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Multidimensional Efficacy Evaluation of Tianji Orthopedic Robot-Assisted Screw Placement Surgery and Traditional Open Surgery in the Treatment of Thoracic Fractures

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ABSTRACT

Objective: To compare the clinical efficacy of Tianji orthopedic robot-assisted surgery and traditional open surgery in the treatment of thoracic fractures. Methods: 30 patients in the robot group and 25 patients in the open group were included. Baseline data such as age, BMI, and gender of the two groups were compared. The ODI scores, Cobb angles, anterior and posterior vertebral height ratios before and after surgery, as well as intraoperative blood loss, vertebral fracture healing time, postoperative hospital stay, screw accuracy rate and scores of the two groups were compared. Results: There was no significant difference in baseline data between the two groups of patients ($P > 0.05$). Before surgery, the ODI scores, Cobb angles, and anterior and posterior vertebral height ratios of the two groups were similar ($P > 0.05$). After surgery, the robot group was superior to the open group in terms of Cobb angle improvement (1-week postoperative review: $t = 2.4880$, $P = 0.0080$; last review: $t = 3.3921$, $P = 0.0007$). The intraoperative blood loss in the robot group was significantly less than that in the open group ($t = 4.0903$, $P = 0.0001$), and the vertebral fracture healing time was shorter ($t = 4.4702$, $P = 0.0000$). In terms of screw accuracy, the number of Grade A screws in the robot group was

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more than that in the open group ($\chi^2 = 10.9506$, $P = 0.0009$), the number of Grade B screws was less than that in the open group ($\chi^2 = 9.9740$, $P = 0.0016$), but the accuracy score was lower than that in the open group ($t = 1.7832$, $P = 0.0401$). Conclusion: Tianji orthopedic robot-assisted surgery has advantages over traditional open surgery in reducing intraoperative bleeding, shortening fracture healing time and improving some imaging indicators in the treatment of thoracic fractures, but there are differences in screw accuracy scores, providing a new reference for the clinical treatment of thoracic fractures.

1. INTRODUCTION

Thoracic fractures are common diseases in the field of spinal surgery, mostly caused by high-energy injuries, commonly seen in traffic accidents and falls from heights [1]. In the current context of an aging population, even minor daily trauma may lead to thoracic fractures. It not only has a high incidence rate but also a high disability and mortality rate [2]. Due to the important tissues and nerves adjacent to the thoracic vertebrae, once a vertebral burst fracture occurs, it will disrupt the stability of the spine, easily damage nerves and blood vessels, and the broken bone fragments are likely to protrude into the spinal canal, causing damage to the spinal cord and cauda equina nerves, resulting in serious consequences such as paralysis [3, 4]. Most patients with mild symptoms choose conservative treatment, but some studies have pointed out that surgical treatment can achieve a more stable internal fixation effect, which is more beneficial to the long-term recovery of patients [5]. For patients with severe symptoms, conservative treatment often has poor results, and long-term bed rest is likely to cause complications such as pneumonia, thrombosis, and pressure ulcers. Therefore, surgical treatment is usually selected. However, traditional open surgery causes great trauma and blood loss to patients. Even for experienced surgeons, it may be difficult. It has been reported that the failure rate of pedicle screw placement is 4.9% - 37.5% [6]. With the progress of technology, the Tianji orthopedic robot has emerged, and its characteristics of precision and safety are highly favored. This study deeply explores the safety, reliability, precision and clinical efficacy of Tianji orthopedic robot-assisted surgery and traditional open surgery in the treatment of thoracic fractures by comparing the collected case data.

2. MATERIALS AND METHODS

2.1. General Information

A retrospective analysis was carried out on 55 patients with thoracic fractures who were hospitalized and underwent surgical treatment in the Department of Spinal Surgery and Bone Oncology, Baise People's Hospital (Southwest Hospital Affiliated to Youjiang Medical University for Nationalities) from March 2021 to December 2024. The patients were divided into a robot-assisted group (30 cases) and a traditional open group (25 cases).

2.2. Inclusion and Exclusion Criteria

1) Inclusion criteria: ① Single-segment fracture without severe spinal cord injury; ② The patient signed the informed consent form; ③ The medical record data were complete.

2) Exclusion criteria: ① Complicated with other severe cardiovascular and cerebrovascular diseases; ② Suffering from mental illness and unable to communicate normally; ③ Complicated with severe organ damage.

2.3. Grouping

Robot group (n = 30, 13 males and 17 females), traditional open group (n = 25, 7 males and 18 females).

2.4. Surgical Methods

2.4.1. Robot Group (See Figures 1-3)

1) After general anesthesia, the patient was placed in the prone position on the operating table to ensure that the abdomen was not compressed. Before the operation, the C-arm machine and the orthopedic robot were checked to be in normal operation, and the body position was confirmed to be correct.

2) Tracer point marking and anatomical calibration matching were carried out: A tracer (dynamic reference frame) was placed in the surgical field without interfering with the operation. The C-arm machine was used for multi-angle fluoroscopy and three-dimensional reconstruction, and the images were uploaded to the robot system. The surgeon planned the screw path on the system and set the length and size of the implanted screws.

3) After the intraoperative simulation was completed, the robotic arm automatically moved to the corresponding point. A 1 - 2 cm small incision was made at this position, and the muscles were bluntly dissected to the lamina or articular process to avoid extensive dissection and reduce trauma to the patient.

4) Click the robot system again to fine-tune the robotic arm and lock the guide channel. Drill a hole through the guide sleeve, and use C-arm fluoroscopy to confirm that the position of the guide needle is accurate and the depth reaches the anterior 1/3 of the vertebral body.

5) Gradually expand the channel and select screws of appropriate size for implantation. Repeat the above steps to complete multi-segment fixation.

6) Use connecting rods and screws to longitudinally distract and restore the height of the vertebral body as much as possible.

7) Irrigate the wound and suture layer by layer.

2.4.2. Traditional Group (See Figure 4, Figure 5)

1) After general anesthesia, the patient was placed in the prone position on the operating table, and the abdomen was padded to prevent long-term compression. Before the operation, the C-arm machine was checked to be in normal operation.

2) The position of the injured vertebra was located by C-arm fluoroscopy and marked.

3) Along the marked line of the posterior midline, the skin, fascia and other tissues were successively incised, and the paravertebral muscles were dissected to the lamina and articular process joints.

4) After the guide needle was inserted, C-arm fluoroscopy was used to confirm that the position was satisfactory. The guide needle was removed and replaced with an appropriate screw, which was inserted manually. After the insertion was completed, fluoroscopy was used again to confirm the accuracy of screw placement. Repeat the above operations in turn to complete multi-segment fixation.

5) Use connecting rods and screws to longitudinally distract the vertebral body and restore the height of the vertebral body as much as possible.

6) Irrigate the wound and suture layer by layer. A drainage tube was left if necessary.

2.4.3. Postoperative Management and Rehabilitation

Within 48 hours after the operation, if a drainage tube was placed and the drainage volume was less than 50 ml, the drainage tube was removed. After the anesthesia effect subsided, the patient was instructed to sit on the bedside wearing a thoracic brace. If there was no dizziness or other discomfort, the patient could get out of bed and perform daily activities and walking while wearing the brace. Postoperative X-ray and CT examinations were arranged to evaluate the position of the screw internal fixation and the reduction effect of the fractured vertebra.

2.5. Observation Indicators

Main indicators: Screw placement accuracy rate (Grade A: The screw is completely within the pedicle without penetrating the cortical bone; Grade B: The screw penetrates the pedicle cortical bone ≤ 2 mm; Grade C: The screw penetrates the pedicle cortical bone > 2 mm; Grade D: The screw penetrates the pedicle cortical bone and may cause nerve or blood vessel injury; Grade E: The screw completely deviates from the pedicle, with obvious risks of nerve, blood vessel or visceral injury) and accuracy score (A = 4, B = 3, C = 2, D = 1, E = 0).

Secondary indicators: Intraoperative blood loss, hospital stay, vertebral fracture healing time, height ratio of the fractured vertebra before and after surgery, Cobb angle before and after surgery, and ODI score before and after surgery.

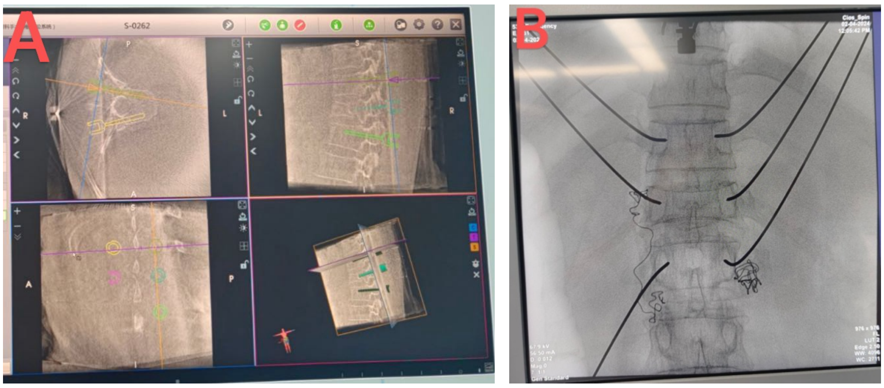

Figure 1. **Preoperative planning and positioning of thoracic fracture internal fixation assisted by robot.**

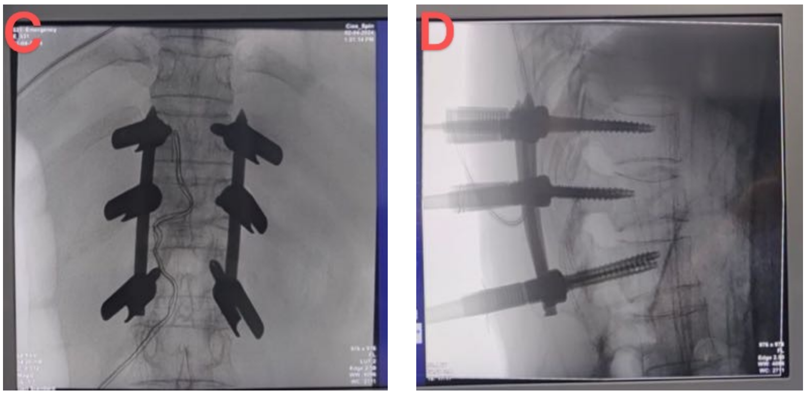

Figure 2. **Anterior and lateral views after screw placement in thoracic fracture internal fixation assisted by robot.**

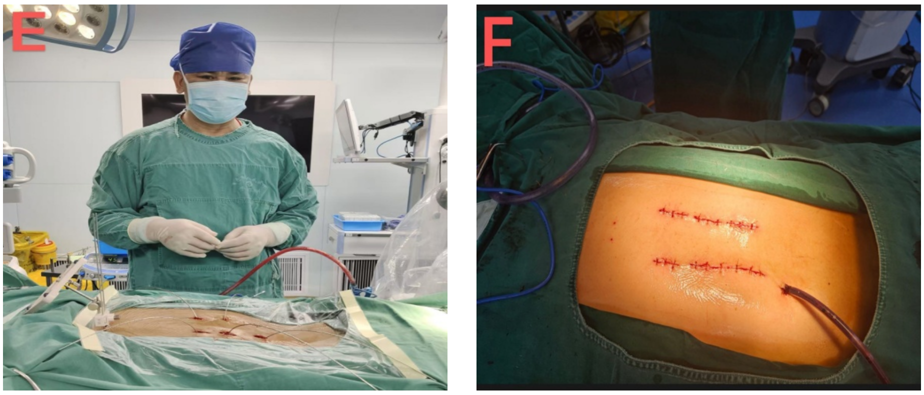

Figure 3. **Intraoperative rod - screw fixation and postoperative incision in thoracic fracture internal fixation assisted by robot.**

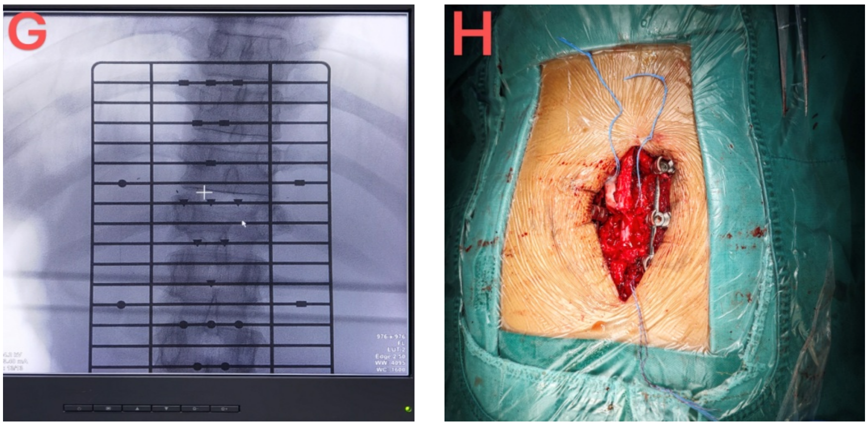

Figure 4. **Preoperative fluoroscopic marking and intraoperative incision in thoracic fracture internal fixation by traditional surgery.**

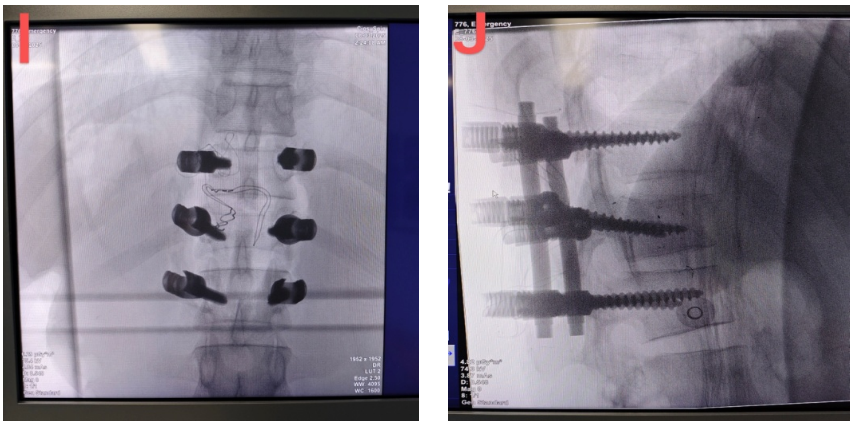

Figure 5. **Anterior and lateral views after screw placement in thoracic fracture internal fixation by traditional surgery.**

2.6. Statistical Analysis

SPSS 26.0 statistical software was used for data analysis. Measurement data were expressed as mean ± standard deviation, and the t-test was used for inter-group comparison; enumeration data were analyzed by χ^2 test, and $P < 0.05$ was considered as the standard for statistically significant differences.

3. RESULTS

3.1. Basic Patient Data

In terms of patient age, the mean age of 30 patients in the robot group was (45.93 ± 10.26) years old, and the mean age of 25 patients in the open group was (50.92 ± 8.99) years old. By t-test, the t-value was 1.8986 and the P-value was 0.0315, indicating a statistically significant difference. In terms of BMI index, the mean value of the robot group was (21.85 ± 2.13), and the mean value of the open group was (21.97 ± 1.67). The t-value was 0.2290 and the P-value was 0.4099, showing no statistically significant difference. In terms of gender composition, there were 13 males and 17 females in the robot group, and 7 males and 18 females in the open group. By χ^2 test, the χ^2-value was 1.3855 and the P-value was 0.3892, indicating no statistically significant difference. These results suggest that the two groups of patients were comparable in terms of BMI index and gender distribution, but there was a certain difference in age. The specific results are shown in Table 1.

3.2. ODI Scores before and after Surgery

The mean preoperative ODI score of the robot group was (45.97 ± 1.77) points, and the postoperative score was (5.27 ± 2.03) points. The mean preoperative ODI score of the open group was (45.32 ± 1.46) points, and the postoperative score was (5.00 ± 1.50) points. When comparing the preoperative ODI scores of the two groups, the t-value was 1.4663 and the P-value was 0.0742, showing no statistically significant difference. When comparing the postoperative ODI scores, the t-value was 0.5511 and the P-value was 0.2920, also showing no statistically significant difference. This indicates that the two surgical methods had similar effects in improving the patient's functional impairment. The specific results are shown in **Table 2**.

3.3. Cobb Angles before Surgery, at 1-Week Postoperative Review and at the Last Review

The mean preoperative Cobb angle of the robot group was (19.97 ± 2.01) degrees, the angle at 1-week postoperative review was (5.43 ± 1.33) degrees, and the angle at the last review was (3.37 ± 0.81) degrees. The mean preoperative Cobb angle of the open group was (19.80 ± 2.72) degrees, the angle at 1-week postoperative review was (6.32 ± 1.31) degrees, and the angle at the last review was (4.24 ± 1.09) degrees. When comparing the preoperative Cobb angles of the two groups, the t-value was 0.2662 and the P-value was 0.3956, showing no statistically significant difference. At the 1-week postoperative review, the t-value was 2.4880 and the P-value was 0.0080, indicating a statistically significant difference. At the last review, the t-value was 3.3921 and the P-value was 0.0007, indicating a statistically significant difference. These results show that the Cobb angles of both groups decreased over time, and the robot group had a better effect in reducing the Cobb angle after surgery than the open group. The specific results are shown in **Table 3**.

3.4. Anterior and Posterior Height Ratios of the Fractured Vertebra before and after Surgery

The mean preoperative anterior and posterior height ratio of the fractured vertebra in the robot group was (64.28 ± 4.27)%, the ratio at 1-week postoperative review was (84.61 ± 4.27)%, and the ratio at the last review was (88.18 ± 4.66)%. The mean preoperative anterior and posterior height ratio of the fractured vertebra in the open group was (62.17 ± 4.16)%, the ratio at 1-week postoperative review was (83.18 ± 2.16)%, and the ratio at the last review was (87.28 ± 2.41)%. When comparing the two groups before surgery, the t-value was 1.8461 and the P-value was 0.0352, indicating a statistically significant difference. At the 1-week postoperative review, the t-value was 1.6044 and the P-value was 0.0573, showing no statistically significant difference. At the last review, the t-value was 0.9204 and the P-value was 0.1808, showing no statistically significant difference. These results indicate that the two groups had similar effects in restoring the height of the fractured vertebra after surgery, and the preoperative anterior and posterior height ratio of the fractured vertebra in the robot group was relatively higher. The specific results are shown in **Table 4**.

3.5. Data Related to Intraoperative and Postoperative Recovery of the Surgery

The mean intraoperative blood loss in the robot group was (103.33 ± 71.55) ml, the mean healing time of the fractured vertebra was (3.60 ± 0.77) days, and the mean postoperative hospital stay was (8.87 ± 7.06) days. The mean intraoperative blood loss in the open group was (404.00 ± 361.69) ml, the mean healing time of the fractured vertebra was (4.56 ± 0.82) days, and the mean postoperative hospital stay was (11.84 ± 6.65) days. When comparing the intraoperative blood loss, the t-value was 4.0903 and the P-value was 0.0001, indicating a statistically significant difference. When comparing the healing time of the fractured vertebra, the t-value was 4.4702 and the P-value was 0.0000, indicating a statistically significant difference. When comparing the postoperative hospital stay, the t-value was 1.5947 and the P-value was 0.0584, showing no statistically significant difference. This indicates that the robot group was superior to the open group in terms of intraoperative blood loss and healing time of the fractured vertebra, while there was no significant difference in postoperative hospital stay between the two groups. The specific results are shown in **Table 5**.

3.6. Accuracy Rates and Scores of Different Screw Classification in the Surgery

In the robot group, there were 166 Grade A screw placements, 11 Grade B screw placements, a total of 177 Grade A + B screw placements, 2 Grade C screw placements, 0 Grade D screw placements, and a total of 179 screw placements. The mean accuracy score was (23.47 ± 1.98) points. In the open group, there were 139 Grade A screw placements, 29 Grade B screw placements, a total of 168 Grade A + B screw placements, 3 Grade C screw placements, 1 Grade D screw placement, and a total of 172 screw placements. The mean accuracy score was (26.00 ± 6.86) points. When comparing the Grade A screw placements between the two groups, the χ^2-value was 10.9506 and the P-value was 0.0009, indicating a statistically significant difference. When comparing the Grade B screw placements, the χ^2-value was 9.9740 and the P-value was 0.0016, indicating a statistically significant difference. When comparing the Grade A + B screw placements, the χ^2-value was 0.2127 and the P-value was 0.6447, showing no statistically significant difference. When comparing the Grade C screw placements, the χ^2-value was 0.0020 and the P-value was 0.9642, showing no statistically significant difference. When comparing the total number of screw placements, the χ^2-value was 0.2397 and the P-value was 0.6244, showing no statistically significant difference. When comparing the accuracy scores, the t-value was 1.7832 and the P-value was 0.0401, indicating a statistically significant difference. These results indicate that there were differences in the accuracy rates of Grade A and Grade B screw placements between the robot group and the open group, and the accuracy score of the robot group was lower than that of the open group. The specific results are shown in Table 6.

Table 1. **Comparison of age, BMI and gender parameters between the two groups of patients.**

Group	Number of Cases	Age	BMI Index	Gender	
				Male	Female
Robot Group	30	45.93 ± 10.26	21.85 ± 2.13	13	17
Open Group	25	50.92 ± 8.99	21.97 ± 1.67	7	18
χ^2 or t-value	—	1.8986	0.2290	1.3855	
P-value	—	0.0315	0.4099	0.3892	

Table 2. **Comparison of ODI scores before and after surgery between the two groups.**

Group	Number of Cases	ODI Score	
		Preoperative	Postoperative
Robot Group	30	45.97 ± 1.77	5.27 ± 2.03
Open Group	25	45.32 ± 1.46	5.00 ± 1.50
t-value	—	1.4663	0.5511
P-value	—	0.0742	0.2920

Table 3. **Comparison of Cobb angles before surgery, at 1-week postoperative review and at the last review between the two groups.**

Group	Number of Cases	Cobb Angle (Unit: Degree)		
		Preoperative	1-week Postoperative Review	Last Review
Robot Group	30	19.97 ± 2.01	5.43 ± 1.33	3.37 ± 0.81
Open Group	25	19.80 ± 2.72	6.32 ± 1.31	4.24 ± 1.09
t-value	—	0.2662	2.4880	3.3921
P-value	—	0.3956	0.0080	0.0007

Table 4. Comparison of anterior and posterior height ratios of the fractured vertebra before and after surgery between the two groups of patients.

Group	Number of Cases	Anterior and Posterior Height Ratio of the Fractured Vertebra (Unit: %)		
		Preoperative	1-week Postoperative Review	Last Review
Robot Group	30	64.28 ± 4.27	84.61 ± 4.27	88.18 ± 4.66
Open Group	25	62.17 ± 4.16	83.18 ± 2.16	87.28 ± 2.41
t-value	—	1.8461	1.6044	0.9204
P-value	—	0.0352	0.0573	0.1808

Table 5. Comparison of data related to intraoperative and postoperative recovery of the surgery between the two groups (robot group and open group).

Group	Number of Cases	Intraoperative Blood Loss	Healing Time of the Fractured Vertebra	Postoperative Hospital Stay
Robot Group	30	103.33 ± 71.55	3.60 ± 0.77	8.87 ± 7.06
Open Group	25	404.00 ± 361.69	4.56 ± 0.82	11.84 ± 6.65
t-value	—	4.0903	4.4702	1.5947
P-value	—	0.0001	0.0000	0.0584

Table 6. Comparison of accuracy rates of different screw classification and scores in the surgery between the two groups (robot group and open group).

Group	Number of Cases	Accuracy Rate (Number of Screws)						Accuracy Score (A = 4, B = 3, C = 2, D = 1, E = 0)
		A	B	A + B	C	D	Total Number of Screws	
Robot Group	30	166	11	177	2	0	179	23.47 ± 1.98
Open Group	25	139	29	168	3	1	172	26.00 ± 6.86
χ^2 or t-value		10.9506	9.9740	0.2127	0.0020	—	0.2397	1.7832
P-value		0.0009	0.0016	0.6447	0.9642	—	0.6244	0.0401

4. DISCUSSION

Thoracic fractures have a high incidence in the field of spinal surgery. If not treated promptly and effectively, they are likely to cause serious complications such as paralysis, pneumonia, and pressure ulcers. In most cases, conservative treatment is ineffective [7]. At present, the surgical treatment method using pedicle screw fixation has become the mainstream. Its purpose is to stabilize the unstable spine and prevent further damage and the development of deformities [8]. Traditional open surgery has many drawbacks. It causes great trauma to patients, with a large amount of intraoperative blood loss and frequent fluoroscopy, increasing the risk of vascular and nerve damage. The literature indicates that the misplacement rate of traditional freehand screw placement is between 10% - 40%. The surgical process depends to a large extent on the operator's tactile sense, and multiple fluoroscopies are required to confirm the accuracy of screw placement. This not only exposes the operator and the patient to radiation for a long time, prolongs the learning curve, but also makes it difficult to ensure accurate screw placement every time [9].

The emergence of orthopedic robot technology provides a new solution to these problems. According to Roser's research results, robot-assisted screw placement can reduce the radiation exposure time by 50%. Compared with traditional open surgery, its learning cycle is shorter, and it has a lower dependence on the operator's experience. Once the operator is familiar with the operation process, the screw placement process can be templated and standardized, thus significantly reducing the screw placement error rate [10]. Spine-Assist, as the first spinal robot, has promoted the development of spinal surgery, and related technologies have been continuously innovated since then [11]. Currently, the self-developed Tianji orthopedic robot in China has been widely used in clinical practice and has become a routine auxiliary device in many medical institutions [12]. Relevant studies have shown that compared with freehand screw placement, robot-assisted operation can significantly improve the screw placement accuracy rate. The navigation system increases the screw accuracy rate from 68% to 95%, and the robotic arm of the robot further improves the screw placement accuracy to 99% [13]. In this study, the screw accuracy score of the robot group was (23.47 ± 1.98) points, and that of the traditional open group was (26.00 ± 6.86) points. The comparison between the two groups showed $P < 0.05$, clearly indicating that the robot group was superior to the traditional open group in the accuracy and safety of screw placement.

In addition, the data of this study also show that the robot group was significantly superior to the traditional open group in terms of intraoperative blood loss, Cobb angle, and healing time of the fractured vertebra. However, there was no significant difference between the two groups in the height ratio of the fractured vertebra before and after surgery, ODI score, and postoperative hospital stay ($P > 0.05$), with no statistical significance. It should be noted that this study is a retrospective analysis, with a relatively limited sample size. The data are from inpatients in the spinal surgery department of our hospital, with strong regional characteristics, and the representativeness of the sample may be poor. More importantly, orthopedic robots are expensive, and the cost remains high. Many grass-roots areas have not yet equipped this equipment. This not only limits its popularization and application but may also cause some patients who intend to go to superior hospitals for robot-assisted treatment to have their case data affected due to changes in their conditions [14, 15].

5. CONCLUSION

Based on the comprehensive analysis of the data of this study, the Tianji orthopedic robot-assisted surgery has obvious advantages over traditional open surgery in the treatment of thoracic fractures. The robot-assisted surgery shows a higher screw placement accuracy rate, less intraoperative blood loss, a smaller postoperative Cobb angle, and a shorter healing time of the fractured vertebra, fully demonstrating its excellent performance in terms of safety, reliability, accuracy, and clinical efficacy. It is expected to be more widely applied and expanded in clinical practice.

6. LIMITATIONS OF THE STUDY

This study has certain limitations. On the one hand, the retrospective research method is adopted, with a small sample size and the source limited to our hospital. This may lead to insufficient universality and representativeness of the research results, making it difficult to comprehensively reflect the application effects of the Tianji orthopedic robot in different regions and different patient groups. On the other hand, the high cost of orthopedic robots limits their popularization in grass-roots areas. This not only affects the promotion of this technology but also poses challenges to the diversity of research samples, which may have a certain impact on the wide applicability of the research conclusions. Future research can consider expanding the sample range and conducting multi-center prospective studies to further verify and improve the results of this study.

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CONFLICTS OF INTEREST

All the authors of this article declare that there is no personal interest conflict related to this study. The research process and results are not interfered by any commercial interests or other improper factors, aiming to provide an objective and scientific reference for the clinical treatment of thoracic fractures.

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