilateral pars screw fixation is commonly used due to its balance between safety and efficacy. Bilateral translaminar fixation provides robust stabilization when feasible, while unilateral translaminar and bilateral pars fixation serve specialized roles. Using a unilateral C2 pedicle clamp offers a valuable alternative in high-risk cases.

List of abbreviations

3D: 3 dimensional.
AAF: Atlantoaxial fixation.
AAI: Atlantoaxial instability.
ADI: Atlantodental interval.
ASIA: American spinal injury association.
BMI: Body mass index.
C1LM: C1 lateral mass.
C2PS: C2 pedicle screws.
C: Cervical.
CT: Computerized tomography.
HRVA: High-riding vertebral artery.
IRB: Institutional review board.
MRI: Magnetic resonance imaging.
NRS: Numeric lower case
PRP: Platelet rich plasma.
SPSS: Statistical Package for Social Sciences.

SRC: Screw rod construct.
TAS: Trans-articular screw.
VA: Vertebral artery.

Disclosure

The authors report no conflict of interest in the materials or methods used in this study or the findings specified in this manuscript.

Funding

The authors received no financial support for the research, authorship, and/or publication of this paper.

REFERENCES

1. Goel A, Rangnekar R, Shah A, Rai S, Vutha R. Mobilization of the vertebral artery-Surgical option for C2 screw fixation in cases with "high riding" vertebral artery. *Oper Neurosurg (Hagerstown).* 2020;18(6):648-651.

2. Yang SY, Boniello AJ, Poorman CE, Chang AL, Wang S, Passias PG. A review of the diagnosis and treatment of atlantoaxial dislocations. *Global Spine J.* 2014;4(3):197-210.

3. Zafarshamspour S, Lesha E, Cecia A, et al. Traumatic atlantoaxial rotatory fixation in adults: A systematic review of published cases. *Neurosurg Rev.* 2024;47(1):90.

4. Tian W, Liu YJ, Liu B, et al. Guideline for posterior atlantoaxial internal fixation assisted by orthopaedic surgical robot. *Orthop Surg.* 2019;11(2):160-166.

5. Huang DG, Hao DJ, He BR, et al. Posterior atlantoaxial fixation: A review of all techniques. *Spine J.* 2015;15(10):2271-2281.

6. Kleinstück FS, Fekete TF, Loibl M, et al. Patient-rated outcome after atlantoaxial (C1-C2) fusion: More than a decade of evaluation of 2-year outcomes in 126 patients. *Eur Spine J.* 2021;30(12):3620-3630.

7. Du YQ, Qiao GY, Yin YH, Li T, Yu XG. Posterior atlantoaxial facet joint reduction, fixation and fusion as revision surgery for failed suboccipital decompression in patients with basilar invagination and atlantoaxial dislocation: Operative nuances, challenges and outcomes. *Clin Neurol Neurosurg.* 2020;194:105793.

8. Chen Q, Brahimaj BC, Khanna R, et al. Posterior atlantoaxial fusion: A comprehensive review of surgical techniques and relevant vascular anomalies. *J Spine Surg.* 2020;6(1):164-180.

9. Zhou LP, Zhang RJ, Zhang HQ, Jiang ZF, Shang J, Shen CL. Effect of high-riding vertebral artery on the accuracy and safety of C2 pedicle screw placement in basilar invagination and related risk factors. *Global Spine J.* 2024;14(2):458-469.

10. Klepinowski T, Żyłka N, Pala B, Poncyljusz W, Sagan L. Prevalence of high-riding vertebral arteries and narrow C2 pedicles among Central-European population: A computed tomography-based study. *Neurosurg Rev.* 2021;44(6):3277-3282.

11. Chang CC, Huang WC, Tu TH, et al. Differences in fixation strength among constructs of atlantoaxial fixation. *J Neurosurg Spine.* 2018;30(1):52-59.

12. Pham MH, Bakhsheshian J, Reid PC, Buchanan IA, Fredrickson VL, Liu JC. Evaluation of C2 pedicle screw placement via the freehand technique by neurosurgical trainees. *J Neurosurg Spine.* 2018;29(3):235-240.

13. Xu R, Bydon M, Macki M, et al. Biomechanical impact of C2 pedicle screw length in an atlantoaxial fusion construct. *Surg Neurol Int.* 2014;5(Suppl 7):S343-S346.

14. Yeom JS, Buchowski JM, Kim HJ, Chang BS, Lee CK, Riew KD. Risk of vertebral artery injury: Comparison between C1-C2 transarticular and C2 pedicle screws. *Spine J.* 2013;13(7):775-785.

15. Byun CW, Lee DH, Park S, Lee CS, Hwang CJ, Cho JH. The association between atlantoaxial instability and anomalies of vertebral artery and axis. *Spine Journal.* 2022;22(2):249-255.

16. Xu S, Ruan S, Song X, Yu J, Xu J, Gong R. Evaluation of vertebral artery anomaly in basilar invagination and prevention of vascular injury during surgical intervention: CTA features and analysis. *Eur Spine J.* 2018;27(6):1286-1294.

17. Vaněk P, Bradáč O, de Lacy P, Konopková R, Lacman J, Beneš V. Vertebral artery and osseous anomalies characteristic at the craniocervical junction diagnosed by CT and 3D CT angiography in normal Czech population: Analysis of 511 consecutive patients. *Neurosurg Rev.* 2017;40(3):369-376.

18. Yamazaki M, Okawa A, Furuya T, et al. Anomalous vertebral arteries in the extra- and intraosseous regions of the craniovertebral junction visualized by 3-dimensional computed tomographic angiography: Analysis of 100 consecutive surgical cases and review of the literature. *Spine (Phila Pa 1976).* 2012;37(22):E1389-E1397.

19. Lee JH, Jahng TA, Chung CK. C1-2 transarticular screw fixation in high-riding vertebral artery: Suggestion of new trajectory. *J Spinal Disord Tech.* 2007;20(7):499-504.

20. Hue YH, Chun HJ, Yi HJ, Oh SH, Oh SJ, Ko Y. Unilateral posterior atlantoaxial transarticular screw fixation in patients with atlantoaxial instability: Comparison with bilateral method. *J Korean Neurosurg Soc.* 2009;45(3):164-168.

21. Neo M, Matsushita M, Iwashita Y, Yasuda T,

Sakamoto T, Nakamura T. Atlantoaxial transarticular screw fixation for a high-riding vertebral artery. *Spine (Phila Pa 1976).* 2003;28(7):666-670.

22. Dorward IG, Wright NM. Seven years of experience with C2 translaminar screw fixation: Clinical series and review of the literature. *Neurosurgery.* 2011;68(6):1491-1499.
23. Mummaneni PV, Haid RW. Atlantoaxial fixation: Overview of all techniques. *Neurol India.* 2005;53(4):408-415.
24. Lehman RA Jr, Dmitriev AE, Helgeson MD, Sasso RC, Kuklo TR, Riew KD. Salvage of C2 pedicle and pars screws using the intralaminar technique: A biomechanical analysis. *Spine (Phila Pa 1976).* 2008;33(9):960-965.
25. Singh DK, Shankar D, Singh N, Singh RK, Chand VK. C2 Screw fixation techniques in atlantoaxial instability: A technical review. *J Craniovertebr Junction Spine.* 2022;13(4):368-377.
26. Parker SL, McGirt MJ, Garcés-Ambrossi GL, et al. Translaminar versus pedicle screw fixation of C2: Comparison of surgical morbidity and accuracy of 313 consecutive screws. *Neurosurgery.* 2009;64(5 Suppl 2):343-349.
27. Elliott RE, Tanweer O, Boah A, Smith ML, Frempong-Boadu A. Comparison of safety and stability of C-2 pars and pedicle screws for atlantoaxial fusion: Meta-analysis and review of the literature. *J Neurosurg Spine.* 2012;17(6):577-593.
28. Galbusera F, Volkheimer D, Reitmaier S, Berger-Roscher N, Kienle A, Wilke HJ. Pedicle screw loosening: A clinically relevant complication?. *Eur Spine J.* 2015;24(5):1005-1016.
29. Aoude AA, Fortin M, Figueiredo R, Jarzem P, Ouellet J, Weber MH. Methods to determine pedicle screw placement accuracy in spine surgery: A systematic review. *Eur Spine J.* 2015;24(5):990-1004.
30. Shea TM, Laun J, Gonzalez-Blohm SA, et al. Designs and techniques that improve the pullout strength of pedicle screws in osteoporotic vertebrae: Current status. *Biomed Res Int.* 2014;2014:748393.
31. Rajinda P, Towiwat S, Chirappapha P. Comparison of outcomes after atlantoaxial fusion with C1 lateral mass-C2 pedicle screws and C1-C2 transarticular screws. *Eur Spine J.* 2017;26(4):1064-1072.