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RESEARCH ARTICLE

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# Comparison of robot-assisted versus fluoroscopically guided treatment of atlantoaxial dislocation in combination with high-riding vertebral artery: a preliminary study

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## Abstract

**Background** Robotic-assisted surgery has emerged as an innovative approach widely adopted in the field of orthopedics. However, its application specifically for managing atlantoaxial dislocation with a high-riding vertebral artery (AAD-HVA) remains underreported in the existing literature.

**Objective** To compare the perioperative outcomes of robotic-assisted (RA) and fluoroscopic-guided free-hand (FH) techniques for atlantoaxial dislocation in combination with a high-riding vertebral artery (AAD-HVA).

**Study design** This was a retrospective study.

**Setting** This research was performed at a single department of spine surgery.

**Methods** Data from patients who underwent atlantoaxial internal fixation between July 2018 and January 2022 at our hospital were retrospectively analyzed. Among the cases, 14 were performed using free-hand (FH) techniques and 11 utilized robotic-assisted (RA) techniques. Data collected included case notes, imaging records, and follow-up data. The reliability of screw placement was evaluated based on the Gertzbein and Robbins scores, while treatment outcomes were assessed using the Japanese Orthopaedic Association (JOA) score, visual analog scale (VAS), neck disability index (NDI), and postoperative complication rate.

**Results** Baseline patient characteristics were comparable between the FH and RA groups. The mean blood loss was markedly lower in the RA group (157.3 ± 49.7 ml) compared to the FH group (290.0 ± 110.3 ml) ($p = 0.03$). Although the average operative time was slightly higher in FH group than in RA group, this disparity did not achieve statistical

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significance ($p = 0.7588$). Moreover, the radiation exposure dose was remarkably higher in FH group (32.7 ± 4.4 mGy) than in RA group (23.0 ± 3.2 mGy) ($p < 0.0001$). The percentage of clinically acceptable screw placement was slightly lower in FH group (87.5%) than in RA group (97.8%), but the observed variance was not statistically meaningful ($p = 0.3669$). Furthermore, the differences in JOA, VAS, and NDI scores between the FH and RA groups were not statistically significant. Additionally, no obvious differences were found in clinical outcomes or complications related to screw implantation between the two groups.

**Limitations** This study has inherent limitations as it was retrospective in nature and conducted at a single center.

**Conclusion** Robotic-assisted surgery for AAD-HVA patients offers a minimally invasive approach, reduced bleeding and lower radiation exposure compared with traditional free-hand surgery.

**Keywords** Robot-assisted, Atlantoaxial dislocation, High-riding vertebral artery

The C1-2 joint, located below the head, plays a crucial role in cervical spine rotation [1]. Various pathologies, including trauma, deformities, and tumors, can affect this joint [2, 3]. Degenerative changes, ligament laxity, or muscle atrophy in the C1-2 joint can result in atlantoaxial dislocation (AAD) [4]. AAD can lead to neck pain in mild cases and serious complications such as spinal cord compression, neurological dysfunction, and paralysis in more severe cases [5]. Surgical intervention is often necessary for affected patients, and different internal fixation techniques are available to address repositioning and decompression [6].

Posterior resection fusion and instrumentation (PRFI) is a well-estblished and effective technique for treating AAD. This method requires the removal of the lateral cortex of the posterior arch of the atlas to leak out the trabecular bone, while we will remove the lateral cortex of the posterior part of the axis to leak out the trabecular bone. However, this technique presents some challenges, such as atlantoaxial screw placement errors, which often have catastrophic consequences [7]. Precise placement of pedicle screws in this region is technically demanding and requires comprehensive intraoperative anatomical and radiological knowledge. Misplacement of screws can lead to severe neurological and arteriovenous complications [8]. In the case of C1-2 fusion, misaligned pedicle screws pose a risk of vascular and nerve injury, with a reported incidence of 8.2% [9]. Freehand screw placement in combination with high-riding vertebral artery (AAD-HVA) presents a significant risk of vascular injury [10]. To address these challenges, robotic assistance (RA) has been proposed to enhance the preciseness of screw placement in spine surgery [11, 12].

The integration of robotics in spine surgery aims to mitigate the risks associated with free-hand (FH) screw placement under fluoroscopic guidance, including potential neurological symptoms, arteriovenous injuries, and excessive exposure to ionizing radiation. This research aims to assess the effectiveness of robot-assisted treatment for AAD-HVA.

## Method

### Research design and participants

In this retrospective cohort study, we examined a consecutive series of patients diagnosed with AAD-HVA who underwent PRFI. The diagnostic criterion for high span is CTA coronal view, based on the fact that the highest span of the vertebral artery at C2 is located below the horizontal line of the exit of the transverse process foramen and within the transverse process foramen. This study evaluated and compared the perioperative outcomes between patients undergoing RA-PRFI and FH-PRFI performed by the same group of surgeons. The surgical team consists of three doctors, who are chief physician, deputy chief physician, and resident physician. This three people medical team only performs upper cervical spine surgery. This research was approved by the hospital institutional review board and conducted between July 2018 and January 2022 (approval number: ID 20180101). The FH group comprised 14 patients who received FH -PRFI, while the other group consisted of 11 patients treated with RA-PRFI. Detailed patient information, including basic demographics, medical history, and relevant scores, can be found in Table 1.

Following administration of anesthetic agents, patients were placed in the prone position with routine sterile sheeting. The PRFI procedure involved a median incision, ensuring the careful protection of vessels while exposing the posterior arch entry point of cervical 1 and the entry point of cervical 2. The Harms technique was employed for fixation, involving the meticulous exposure of the posterior part of the pedicle. This was followed by the use of a grinding drill for opening, manual drilling of holes, and implantation of C1 lateral mass screws and C2 pedicle screws under fluoroscopic guidance. Intraoperative confirmation of the precise placement of the internal fixation was performed using the C-arm. Two appropriately sized rods were used to connect C1-2, and a large amount of autologous iliac bone is used for posterior bone grafting.

RH-PRFI was performed using the Beijing Tinavi robot (Fig. 1) as the surgical tool. Following general anesthesia,

**Table 1** Comparative analysis of demographic features in patients

| | FH group (*n* = 14) | RA group (*n* = 11) | *P*-value |
|---|---|---|---|
| Age (years) | 60.1 ± 11.6 | 48.9 ± 8.1 | 0.0154* |
| Gender (n) | | | |
| Male | 7 | 6 | 0.8213 |
| Female | 7 | 5 | |
| Diabetes (n) | | | |
| With diabetes | 2 | 2 | 0.7920 |
| Without diabetes | 12 | 9 | |
| Symptom duration (years) | 10.1 ± 4.9 | 7.0 ± 3.8 | 0.1167 |
| Postoperative hospital stay (days) | 10.8 ± 3.4 | 8.9 ± 2.5 | 0.1588 |
| Follow-up time (months) | 12.4 ± 4.6 | 8.9 ± 4.8 | 0.0952 |
| Pre-JOA | 5.7 ± 1.0 | 6.5 ± 0.9 | 0.0533 |
| Pre-VAS | 2.0 ± 0.7 | 2.1 ± 0.7 | 0.7462 |
| Pre-NDI (%) | 41.3 ± 14.4 | 49.5 ± 5.2 | 0.0982 |
| Pathology | | | |
| Trauma | 0 | 1 | 0.4439 |
| Degeneration | 6 | 2 | |
| Congenital malformation | 6 | 6 | |
| Rheumatoid arthritis | 2 | 2 | |
| Tumor | 0 | 0 | |

Values are shown as mean ± SD or number(%) unless stated otherwise. *$p < 0.05$

the patient was positioned in the prone position, and the head was securely fixed to the head frame. Meanwhile, a tracer was attached to the head frame to maintain the alignment between the head, head frame, and tracer throughout the procedure. The posterior resection fusion internal fixation was then performed through a median incision, with careful attention given to protecting the vessels and exposing the posterior arch entry point of cervical 1 and the entry point of cervical 2. Import preoperative CT data into the robot for intraoperative data matching, the data was uploaded to the robot's central processing unit for optimal screw sizing and determination of the screw entry point (Fig. 2). To assess accuracy, three reference points were identified within the surgical field and validated using the robotic system. Intraoperatively, a guide wire was inserted through a trocar on the robotic arm, guided by fluoroscopy, and C1 lateral mass screws and C2 pedicle screws were then implanted. Finally, an intraoperative O-arm evaluation was performed to determine the exact position of the internal fixation. Two appropriately sized rods were used to connect C1-2, and a large amount of autologous iliac bone is used for posterior bone grafting.

Before closing the surgical wound, use 20 ml 2 g tranexamic acid (First Pharmaceutical Co., Ltd.) to routinely rinse the wound. Placement of drainage tube for measuring postoperative drainage volume. The radiation dose will be recorded by C-ARM, and the data will be exported by a specialized intraoperative radiologist. The intraoperative blood loss is estimated as the total amount of suction minus the amount of flushing fluid plus the amount of blood on the gauze.

Postoperative assessments included the evaluation and comparison of various factors between the two study groups, including intraoperative hemorrhage, overall operative time (from initial incision to application of surgical dressing), length of hospital stay following surgery, radiation exposure, and fusion rate.

Two days after the surgical procedure, CT scans were performed to determine the position of the screws. Radiologists and chief surgeons reviewed the CT images to determine the number of screws in a competent position, and the Gertzbein and Robbins grading system [13] was used for grading. The grading system consisted of four grades: grade 0 indicated that the screw was entirely within the bone, grade 1 indicated that the screw penetrated the cortex by < 2 mm, grade 2 indicated penetration of ≥ 2 but < 4 mm, and grade 3 indicated penetration of ≥ 4 mm. Screws graded as 0 or I were considered clinically acceptable, while screws graded as 2 or 3 were deemed unacceptable and could potentially lead to serious complications. Patients with misaligned screws underwent immediate magnetic resonance angiography or CT angiography to assess potential vascular injury.

Patient evaluations were conducted at 1, 4, 12, 24, and 36 weeks postoperatively, according to the Japanese Orthopaedic Association (JOA) score and visual analog scale (VAS). Additionally, the Neck Disability Index (NDI) score was measured at 3, 6, and 12 months post-surgery to evaluate the overall outcome.

### Statistical analysis

Statistical tests were carried out with SPSS v20.0. Continuous data are reported as mean ± standard deviation, while categorical variables are presented as numbers (%). Data normality was examined using the Shapiro−Wilk test. Follow-up and preoperative parameters, such as JOA and VAS scores, were analyzed with paired t-tests. Independent t-tests were utilized to analyze surgical outcomes and postoperative imaging data between the two groups. Descriptive statistics were applied to enumeration data based on group characteristics. Statistical significance was defined as $p < 0.05$.

## Results

Between July 2018 and January 2022, there were 25 patients who received PRFI. Among them, 11 patients underwent RA-PRFI, while 14 underwent FH-PRFI. There was a notable difference in age between the RA and FH groups, with the RA group having an average age of 48.9 ± 8.1 months, compared to 60.1 ± 11.6 months in the FH group ($p < 0.001$; Table 1). However, no obvious differences were noted between the two groups with regards to sex, body mass index or diabetes prevalence,

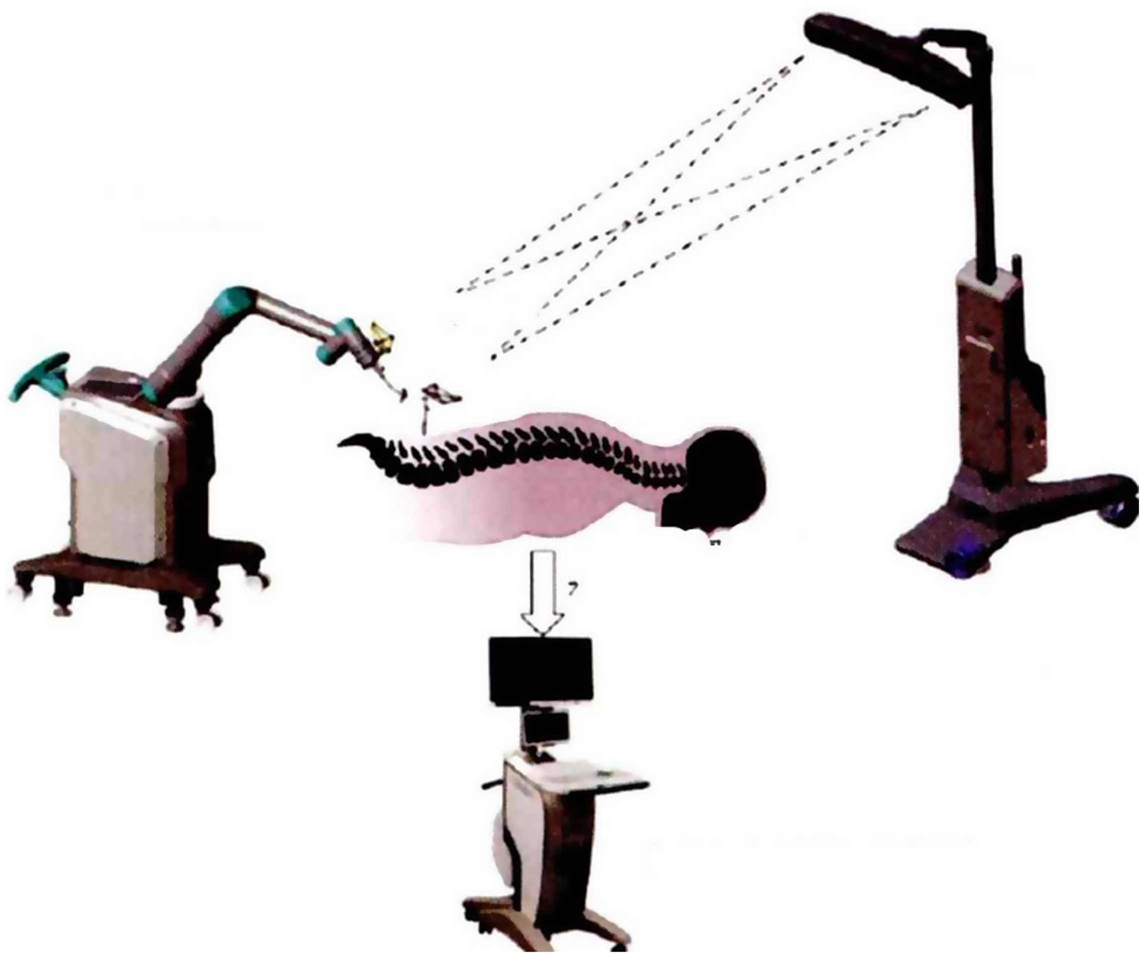

**Fig. 1** Schematic diagram of robot surgery operation

symptom duration, postoperative hospital stay, follow-up time, preoperative JOA, preoperative VAS, preoperative NDI, and pathology.

The difference in operative time between the two groups was not statistically significant, with the RA group having an average operative time of 265.5 ± 86.5 min and the FH group having a mean operative time of 254.3 ± 84.8 min ($p = 0.7588$). Both groups exhibited complete bony fusion at follow-up, resulting in a fusion rate of 100%. Regarding the radiation dose administered during the procedure, the average dose for the RA group was 23.0 ± 3.2 mGy, while the FH group had an average dose of 32.7 ± 4.4 mGy ($p < 0.0001$). Furthermore, the mean blood loss during the surgery was 157.3 ± 49.7 ml in the RA group and 290.0 ± 110.3 ml in the FH group, revealing a statistically significant variance ($p = 0.0017$; Table 2).

In total, 50 C1 lateral mass screws and C2 pedicle screws were implanted in both the C1 and C2 vertebrae, and their placement was evaluated using thin-section CT scans (Table 3). In the RA group, 38 screws (86.4%) were categorized as grade 0, 5 screws (11.4%) as grade I, and 1 screw (2.2%) as grade II. For the FH group, 42 screws (75.0%) were grade 0, 8 screws (14.2%) were grade I, 5 screws (9.0%) were grade II, and 1 screw (1.8%) was grade III. Additionally, the rates of screw placement considered "clinically acceptable" were 97.8% and 87.5% in the RA and FH groups, respectively ($p = 0.3669$).

As depicted in Fig. 3, at the final follow-up periods of 1 week, and 1, 3, and 6 months post-surgery, both groups exhibited a remarkable improvement in JOA scores compared to baseline levels ($p = 0.35$). The VAS scores demonstrated a slight increase at 1 week after the operation in both groups when compared to the preoperative levels, followed by a gradual decrease during subsequent follow-ups ($p = 0.57$). The NDI scores at 3 and 6 months, and the final post-operative follow-up showed significant improvement in both groups ($p = 0.62$). However, the differences in JOA, VAS and NDI scores between the two groups at all postoperative time points were not statistically significant ($p = 0.35$, $p = 0.57$, and $p = 0.62$,

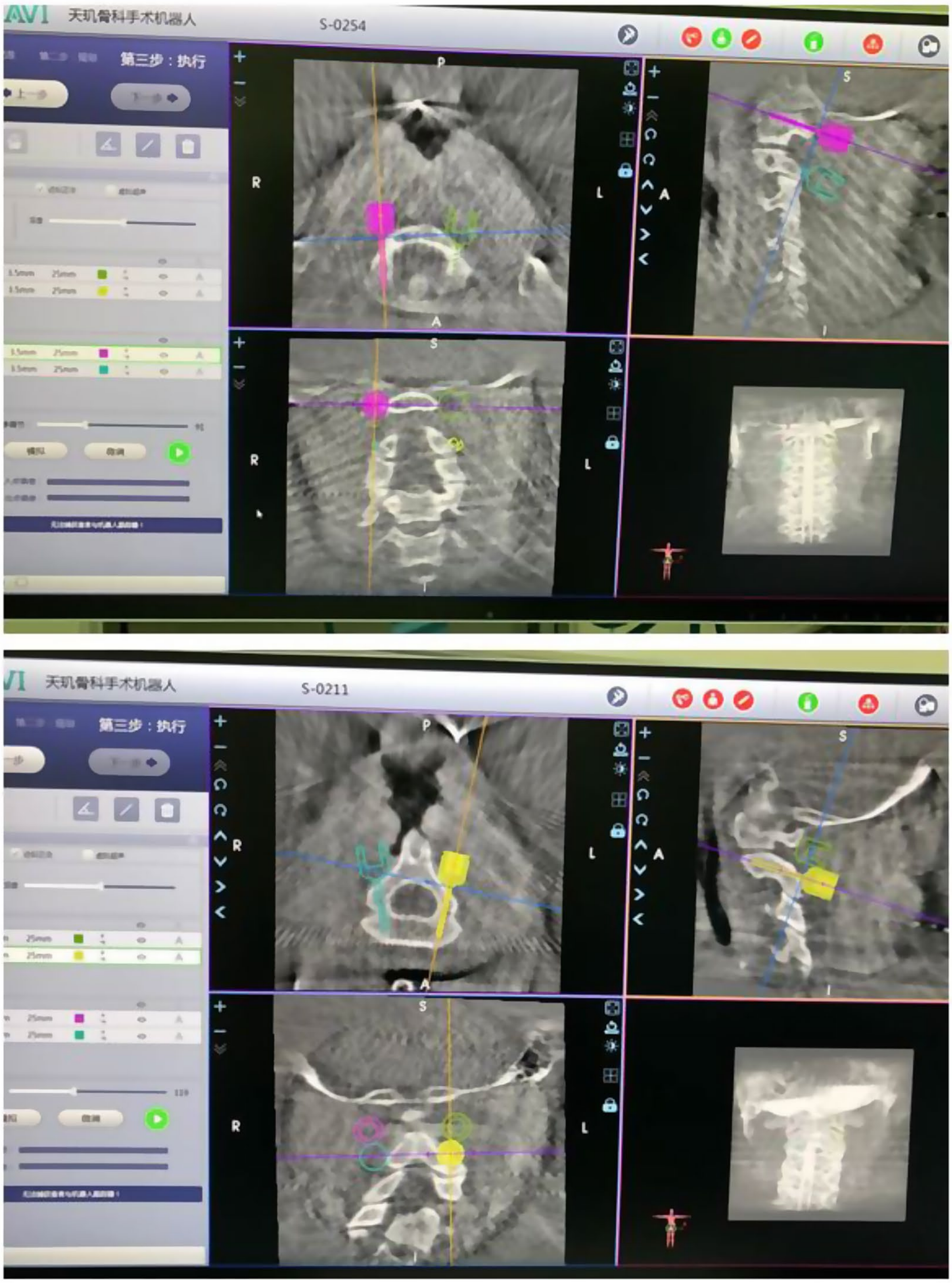


**Fig. 2** Robot intraoperative planning diagram

respectively). This indicates that both procedures contribute to pain reduction and postoperative functional recovery.

No obvious complications were found in both groups, and in addition, no perioperative complications, such as wound infection, were detected.

## Discussion

Over the past two decades, robotic surgical systems have increasingly been employed for the implantation of spinal pedicle screws, with a significant focus on the lumbar and thoracic spine in previous research [11, 14–16]. However, the application of robotic assistants in upper cervical spine surgery has been limited, and there is a scarcity of

**Table 2** Comparative analysis of operative parameters in patients

| Parameters | FH group (*n* = 14) | RA group (*n* = 11) | *P*-value |
|---|---|---|---|
| Estimated blood loss (mL) | 290.0 ± 110.3 | 157.3 ± 49.7 | 0.0017* |
| Surgical duration (min) | 254.3 ± 84.8 | 265.5 ± 86.5 | 0.7588 |
| Radiation dosage (mGy/screw) | 32.7 ± 4.4 | 23.0 ± 3.2 | < 0.0001* |
| Fusion rate, unfused/fused (%) | 0/14 (100) | 0/11 (100) | ns |

Values are shown as mean ± SD or number(%) unless stated otherwise. *$p < 0.05$

**Table 3** Preciseness of the screw position based on the grading system

| | FH group, number (%) | RA group, number (%) |
|---|---|---|
| Grade 0 | 42 (75.0) | 38 (86.4) |
| Grade 1 | 8 (14.2) | 5 (11.4) |
| Grade 2 | 5 (9) | 1 (2.2) |
| Grade 3 | 1 (1.8) | 0 (0) |
| Total | 56 (100) | 44 (100) |
| *P* -value | 0.3669 | |

Values are shown as mean ± SD or number(%) unless stated otherwise. *$p < 0.05$

relevant articles on the use of robotics in this particular surgical area [17]. Currently available literature consists primarily of a few case reports and one comparative study [6, 15, 18–22]. Moreover, when performing surgeries for AAD-HVA, there is a risk of vertebral artery injury during the placement process, especially when dealing with unilateral dominant vertebral arteries. Such injuries can have severe consequences, including compromised blood supply to the brain and the occurrence of complications such as cerebellar infarction [23]. For AAD-HVA, there is a notable absence of relevant studies exploring the use of robotic assistance in the existing literature [24].

The results indicated no obvious differences between the RA and FH groups regarding sex, body mass index, diabetes prevalence, symptom duration, postoperative hospital stay, follow-up time, preoperative JOA, preoperative VAS, preoperative NDI, and pathology. However, a notable difference was observed in FH group, where a higher number of degenerative patients were present. Age did not play a significant role in this study.

The RA group benefited from the assistance of robotic technology, resulting in a reduction in the number of fluoroscopies required. Additionally, our hospital had a dedicated intraoperative robotic service team with prior experience in lumbar spine procedures, contributing to a smooth collaboration with the surgeons [25, 26]. Both groups achieved successful bony fusion during follow-up. The RA group experienced remarkably lower mean blood loss compared to the FH group. The possible reason for less bleeding is that the RA group has smaller trauma, reflected in smaller wounds and less muscle and soft tissue dissection. Given the concern regarding radiation exposure for surgeons in spine surgery, especially with the increasing use of robotics, previous studies have demonstrated superior rates of robot-assisted screw placements compared to unassisted methods [27]. In our study, we observed reduced invasiveness decreased intraoperative bleeding and lower radiation exposure with the use of robotic systems.

There are few important limitations inherent in our study that should be recognized. Firstly, this research was performed at a single center and relied on retrospective data analysis, which may introduce inherent biases and limit the generalizability of the findings. Secondly, the study's sample size was relatively small, which may impact the statistical power and precision of the results. Additionally, the follow-up time was slightly short, potentially limiting the assessment of long-term outcomes. These limitations highlight the need for future research involving larger sample sizes, longer follow-up

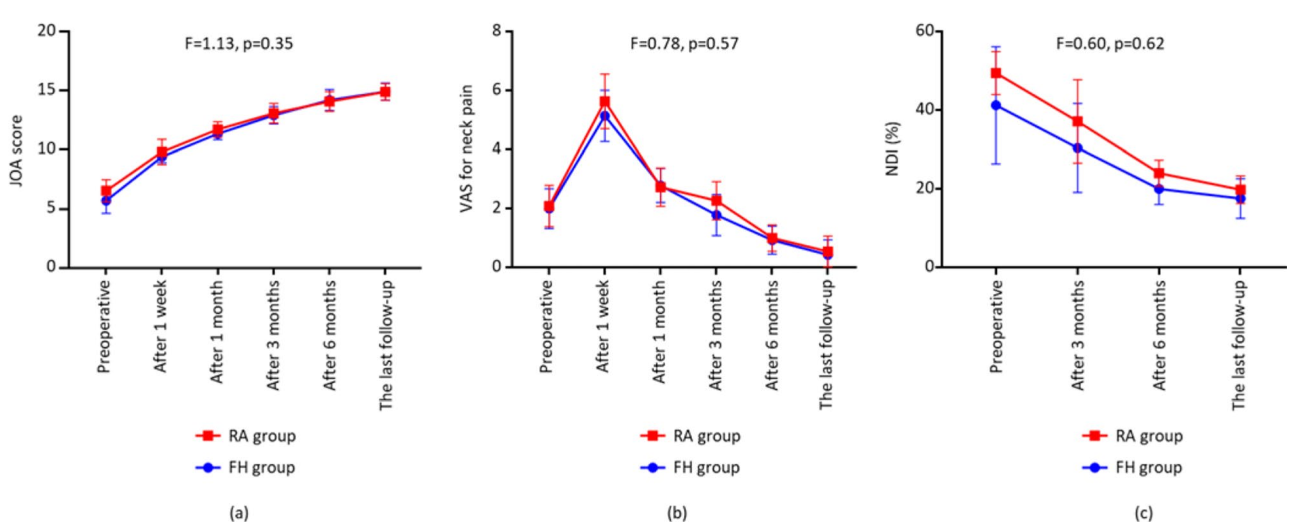


**Fig. 3** Preoperative and postoperative evaluation indicators

durations, and multicenter collaborations to further validate our findings.

## Conclusion

In conclusion, our research suggests that robot-assisted surgery offers advantages over conventional fluoroscopically guided FH surgery for patients with AAD-HVA. It demonstrates that robot-assisted surgery is associated with reduced invasiveness, decreased intraoperative bleeding and lower radiation exposure. However, further research is necessary to confirm these findings and provide more robust evidence in the field.

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**Author contributions**
Houkun Li, Dingjun Hao wrote the main manuscript text and Yong-Chao Duan, Le-Qun Shan prepared Figs. 1, 2 and 3. Liang Yan made statistical analysis. All authors reviewed the manuscript.

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**Data availability**
No datasets were generated or analysed during the current study.

## Declarations

**Competing interests**
The authors declare no competing interests.

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**References**

1. Chen Q, Wang H, Zhang M, et al. Open reduction for potentially reducible atlantoaxial dislocation secondary to transverse ligament laxity in patients with rheumatoid arthritis. World Neurosurg. 2022;167:e789–94.
2. Li T, Du YQ, Yin YH, et al. Treatment of reducible atlantoaxial dislocation and basilar invagination using the Head Frame reduction technique and atlanto-axial arthrodesis. Global Spine J. 2022;12:909–15.
3. Ning S, Yang S, Ding W et al. Posterior atlantoaxial dislocation without fracture or neurological symptoms treated by transoral-posterior approach surgery: a case report and literature review. Eur Spine J. 2019;28:37–40.
4. Ishikawa Y, Miyakoshi N, Hongo M, et al. Pyogenic atlantoaxial rotational dislocation representing adult Torticollis with vertebral artery occlusion: a Case Report and Review. World Neurosurg. 2020;144:82–7.
5. Tang X, Tan M, Yi P, et al. Atlantoaxial dislocation and os odontoideum in two identical twins: perspectives on etiology. Eur Spine J. 2018;27:259–63.
6. Fan M, Liu Y, He D et al. Improved accuracy of cervical spinal surgery with Robot-assisted screw insertion: a prospective, randomized, controlled study. Spine (Phila Pa 1976) 2020;45:285–91.
7. Timon F, Remco J, Alex Roth et al. Instrumentation techniques to prevent proximal junctional kyphosis and proximal junctional failure in adult spinal deformity correction: a systematic review of clinical studies. Global Spine J. 2022;12:1282–96.
8. Li C, Tian Y, Ren Q et al. Treatment of Atlantoaxial dislocation in children with Down Syndrome using posterior atlantoaxial screw fixation. Front Surg. 2022;9:877929.
9. Goel A. Torticollis and rotatory atlantoaxial dislocation: a clinical review. J Craniovertebr Junction Spine. 2019;10:77–87.
10. Liu Z, Jian Q, Duan W, et al., et al. Atlantoaxial dislocation with Bony Fusion of C1/2 Facet Joints Treated with posterior joint release, distraction and reduction. Spine Surg Relat Res. 2022;6:175–80.
11. Fiani B, Quadri SA, Farooqui M et al. Impact of robot-assisted spine surgery on health care quality and neurosurgical economics: a systemic review. Neurosurg Rev. 2020;43:17–25.
12. Chang M, Wang L, Yuan S, et al. Percutaneous Endoscopic Robot-assisted transforaminal lumbar Interbody Fusion (PE RA-TLIF) for lumbar spondylolisthesis: a technical note and two years clinical results. Pain Physician. 2022;25:E73–86.
13. Gertzbein S, Robbins S. Accuracy of pedicular screw placement in vivo. Spine. 1990;15:11–4.
14. Siddiqui MI, Wallace DJ, Salazar LM et al. Robot-assisted Pedicle Screw Placement: learning curve experience. World Neurosurg. 2019;130:e417–22.
15. McDonnell JM, Ahern DP, ÓD T, et al. Surgeon proficiency in robot-assisted spine surgery. Bone Joint J. 2020;102–b:568–72.
16. Lee NJ, Zuckerman SL, Buchanan IA, et al. Is there a difference between navigated and non-navigated robot cohorts in robot-assisted spine surgery? A multicenter, propensity-matched analysis of 2,800 screws and 372 patients. Spine J. 2021;21:1504–12.
17. Lai YP, Lin YH, Wu YC et al. Robot-assisted pedicle screw placement led to lower screw loosening rate than fluoroscopy-guided technique in transforaminal lumbar interbody fusion for lumbar degenerative disease: a single-center retrospective study. J Clin Med. 2022;11:4989.
18. Lee NJ, Leung E, Buchanan IA et al. A multicenter study of the 5-year trends in robot-assisted spine surgery outcomes and complications. J Spine Surg 2022;8:9–20.
19. Ekici MA, Ozbek Z, Gokoglu A et al. Surgical management of cervical spinal epidural abscess caused by Brucella melitensis: report of two cases and review of the literature. J Korean Neurosurg Soc 2012;51:383–7.
20. Fatima N, Massaad E, Hadzipasic M, et al. Safety and accuracy of robot-assisted placement of pedicle screws compared to conventional free-hand technique: a systematic review and meta-analysis. Spine J. 2021;21:181–92.
21. Fayed I, Tai A, Triano MJ et al. Lateral versus prone robot-assisted percutaneous pedicle screw placement: a CT-based comparative assessment of accuracy. J Neurosurg Spine. 2022;37:112–20.
22. Feng S, Tian W, Sun Y et al. Effect of Robot-assisted surgery on lumbar pedicle screw internal fixation in patients with osteoporosis. World Neurosurg. 2019;125:e1057–62.
23. Gao S, Lv Z, Fang H. Robot-assisted and conventional freehand pedicle screw placement: a systematic review and meta-analysis of randomized controlled trials. Eur Spine J. 2018;27:921–30.
24. Gao S, Wei J, Li W et al. Accuracy of Robot-assisted Percutaneous Pedicle Screw Placement under Regional Anesthesia: a retrospective cohort study. Pain Res Manag. 2021;2021:6894001.
25. Du J, Gao L, Huang D et al. Radiological and clinical differences between robotic-assisted pedicle screw fixation with and without real-time optical tracking. Eur Spine Journal: Official Publication Eur Spine Soc Eur Spinal Deformity Soc Eur Sect Cerv Spine Res Soc. 2021;30:142–50.
26. Yang J, He B, Tian F et al. Accuracy of robot-assisted percutaneous pedicle screw placement for treatment of lumbar spondylolisthesis: a comparative cohort study. Med Sci Monitor: Int Med J Experimental Clin Res. 2019;25:2479–87.
27. Tovar MA, Dowlati E, Zhao DY et al. Robot-assisted and augmented reality-assisted spinal instrumentation: a systematic review and meta-analysis of screw accuracy and outcomes over the last decade. J Neurosurg Spine. 2022;37:299–314.

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