

Clinical Study of Tianji Robotic-Assisted Surgery for Upper Cervical Spine Fractures

Chengkua Huang¹, Yuanjian Huang^{1,2}, Weikang Yang^{1,2}, Qianhou Zhou^{1,2}, Xianhai Zeng^{1,2}, Junlei Tan^{1,2}, Mei Zhang², Guosheng Su^{3*}, Sheng Nong^{4*}

¹Baise City People's Hospital (Affiliated Southwest Hospital of Youjiang Medical University for Nationalities), Baise, China; ²Graduate School of Yirong National Medical College, Baise, China; ³The Clinical Laboratory Department of the People's Hospital of Guangxi-ASEAN Economic and Technological Development Zone (Nanning No. 10 People's Hospital), Nanning, China; ⁴School of Public Health Management, Youjiang Medical University for Nationalities, Baise, China

Correspondence to: Guosheng Su, 563449581@qq.com; Sheng Nong, 419474445@qq.com

Keywords: Tiangui Robot, Assisted Surgery, Upper Cervical Spine Fracture, Clinical Study, Fracture Repair

Received: August 26, 2024

Accepted: September 15, 2024

Published: September 18, 2024

Copyright © 2024 by author(s) and Scientific Research Publishing Inc.

This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

ABSTRACT

Object: To compare the safety, clinical efficacy, and complication rate of “Tianji” robot-assisted surgery with traditional open surgery in the treatment of cervical vertebrae fracture. **Methods:** 60 patients with upper cervical vertebrae fracture admitted to Baise People's Hospital between November 2018 and April 2024 were retrospectively analyzed. Among these patients, 29 underwent “Tianji” robot-assisted surgery (Robot group), and 31 underwent traditional C-arm fluoroscopy-assisted open surgery (Open group). Statistical analysis of the data was performed using SPSS 27.0 software to compare general data (gender, age, BMI), preoperative and postoperative visual analogue scale (VAS) scores, neck disability index (NDI), intraoperative blood loss, accuracy of screw placement on imaging, and the number of complications in both groups for comprehensive evaluation. A P value < 0.05 was deemed to have achieved statistical significance. **Results:** There was no significant difference in preoperative VAS scores between the two groups (Robot group: 8.34 ± 0.61 ; Open group: 8.26 ± 0.68 , $P = 0.317$). There was also no significant difference in VAS scores at 1 week postoperatively (Robot group: 6.90 ± 0.31 ; Open group: 6.94 ± 0.36 , $P = 0.3237$). Preoperative NDI scores showed no significant difference between the two groups (Robot group: 43.31 ± 2.67 ; Open group: 43.84 ± 2.67 , $P = 0.2227$), and the difference in NDI scores at 1 week postoperatively was also not significant (Robot group: 35.69 ± 4.24 ; Open group: 37.35 ± 3.48 , $P = 0.0509$). Intraoperative blood loss in the Robot group was significantly lower than in the Open group (246.21 ± 209 ml vs 380.65 ± 328.04 ml, $P = 0.0308$), with a statistically significant difference. The operation time was longer

in the Robot group (3.75 ± 0.74 h) compared to the Open group (2.74 ± 0.86 h). In terms of screw placement accuracy, the Robot group had a higher accuracy rate for Class A screws compared to the Open group (102 screws vs 94 screws, $P = 0.0487$), and the accuracy rate for Class B screws was also higher in the Robot group (13 screws vs 29 screws, $P = 0.0333$), with both differences being statistically significant. There was no significant difference in the number of complications between the two groups (Robot group: 8 cases; Open group: 10 cases, $P = 0.6931$). Conclusion: Patients treated with “Tianji” robot-assisted surgery for upper cervical vertebrae fracture had lower intraoperative blood loss and higher screw placement accuracy compared to those undergoing traditional C-arm fluoroscopy-assisted open surgery, indicating that this robot-assisted surgery can effectively reduce intraoperative blood loss and improve screw placement accuracy.

1. INTRODUCTION

The upper cervical spine is located between the head and torso, and is a segment of the spine with relatively large mobility, responsible for supporting the head, protecting the spinal cord, and maintaining the flexibility of the neck. However, due to the lack of strong protection in this area and the relatively small size of the vertebral body in the upper cervical spine compared to other vertebral bodies, even slight injury can lead to upper cervical spine fractures. These fractures may not only affect the stability of the spine, but also compress the spinal cord, leading to serious nerve damage. Therefore, the principle of treating upper cervical spine fractures is to restore the stability of the cervical spine and reduce the compression on the spinal cord through surgical treatment. Currently, for the treatment of upper cervical spinal fracture dislocation, preoperative skull traction is often used as an auxiliary means of reduction and temporary fixation. Although this method can alleviate symptoms to a certain extent, the final treatment still requires surgery to relieve the compression on the spinal cord and restore the normal sequence of the vertebrae [1]. Traditional C-arm fluoroscopy-guided open surgery with manual nail placement has many shortcomings in clinical application, such as a large amount of bleeding during surgery and low accuracy of nail placement, which may affect the safety and effectiveness of the surgery [2]. With the continuous development of intelligent technology, intelligent robotic navigation-assisted orthopedic surgery techniques are gradually being widely used in clinical practice. The domestic “Tianji” orthopedic surgical robot, with its significant advantages in accuracy and minimally invasive procedures, is showing good prospects in the treatment of upper cervical spine fractures. Combining the concept of “minimally invasive surgery”, robot-assisted surgery can not only improve the accuracy of surgery and reduce the occurrence of postoperative complications, but also potentially enhance the postoperative recovery effect of patients. In the future, robot-assisted treatment is expected to become the mainstream of orthopedic minimally invasive surgery and drive further development in the treatment of upper cervical spine fractures. In order to understand the safety, clinical efficacy, and incidence of complications of the “Tianji” robot-assisted surgery compared to traditional open surgery in the treatment of upper cervical spine fractures, the research team conducted a series of comparative studies, and the research results are reported as follows.

2. MATERIALS AND METHODS

2.1. Inclusion Criteria and Exclusion Criteria

Inclusion criteria: 1) A clear history of cervical spine trauma; 2) X-ray, CT, MRI confirmed diagnosis of cervical spine fracture; 3) The fracture type has indications for internal fixation surgery and obtain the patient's consent.

Exclusion criteria: 1) Patients who cannot tolerate surgery due to severe systemic diseases, such as severe coronary heart disease, cerebrovascular disease, severe renal insufficiency, liver failure, etc.; 2) History

of skin infections, tumors, and severe bone diseases such as severe osteoporosis; 3) History of cervical spine surgery.

2.2. General Information

A total of 60 cases were included in this retrospective analysis from November 2018 to April 2024 in our hospital, diagnosed with upper cervical spine fractures and underwent surgical treatment, based on the actual situation of our hospital starting the “Tianji” robot-assisted surgery in 2020. Among them, 31 cases who underwent open surgery with C-arm fluoroscopy-guided hand insertion of screws from November 2018 to September 2020 were classified as the Open group, and 29 cases who underwent robot-assisted surgery with the “Tianji” robot from April 2020 to April 2024 were classified as the Robot group. This study was approved by the hospital ethics committee, and because it was a retrospective analysis, patient informed consent was waived. All surgeries in the aforementioned cases were performed under the guidance of the chief of the Department of Spinal Surgery in our hospital, and by the same team of attending physicians.

2.3. Preoperative Preparation

Both the robot-assisted group and the open surgery group underwent routine protective cranial traction before surgery. Comprehensive preoperative imaging assessments included cervical spine X-ray, CT, MRI, echocardiography, lower limb vascular ultrasound, cranial CT, and chest CT or chest X-ray. Blood tests, including complete blood count, liver and kidney function tests, electrolytes, and coagulation function tests, were also performed. The surgical plan was determined after preoperative evaluations, and a comprehensive assessment was made to determine whether the patient could tolerate the surgery. During this period, symptomatic treatments such as gastric protection, pain relief, neurotrophic support, anti-swelling measures, correction of electrolyte imbalances, and prophylactic anticoagulation, were provided. Both groups received a prophylactic intravenous infusion of 1 g cefazolin sodium dissolved in 100 ml saline 30 minutes before surgery to prevent infection. If the surgery exceeded 3 hours or the intraoperative blood loss was greater than 1500 ml, additional antibiotics were administered.

2.4. Robot-Assisted Surgical Methods

Connect the robot and the 3D C-arm, install the head holder after the anesthesia takes effect, position the patient in the prone position, and secure with adhesive tape. Perform routine disinfection, drape towels, make a skin incision at the posterior midline of the injured segment in the neck, install the tracker, perform a 3D CT scan for localization, transfer the data to the robot for planning the entry points and length, angle of the pedicle screws (as shown in [Figure 1](#)). Execute the screw insertion command program, place the sleeve

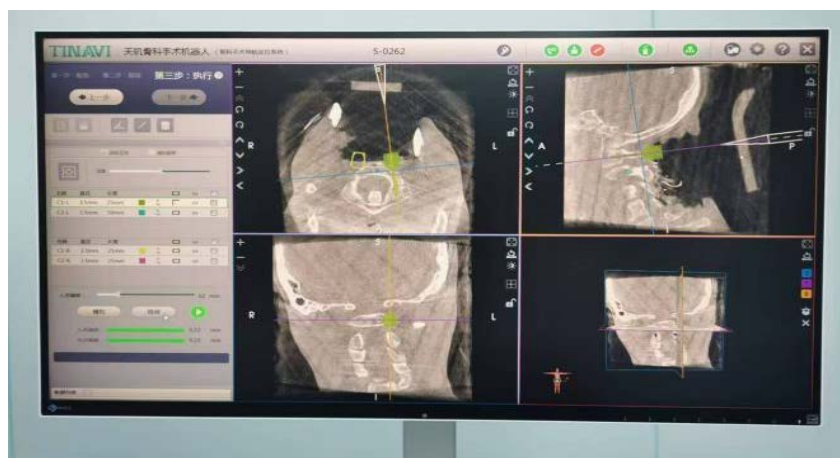


Figure 1. Robot planning in nail points.

after the robotic arm reaches the planned entry point of the vertebral body, and sequentially drill the Kirschner wire into the planned channel with the electric drill (as shown in [Figure 2](#)). Perform another 3D C-arm scan, confirm the proper position of the Kirschner wires (as shown in [Figure 3](#), [Figure 4](#)), mark the entry points, open the channels, sequentially insert the pedicle screws after tapping and depth measurement, install the connecting rod, perform another fluoroscopy and 3D C-arm scan (as shown in [Figures 5-7](#)), confirm good fracture reduction, proper screw position, irrigate the wound with saline solution (as shown in [Figure 8](#)), place a drainage tube in the wound, suture layer by layer, cover the surgical incision with sterile dressings, and conclude the surgery.



Figure 2. Path planning and planning for needle insertion in K-wire.



Figure 3. C-arm scan to confirm the position of the Kocher needle (anteroposterior view).



Figure 4. C-arm scan to locate the K-wire position (lateral view).



Figure 5. Intraoperative C-arm scan of the position of pedicle screws (lateral view).



Figure 6. C-arm scan of the position of pedicle screws (anteroposterior view).

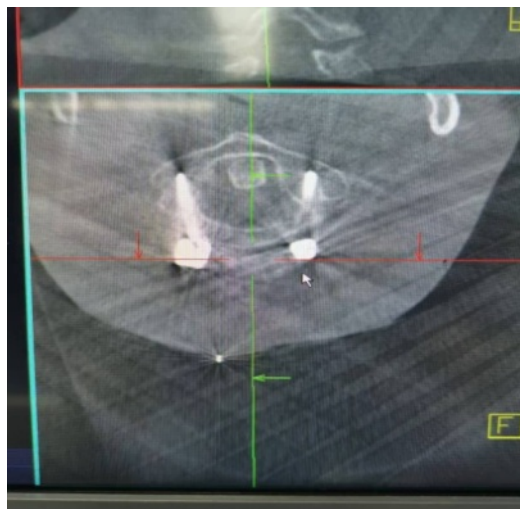


Figure 7. Position of pedicle screws by C-arm scanning (coronal view).

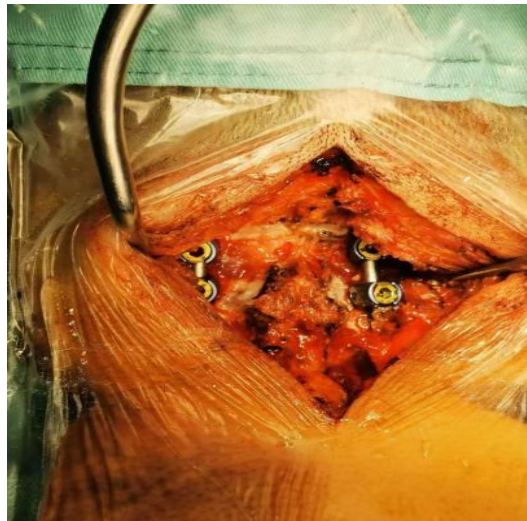


Figure 8. Surgical incision after completion of pin fixation.

2.5. Open Reduction Internal Fixation (ORIF) Technique

Install the head frame, place the patient in a prone position, expose the spinous process, lamina, and facet joint from the posterior approach, select the pedicle screws and grind the bone cortex at the entry point, adjust the angle, drill the pilot hole, confirm the bone channel with a probe, place the guide pin, confirm the position with fluoroscopy, tap, confirm the screw trajectory, insert the appropriate pedicle screw, confirm the position with fluoroscopy again, install the connecting rod, reduce the fracture, flush the wound with saline, insert a drainage tube, close the layers, cover the incision with sterile dressing, and complete the surgery.

2.6. Postoperative Care

The robot group and the open group both need absolute bed rest for at least 6 hours after surgery. Cefoperazone is given postoperatively to prevent infection, and treatment continues with gastric protection, pain relief, nutrition for nerves, anti-edema, prevention and treatment of electrolyte disorders, prophylactic anticoagulation, etc. Postoperatively, when the drainage volume is less than 30 milliliters, the drainage tube can be removed and the patient is instructed to undergo rehabilitation training; Follow-up examinations include cervical spine X-rays, CT scans, and three-dimensional reconstructions.

2.7. Statistical Methods

Using SPSS 27.0 software to analyze the statistical data in this study, the chi-square test was used for categorical data, presented using percentages (%); the t-test was used for continuous data, presented as mean \pm standard deviation “ $x \pm s$ ”. $P < 0.05$ indicates statistical significance.

3. RESULTS

3.1. Comparison of General Information between Two Groups of Patients

This study was divided into a robot group and an open group based on the need for robot-assisted surgical treatment. The robot group consisted of 19 males and 10 females who met the inclusion criteria, totaling 29 individuals; the open group consisted of 16 males and 15 females who met the inclusion criteria, totaling 31 individuals. The mean age of the robot group was 50.24 ± 10.36 years, and that of the open group was 50.23 ± 12.70 years. The mean BMI of the robot group was 24.34 ± 3.54 , while that of the open group was 23.88 ± 2.90 . In terms of the comparison of fracture sites between the two groups, there were a total of

21 patients with single-segment fractures in the robot group, including 11 in the C1 segment, 10 in the C2 segment, and 8 in the C1 + C2 dual segment; while in the open group, there were a total of 24 patients with single-segment fractures, including 10 in the C1 segment, 14 in the C2 segment, and 7 in the C1 + C2 dual segment.

The general data of two groups of patients, including gender, age, body mass index (BMI), number of single-segment surgical cases, and number of double-segment surgical cases, were compared, and the differences were not statistically significant ($P > 0.05$). See [Table 1](#) and [Table 2](#) for details.

Table 1. Comparison of general data in two groups.

Group	Number		age	BMI
	Male	Female		
Robot Group (n = 29)	19	10	50.24 ± 10.36	24.34 ± 3.54
Open Group (n = 31)	16	15	50.23 ± 12.70	23.88 ± 2.90
X ² or t value	1.1918		0.0033	0.5521
P value	0.2750		0.4987	0.2915

Table 2. Comparison of Fracture Sites Between the Two Groups.

Group	Number	Spinal Segment		
		C1	C2	C1 + C2
Robot Group (n = 29)	29	11	10	8
Open Group (n = 31)	31	10	14	7
X ² value	—	0.2120	0.7119	0.2002
P value	—	0.6452	0.3988	0.6545

3.2. Comparison of VAS Scores between Two Groups of Patients before Surgery, 1 Week after Surgery, and at the Last Follow-Up

The preoperative VAS score of the “Tian Ji” robot-assisted surgery group was 8.34 ± 0.61 , the postoperative VAS score at 1 week was 6.90 ± 0.31 , and the VAS score at the last follow-up was 1.28 ± 0.96 ; the preoperative VAS score of the traditional C-arm fluoroscopy-assisted open surgery group was 8.26 ± 0.68 , the postoperative VAS score at 1 week was 6.94 ± 0.36 , and the VAS score at the last follow-up was 1.52 ± 0.85 . There was no statistically significant difference in the VAS scores between the two groups before surgery, at 1 week after surgery, and at the last follow-up ($P = 0.3170 > 0.05$, $P = 0.3237 > 0.05$, $P = 0.1544 > 0.05$). Refer to [Table 3](#).

The study involved the comparison of NDI scores among two groups of patients before surgery, 1 week after surgery, and at the final follow-up.

The preoperative NDI score of the “Tianji” robotic-assisted surgery group was 43.31 ± 2.67 , the NDI score at 1 week postoperatively was 35.69 ± 4.24 , and the NDI score at the last follow-up was 5.38 ± 5.41 ; the preoperative NDI score of the traditional C-arm fluoroscopy-assisted open surgery group was 43.84 ± 2.67 , the NDI score at 1 week postoperatively was 37.35 ± 3.48 , and the NDI score at the last follow-up was 7.00 ± 6.12 . There was no statistically significant difference in NDI scores between the two groups before surgery, at 1 week postoperatively, and at the last follow-up ($P = 0.2227 > 0.05$, $P = 0.0509 > 0.05$, $P = 0.1416 >$

0.05). See [Table 3](#).

Table 3. Comparison of various indicators between the two groups.

Group	VAS Score			NDI Score		
	Preoperative	Postoperative 1 Week	Final Follow-up	Preoperative	Postoperative 1 Week	Final Follow-up
Robot Group (n = 29)	8.34 ± 0.61	6.90 ± 0.31	1.28 ± 0.96	43.31 ± 2.67	35.69 ± 4.24	5.38 ± 5.41
Open Group (n = 31)	8.26 ± 0.68	6.94 ± 0.36	1.52 ± 0.85	43.84 ± 2.67	37.35 ± 3.48	7.00 ± 6.12
T Value	0.4785	0.4597	1.0268	0.7684	1.6622	1.0834
P Value	0.3170	0.3237	0.1544	0.2227	0.0509	0.1416

3.3. Comparison of Intraoperative Blood Loss between Two Groups of Patients

The intraoperative blood loss in the “Tianji” robot-assisted surgery group was 246.21 ± 209 milliliters, while in the traditional C-arm fluoroscopy-guided open surgery group, the intraoperative blood loss was 380.65 ± 328.04 milliliters. The difference in intraoperative blood loss between the two groups was statistically significant, with a P value of $0.0308 < 0.05$, as shown in [Table 4](#).

3.4. Comparison of Operation Times in Two Groups of Patients

The operation time of the “Tianji” robotic assisted surgery group was 3.75 ± 0.74 hours, while the operation time of the traditional C-arm fluoroscopy-guided nail placement open surgery group was 2.74 ± 0.86 hours. Due to the significantly longer operation time of the robotic group compared to the open group, no P value calculation was performed. Refer to [Table 4](#).

Table 4. Comparison of intraoperative blood loss and surgery time between the two groups.

Group	Intraoperative Blood Loss	Surgery Time
Robot Group (n = 29)	246.21 ± 209	3.75 ± 0.74
Open Group (n = 31)	380.65 ± 328.04	2.74 ± 0.86
T Value	1.9056	4.8608
P Value	0.0308	0.0000

3.5. Comparison of Accuracy of Screw Placement in Two Patient Groups

According to the Gertzbein-Robbins classification criteria of pedicle screw placement accuracy, the level of accuracy of screw placement is judged from the CT axial plane [3]. Class A, no cortical violation; Class B, cortical penetration < 2 mm; Class C, $2 \text{ mm} \leq$ cortical penetration < 4 mm; Class D, $4 \text{ mm} \leq$ cortical penetration < 6 mm; Class E, cortical penetration $\geq 6 \text{ mm}$. Class A screw placement is the most accurate, Class B screw placement is relatively acceptable, while the accuracy of Class C, D, and E screw placements is poor [4].

The robot group placed a total of 227 screws, with 102 screws of type A, 13 of type B, 3 of type C, and 0 of types D and E. Combined A and B screws totaled 115. The open group placed a total of 260 screws, with 94 screws of type A, 29 of type B, 6 of type C, and 8 of types D and E. Combined A and B screws totaled 123.

There was a statistically significant difference in the number of type A and B screws placed between the robot group and the open group ($P < 0.05$). See [Table 5](#).

Eight cases of postoperative complications occurred in the robot group, including two cases of vertebral artery injury, two suspected incision infections, three incision infections, and one case of numbness in both upper limbs after surgery; there were 10 cases of postoperative complications in the open group, including seven cases of vertebral artery injury, two suspected incision infections, one incision infection, and one case of mental disorders after surgery; all these complications improved after symptomatic treatment and the patients were discharged. There was no statistically significant difference in the number of complications between the two groups ($P > 0.05$). See [Table 5](#).

Table 5. Comparison of accuracy and complications between the two groups.

Group	Comparison of Accuracy (Number of Screws)						Total Number	Complications
	A	B	A + B	C	D	E		
Robot Group (n = 29)	102	13	115	3	0	0	227	8
Open Group (n = 31)	94	29	123	6	2	6	260	10
X ² Value	3.8849	4.5293	0.5453	0.2198	—	3.5769	4.4723	0.1557
P Value	0.0487	0.0333	0.4602	0.6392	—	0.0586	0.0344	0.6931

4. DISCUSSION

In the 1990s, the pedicle screw fixation technique was first applied by Japanese scholars to treat upper cervical spine fractures and dislocations. As the technique has developed, pedicle screw fixation has gradually become the mainstream treatment for upper cervical spine fractures [5]. However, due to the proximity of the cervical spine to many important structures, such as the vertebral artery, para-vertebral ligaments, nerves, and muscles, it is necessary for surgeons to have higher surgical skills to avoid postoperative complications and promote early recovery. This requires spinal surgeons to have a longer process of mastering surgical techniques. According to relevant literature, robots were first used in orthopedic surgery in 1992, starting with robot-assisted hip replacement surgery. Due to its minimally invasive, intelligent, and precise advantages, many countries subsequently began developing robot-assisted surgery technology [6]. While the development of robot-assisted surgery technology in China started later, it has progressed rapidly. The domestically produced “TiRobot” surgical robot has been widely used in orthopedic clinical surgery since its launch in 2016. During the use of the “TiRobot” robot-assisted surgery, it was found that robot-assisted surgery has advantages, such as minimally invasive and precision compared to traditional open surgery [7-9]. The precise placement of screws and a better surgical field are required to restore cervical stability and relieve spinal cord compression. The disadvantages of traditional surgery include a large amount of bleeding, poor visibility, and low precision. The “TiRobot” surgical robot can effectively solve these problems. The optical tracking system, like the perspective eyes of the “TiRobot,” can not only see into every deep muscle and bone, but also observe every step of the surgery in real time. This reduces the slow postoperative recovery caused by excessive trauma in traditional open surgery. Furthermore, the mechanical arm, like the “steady hand” of the “TiRobot,” is not only flexible in movement but also stable in operation, achieving submillimeter precision. This provides favorable assurance for surgeons to precisely place internal fixation devices during surgery. Currently, literature on the use of the “TiRobot” robot-assisted surgery mainly focuses on the treatment of femoral neck fractures, thoracolumbar fractures, pelvic fractures [10-12], and there are relatively few reports on the use of the “TiRobot” robot-assisted surgery for upper cervical spine fractures.

Advantages of robot-assisted cervical spine surgery include the following [13, 14]: 1) Higher precision:

Robot surgical systems can provide high-precision surgical positioning and operation through advanced image-guided technology, helping doctors to more accurately locate and avoid the carotid artery, thus reducing surgical risks. 2) Minimal trauma: Robot surgical systems cause less trauma to patients, usually resulting in reduced bleeding, less pain, and shorter recovery times. 3) Robot surgical systems are typically equipped with a three-dimensional C-arm visual system, allowing doctors to have a clearer view of the patient's anatomical structures during surgery, thus helping to avoid damaging surrounding important tissues. 4) Fine operation accuracy: Robot surgical systems can reduce external factors' interference with the surgery, improve the stability and accuracy of surgical operations, and help prevent errors.

The results of this study showed that there were no significant differences in VAS and NDI scores between the two groups of patients preoperatively, postoperatively, and at the last follow-up ($P > 0.05$), which may be due to the small sample size included in this study. The difference in intraoperative blood loss between the two groups of patients was statistically significant, with less blood loss in the robotic group compared to the open group. However, the robotic group had a longer operation time than the open group, possibly due to the initial introduction of the "Tianji" robot for orthopedic surgery at our hospital, leading to a lack of proficiency in using the newly introduced robot. With the increasing proficiency in using the robot for assisted operations, the operation time in the robotic group is expected to gradually decrease in the future. Despite the longer operation time in the robotic group compared to the open group, the blood loss during surgery was still less in the robotic group, highlighting the advantage of the "Tianji" robot-assisted surgery in having less trauma compared to traditional open surgery. In terms of the accuracy of screw placement, the robotic group was significantly superior to the open group, with a statistically significant difference in the data between the two groups ($P < 0.05$). It is considered that the open group relies on the experience and surgical skills of the main surgeon for manual screw placement during C-arm fluoroscopy-assisted surgery, which may lead to unsatisfactory screw placement. In contrast, the robotic-assisted surgery group with the "Tianji" robot can reconstruct a three-dimensional structure after C-arm scanning and generate a three-dimensional image on the robot's main computer, allowing for the use of screws of different lengths and different entry routes and channels to effectively reduce errors in manual screw placement and improve accuracy [15]. There was no statistical difference in the number of postoperative complications between the two groups of patients, but it is possible that the number of complications in the robotic group will decrease with an increased sample size. During the placement of pedicle screws in the cervical spine, due to the proximity to the vertebral artery, intraoperative manipulation can easily cause vertebral artery injury. While the number of cases with vertebral artery injury as a postoperative complication was lower in the robotic group than the open group, the data did not show statistical significance, possibly due to the small sample size in this study. With a larger sample size, statistically significant data differences may be obtained, further confirming the safety advantage of robotic-assisted surgery over traditional open surgery.

In general, robotic-assisted cervical spine surgery can provide a safer, more precise, and more effective surgical option, bringing better surgical experience and faster recovery for patients. This study aims to compare robotic-assisted nail placement surgery with traditional manual nail placement surgery to confirm the advantages of precision and minimally invasive robotic-assisted surgery, and to gain clinical application value and socio-economic value.

5. CONCLUSION

The "Tianji" robot-assisted surgery in the treatment of upper cervical spine fractures has the advantages of less intraoperative blood loss and higher accuracy of screw placement compared to traditional open surgery with C-arm fluoroscopy for nail placement. However, due to the small sample size, there was no statistical difference in VAS score, NDI score, and postoperative complications. Increasing the sample size may lead to data with statistical differences. In terms of operation time, the robot group was longer than the open group, possibly due to the lack of proficiency in using the "Tianji" robot during the initial introduction. It is believed that with improved technical skills, the operation time will significantly decrease in the later stage, thus reducing the risk of surgical infection.

6. LIMITATIONS OF THE STUDY

Based on the findings of this study, the number of cases observed in this study is limited, which has certain limitations. Future research could consider expanding the sample size to further verify the differences between robot-assisted upper cervical surgery and traditional manual transpedicular screw placement surgery. Combining clinical symptoms and functional evaluation indicators, in-depth research on the advantages and disadvantages of robot-assisted upper cervical surgery, collaborating with enterprises to develop cervical hollow pedicle screws, and clinical transformation to expand their clinical application areas. Through further research, a more comprehensive understanding of the clinical effects can be obtained, providing more effective treatment options for patients.

ACKNOWLEDGEMENTS

During the research process of this project, we have received assistance from many departments, individuals, and other personnel who were not involved in this project. All members of the project express our sincere gratitude to the departments and individuals who have provided support and assistance to this project, and wish them good health and all the best.

PROJECT FUNDING

2022 Baise City level financial science and technology plan project (No. BK20222013), 2022 Guangxi Zhuang Autonomous Region Health Commission self-funded research project in Western medicine category (No. Z-L20221840).

CONFLICTS OF INTEREST

The authors declare no conflicts of interest regarding the publication of this paper.

REFERENCES

1. Su, L., Zhou, Y.J., Wang, Y., *et al.* (2024) The Research Progress in Surgical Treatment of Cervical Spine Fractures and Dislocations. *Chinese Journal of Spine and Spinal Cord*, **34**, 438-443.
2. Lang, Z., Yuan, Q., Fan, M.X., *et al.* (2024) Robot-Assisted Magerl Screw Internal Fixation for Upper Cervical Spine Diseases. *Beijing Biomedical Engineering*, **43**, 280-284.
3. Zhu, B., Zhang, Y.J., Yang, Z.Y., *et al.* (2024) Comparison of Personalized 3D Printed Guide and Robot-Assisted Screw Fixation for Adult Degenerative Scoliosis Vertebral Pedicle Screw Placement. *Chinese Journal of Spine and Spinal Cord*, **34**, 135-142.
4. Zhao, T., Huang, C.K. and Su, G.S. (2024) Application Effect of Robot-Assisted Percutaneous Pedicle Screw Placement and Conventional Open Pedicle Screw Placement in Lumbar Vertebral Fractures. *Minimally Invasive Medicine*, **19**, 19-26.
5. Liu, Y., Zhao, Z.G., Wang, X., *et al.* (2022) Robot-Assisted Pedicle Screw Fixation for the Treatment of Cervical Spine Fracture and Dislocation. *Chinese Journal of Orthopedics*, **30**, 1941-1946.
6. Liu, S., Lei, T.H., Gu, F., *et al.* (2024) Review on the Application of Tianji Orthopedic Surgical Robot in the Field of Traumatic Orthopedics. *Medical Equipment*, **45**, 104-110.
7. Yin, Y.B., Wang, Z.X., Yi, Z., *et al.* (2023) Introduction to the Tianji Orthopedic Robot-Assisted Percutaneous Screw Internal Fixation Technique for Quadrangular Fusion. *Journal of Restorative and Reconstructive Surgery in China*, **37**, 764-766.
8. Yang, C.Z., Liu, G., Tang, J.L. *et al.* (2022) Percutaneous Iliosacral Hollow Screw Internal Fixation Assisted by Tianji Orthopedic Robot in the Treatment of Posterior Pelvic Ring Injuries Combined with Sacral Bone Deformity.

Chinese Journal of Reparative and Reconstructive Surgery, **36**, 940-945.

9. Zheng, S., Wang, B., Han, Z.C., *et al.* (2022) Efficacy Observation of the “Tianji” Orthopedic Surgical Robot-Assisted Percutaneous Screw Fixation in the Treatment of Simple Isthmic Spondylolysis. *Journal of the Chinese PLA Medical School*, **43**, 617-621.
10. Liu, Y.J., Wang, Z.D., Xu, C., *et al.* (2023) Minimally Invasive Treatment of Elderly Garden II, III Type Femoral Neck Fractures with Tianji Orthopedic Robot-Assisted Dynamic Locking Nail System: Early Clinical Efficacy. *Chinese Journal of Reparative and Reconstructive Surgery*, **37**, 1471-1476.
11. Ma, M.Z., Wang, Z.C., Ye, J.W. and Chen, X. (2023) Efficacy Analysis of “Tianji” Orthopedic Robot-Assisted and Manual Pedicle Screw Fixation for Thoracic Vertebral Osteoporotic Vertebral Compression Fractures Surgery. *Chinese Journal of Reparative and Reconstructive Surgery*, **37**, 1106-1112.
12. Liu, K.X., You, M.Z., Huang, M.R., *et al.* (2022) Preliminary Application of Tianji Orthopedic Robot Combined with Artis Zeego System for Minimally Invasive Treatment of Pelvic Fractures. *Chinese Journal of Reparative and Reconstructive Surgery*, **36**, 929-933.
13. Lin, S., Tang, L.Y., Wang, F., *et al.* (2023) Tirobot-Assisted Percutaneous Kyphoplasty in the Management of Multilevel (More Than Three Levels) Osteoporotic Vertebral Compression Fracture. *International Orthopaedics*, **47**, 319-327. <https://doi.org/10.1007/s00264-022-05580-1>
14. Zhu, Z.D., Xiao, C.W., Tan, B., *et al.* (2021) Tirobot-Assisted Percutaneous Cannulated Screw Fixation in the Treatment of Femoral Neck Fractures: A Minimum 2-Year Follow-Up of 50 Patients. *Orthopaedic Surgery*, **13**, 244-252. <https://doi.org/10.1111/os.12915>
15. Mao, J.Z., Soliman, M., Karamian, B.A., *et al.* (2023) Anatomical and Technical Considerations of Robot-Assisted Cervical Pedicle Screw Placement: A Cadaveric Study. *Global Spine Journal*, **13**, 1992-2000. <https://doi.org/10.1177/21925682211068410>