TiRobot-assisted channel screw fixation for elderly patients with fragility fractures of the pelvis: A retrospective study

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Abstract

Objective

The incidence of fragility fracture of the pelvis (FFP) in the elderly population is increasing, and FFP that require fixation are a challenge for orthopedic surgeons. The aim of the study was to investigate the clinical efficacy of TiRobot-assisted channel screws fixation in the treatment of elderly FFP patients.

Method

Between May 2020 and September 2022, 46 elderly FFP patients were separately treated using channel screws fixation assisted by the TiRobot (TiRobot-assisted group) and conventional freehand surgery (freehand group). Postoperative outcomes between groups, including excellent and good fracture reduction based on Matta criteria and screw implantation accuracy based on Gras criteria, were compared. Changes in the Visual Analog Scale (VAS) pain score and the Majeed score (reflecting functional recovery) were recorded and compared between groups before and after surgery and during the 24-week of follow-up.

Results

A total of 90 screws were placed in all patients. Fifty-one screws were implanted in the TiRobot-assisted group (24 patients) and 39 screws (22 patients) in the freehand group. There were no screw-related complications or revision surgery in any group. The Matta value of TiRobot-assisted group was 5.13 ± 3.52, which was significantly lower than that of freehand group (9.00 ± 3.68); the excellent and good rate of the former (91.67%) was significantly higher than that of the latter (72.73%), and the differences were statistically significant (p = 0.0007; p < 0.001). In terms of screw placement, the accuracy rate was 100% in the TiRobot-assisted group, better than that in the freehand group where it was only 85.7% (p < 0.001). At each time point in the early postoperative period, the VAS score of the TiRobot-assisted group was significantly lower than that of the freehand group (all p < 0.05), and was close to consistent by the last follow-up. While the Majeed score of the former was significantly higher than that of the latter at each time point of follow-up; the difference between the two groups was statistically significant (all p < 0.0001).

Conclusion

TiRobot-assisted channel screw fixation of elderly FFP patients is advantageous over conventional freehand surgery, with less invasion, more precise positioning, more accurate screw placement, better fracture reduction, early pain relief and rapid recovery, suggesting that it is a better method to stabilize FFP in the elderly population.
Introduction

Fragility fracture of the pelvis (FFP), also known as osteoporotic pelvic fracture, has become one of the common entity affecting the health of the older population worldwide\(^1,2\). Due to the changes in the microstructure of bone tissue, the decrease in bone quality and density in patients with osteoporosis, bone fragility and fracture susceptibility will be increased\(^1,3\). Coinciding with the aging of the population, the incidence of osteoporosis in the elderly has increased, and the incidence of FFP has increased year by year. It is reported that 1.5 million osteoporotic fractures occur annually in the United States, with a 24% increase between 1993 and 2010\(^4\). The authors further discussed the possible high economic burden of this disease from 2005 to 2025\(^5\). In the UK, osteoporotic fractures occur in 20% of men and 50% of women over the age of 50\(^3\). An analysis of European national hospital registration systems for low-energy pelvic fractures between 1970 and 2013 found that the incidence of FFP in the elderly has increased significantly, with an average annual increase of 9% and a total increase of 399% during the period. According to this trend, the number of cases will increase 2.4 times by 2030\(^6\). Unlike traumatic pelvic fractures in general, patients with FFP present with intense pain, loss of mobility, and diminution of independency. Treatment options include surgical treatment and conservative treatment. The aim is to relieve pain as soon as possible, restore the ability to move as soon as possible, and prevent and control the occurrence of complications. Due to the high incidence of complications of conservative treatment, there is also a high mortality within 1 year after injury. Therefore, most scholars believe that surgical treatment should be the first choice for this patient population.

Over the years, for the treatment of this disease, the surgical mode has changed from the traditional open surgery with high risk and many complications to minimally invasive surgery, and manual screw implantation and internal fixation has been widely used in clinical practice. In recent years, robot-assisted surgery has been applied to a variety of orthopedic procedures, including joint replacement, spine surgery, bone tumor surgery, arthroscopic surgery, and fracture fixation\(^7\text{"}^{10}\), and has achieved accelerated postoperative recovery. Wu et al.\(^11\) took the lead in using Tianji Orthopedic robot system to carry out robot-assisted percutaneous minimally invasive pelvic fixation. Compared with the traditional manual operation, it can make the screw implantation more accurate, and can greatly reduce the intraoperative X-ray radiation exposure, and shorten the operation time and reduce the amount of blood loss. Liu et al.\(^12\) applied Tianji Orthopedic robot in the minimally invasive treatment of pelvic posterior ring and anterior ring fractures, indicating that robot-assisted patients could significantly reduce intraoperative bleeding and move early after surgery, and most patients achieved good healing after 3–6 months of postoperative follow-up. Long et al.\(^8\) performed sacroiliac joint screw fixation with the assistance of Tianji robot. They conducted a comparative study with the traditional freehand operation, showing that the robot group was superior to the traditional operation group in terms of intraoperative fluoroscopy times and total duration, operation time, incision size and anesthesia time. To date, however, there is no standard surgical procedure for FFP, and appropriate studies are few or pending.
The current situation is that most hospitals still use freehand empirical screw placement under fluoroscopy for osteoporotic pelvic internal fixation. Following the introduction of the TiRobot system in our hospital, we performed robot-assisted channel screw fixation of FFP and obtained some preliminary clinical results. The purpose of this investigation is as follows: (i) to investigate the clinical efficacy of TiRobot-assisted surgical procedure; (ii) to discuss the superiority in application of this surgical procedure and (iii) to summarize the surgical precautions and limitations of robot-assisted FFP surgery.

**Methods**

**Inclusion and exclusion criteria**

The inclusion criteria included: 1) patients who were at least 65 years old with osteoporotic pelvic fractures; 2) patients who had the bone mineral density test T value ≤-2.5SD, and fresh fracture of FFP classification I-IV; 3) patients who had undergone TiRobot-assisted channel screw fixation or conservative treatment; 4) follow-up time ≥ 6 months; 5) complete clinical data. Exclusion criteria were patients who: 1) were open or obsolete fracture; 2) were pathological fracture (such as bone metastasis of cancer, primary bone tumor, and metabolic bone disease); 3) could not tolerate the operation because of comorbidities, such as serious heart, lung, liver, kidney and other internal diseases; 4) could not cooperate with treatment (including rehabilitation) due to mental illness; and 5) could not undergo closed reduction because of multiple injuries or severe osteoporotic pelvic fractures.

**General information of patients**

This retrospective study reviewed a case series from May 2020 to September 2022. The study protocol was approved by our Institutional Review Board (CZX2022-KY-107). Informed consent was obtained from all participants included in the study. A total of 46 patients were admitted in this study and underwent cannulated screw fixation of osteoporotic pelvic fractures at the authors’ institution. Preoperative X-rays and computer tomography (CT) scans of all patients were used to evaluate the management protocol of pelvic fracture.

A total of 24 patients ranging in age from 65 to 87 years (8:16 of male-to-female ratio and 73.21 years of mean age) were treated with TiRobot-assisted cannulated screw fixation (TiRobot-assisted group, RA). According to FFP classification: FFP Type I Anterior injury only. Type la: isolated unilateral anterior disruption. Type Ib: isolated bilateral anterior disruption. FFP Type II non-displaced posterior injury. Type IIa: isolated, non-displaced sacral fracture without involvement of the anterior pelvic ring. Type IIb: non-displaced sacral crush with anterior disruption. Type IIc: non-displaced sacral, iliosacral or ilium fracture with anterior disruption. FFP Type III displaced unilateral posterior injury. Type IIIa: displaced unilateral iliac fracture. Type IIIb: displaced unilateral iliosacral disruption. Type IIIc: displaced unilateral displaced sacral fracture. FFP Type IV displaced bilateral posterior injury. Type IVa: bilateral iliac fracture or bilateral iliosacral disruption. Type IVb: bilateral sacral fracture, spinopelvic dissociation. Type IVc: combination of different dorsal instabilities. The patients were classified accordingly: 4 cases of type I, 12 cases of type
II, 3 cases of type III, and 5 cases of type IV. Twenty-two patients who had undergone conventional surgery with manual positioning during the same time period were selected as the control group (Freehand group, FH). They were 7 men and 15 women ranging in age from 66 to 88 years (mean age of 74.14 years). The patients were classified according to FFP: 5 cases of type I, 10 cases of type II, 4 cases of type III, and 3 cases of type IV.

Patient characteristics are presented in Table 1. There was no statistically significant difference in general characteristics between the two groups (all p > .05).

### Table 1
Baseline demographic and clinical characteristics of the included participants

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>TiRobot-assisted group (n = 24)</th>
<th>Freehand group (n = 22)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, mean (SD), y</td>
<td>73.21(6.29)</td>
<td>74.14(7.32)</td>
<td>0.646</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>16</td>
<td>15</td>
<td>0.913</td>
</tr>
<tr>
<td>Male</td>
<td>8</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>BMD-T value (SD)</td>
<td>-3.12(0.27)</td>
<td>-3.09(0.26)</td>
<td>0.706</td>
</tr>
<tr>
<td>FFP classification</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>4</td>
<td>5</td>
<td>0.837</td>
</tr>
<tr>
<td>II</td>
<td>12</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>5</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>VAS score (SD)</td>
<td>5.46(1.20)</td>
<td>5.27(1.35)</td>
<td>0.615</td>
</tr>
<tr>
<td>Majeed score (SD)</td>
<td>37.21(3.73)</td>
<td>36.05(2.87)</td>
<td>0.240</td>
</tr>
</tbody>
</table>

Abbreviations: SD, Standard deviation; BMD-T, Bone mineral density test value; FFP, Fragility fracture of the pelvis; VAS score, Visual analogue scale score; Majeed score, Majeed pelvic outcome score (a functional scoring system specifically developed for pelvic injuries, with an overall value of 100 points).

### Surgical equipment and procedure (TiRobot-assisted)

Twenty-four patients in the TiRobot-assisted surgery group received cannulated screw fixation treatment. The operation was performed with the help of TiRobot, the second generation of the orthopaedic surgical robot of Beijing TiNAVI Medical Technology (TiRobot ForcePro Superior, China) (Fig. 1). Internally fixed implants used association for the study of osteosynthesis (AO) (6.5 mm) cannulated screw (GJYDV III) produced by Suzhou Youbet Medical Equipment Co., LTD, China. Check whether the robot is fully
equipped before operation. Conduct routine preoperative preparation for the workstation, the optical tracking system, the robotic arm, the C-arm X-ray machine, and other equipment. Turn on the power and connect the equipment. Check that the device is functioning properly. Log in to the system, record medical records, and select surgical tools.

Surgical procedure

After administering the general anesthesia, the patient was placed in a supine position with routine disinfection and covering. For type III and IV pelvic fractures with obvious displacement, bone traction reduction, indirect obstruction reduction with different diameters of guide needle channel and screw channel planned by Tianji Robot, and limited incision minimally invasive reduction of pelvis were used for closed reduction. (1) 3D image acquisition: the robot, C-arm machine and optical tracking camera are placed in a reasonable position. The "Human tracer (Track)" was placed in the iliac region without interfering with the operation, and anteroposterior (AP) and lateral C-arm X-rays were taken to confirm that the calibration point of the scale and the bone structure of the proposed nail were included in the collected images. The 3D image of the pelvic region is captured and transmitted to the main screen of the Tianji robot. (2) Path planning and cannulated screw placement: select the appropriate entry point and direction to complete the planning of the target screw. Select "Simulation" mode and run the robot arm to the target position. The surgical incision of 0.5-1cm was made on the skin of the body along the position shown by the robotic arm. The muscle tissue was bluntly separated until it reached the bone surface, and the guide needle sleeve was inserted until the tip of the sleeve touched the bone surface. The automatic execution mode of TiRobot 2.0 system was adopted. The software execution interface is available after the end function is enabled (enabled by default). After the foot pedal is connected, automatic simulation is performed based on the current position of the robot arm (Fig. 4). Guide needle and cannulated screws are placed in turn along the direction of the sleeve according to the pre-planned length and direction. A 3D image is then taken. The incision is closed and covered with sterile dressing. Figure 2 shows a patient with an osteoporotic pelvic fracture to illustrate the surgical procedure.

Surgical operation (Conventional)

The patient was placed in a supine position and lateral C-arm X-ray fluoroscopy of the pelvis was performed. Lateral images of the first sacral vertebra and ICD projection line were located on the affected side. A 1cm incision was made and the guide needle was implanted into sacral vertebra channel under fluoroscopy. Then, the C-arm X-ray fluoroscopy repeatedly viewed the entrance and exit positions of the first sacral vertebra of the pelvis; intermittent dynamic fluoroscopy was performed to monitor whether the guide needle was drilled into the sacroiliac joint and the sacral vertebral body to the midline. The position of the guide needle was satisfactory in the lateral, entrance and exit positions of the pelvis under fluoroscopy. After measuring the length, a cannulated screw is inserted and fixed. The incision was sutured after the fluoroscopy was correct again.

Outcome parameters
Matta value was used to evaluate the quality of fracture reduction based on radiographic measurements. The post-treatment radiograph was evaluated based on Matta criteria: A (excellent, less than or equal to 4mm fracture gap or step off deformity), B (good, 5-10mm gap or step off), C (fair, 11-20mm gap or step off) and D (poor, more than 20mm gap or step off).

Gras criteria was used to evaluate the accuracy of screw placement. The position of screw placement was assessed using three categories: Class I (excellent, secure placement, completely in the cancellous bone), Class II (fair, secure placement, but contacting the cortical bone) and Class III (poor, malplacement, penetrating the cortical bone).

Visual analogue scale (VAS) pain score was a common method to evaluate the intensity of subjective pain and the degree of psychological sensation. In clinical assessment, a score of 1–3 indicates mild pain; a score of 4–6 indicates moderate pain; and a score of 7–10 indicates severe pain. The lower the score, the milder the symptoms.

Majeed score was used to assess the postoperative recovery of pelvis function. The score system mainly includes seven aspects: pain, working, sitting, standing, walking distance, independent gait, and sexual function. The maximum score is 100 points (best possible outcome). Total scores of < 70, 70–80, 80–90, and 90–100 indicate poor, fair, good, and excellent outcomes, respectively.

**Postoperative treatment and follow-up**

The postoperative regimens were similar between groups. These patients were given analgesic treatment, anticoagulant drugs, lower extremity pressure pump, ankle pump training and other measures to prevent lower extremity deep vein thrombosis. Salmon calcitonin nasal spray can be used for postoperative anti-osteoporosis treatment. Prophylactic anti-infection treatment was used for 24 h after the surgery. Meanwhile, the postoperative pelvic radiographs and CT scans were performed for postoperative evaluation of the reduction and screw placement. At 24 h after the surgery, the patients were assisted with gentle passive hip flexion activities 2–3 times a day and were instructed to carry out lower-limb strength training. The patients were allowed to perform proactive bending of the hip and the knees in bed 2 weeks after the surgery. After 4 weeks, the patients could perform partial weight-bearing movements with the help of a walker. After 12 weeks the fracture line was obviously blurred, the patients were allowed to perform full weight-bearing movements. Matta value and Gras criteria were used to evaluate the quality of fracture reduction and the accuracy of screw placement. During the 24-week follow-up period, VAS score was used to continuously record and evaluate pain changes in patients, while Majeed score was used to evaluate the process and outcome of postoperative recovery of pelvis function. The fracture healing rate and adverse events were recorded, including wound infection, hypostatic pneumonia, lower extremity deep vein thrombosis, channel screw loosening, fracture redisplacement, malunion, and nonunion.

**Statistical Analysis**
Stata 17.0 version (Stata Corp LP) was used to analyze the study data. The measurement data were tested by Kolmogorov-Smirnov normal analysis. Normally distributed data was conveyed as mean (SD); the t test was applied for evaluation between the 2 cohorts. Non-parametric Mann-Whitney U test was applied for non-normally distributed data. The data among all groups were compared by chi-square test. If the theoretical frequency was too small, Fisher’s exact probability method was used. The changes from baseline in mean VAS score and Majeed score were analyzed using repeated-measures ANOVA. Effect sizes are described as Cohen d. All statistical analyses were two sided, and p values less than 0.05 were considered indicative of statistically significant difference.

Results

Between May 2020 and September 2022, a total of 46 patients were treated with screw implantation, of which 51 screws were used in RA group and 39 screws were used in FH group. All patients were followed up for 6 months and were re-examined every 4–6 weeks. In both groups, there were no consequences from vascular injury, wound infection, channel screw loosening, fracture redisplacement, malunion, or nonunion.

Fracture reduction

Using the Matta criteria evaluated the effectiveness of fracture reduction. The overall excellent and good pelvic fracture reduction rates were 91.67% in the RA group (18 excellent cases, four good cases, and two fair cases) and 72.73% in the FH group (2 excellent cases, fourteen good cases, and five fair cases). The difference between the two groups was statistically significant (p < .001), as shown in Table 2 and Fig. 3(A). Based on the Matta value, the effect of fracture reduction in the RA group was significantly better than that in the FH group (p = .0007), as seen in Table 3.

<table>
<thead>
<tr>
<th>Index</th>
<th>TiRobot-assisted group</th>
<th>Freehand group</th>
<th>$\chi^2$ value</th>
<th>$P$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matta criteria</td>
<td>18/4/2</td>
<td>2/14/5/1</td>
<td>20.59</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>(A/B/C/D)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gras criteria</td>
<td>16(41)/8(10)</td>
<td>6(14)/13(20)/3(5)</td>
<td>4.695</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>(I/II/III)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: Matta criteria (A/B/C/D), the postoperative radiograph (excellent/good/fair/poor); Gras criteria (I/II/III), CT scans of screw placement (excellent/good/poor); (screws) *, number of implanted screws.
Table 3
The treatment effects of TiRobot-assisted group and freehand group

<table>
<thead>
<tr>
<th>Outcome assessments</th>
<th>TiRobot-assisted group (n = 24)</th>
<th>Freehand group (n = 22)</th>
<th>Difference (95% CI)</th>
<th>P value</th>
<th>Effect sizea</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matta’s value (SD)</td>
<td>Posttreatment 5.13(3.52)</td>
<td>9.00(3.68)</td>
<td>3.88(1.73 to 6.02)</td>
<td>.0007</td>
<td>1.08</td>
</tr>
<tr>
<td>VAS score (SD)</td>
<td>1 week posttreatment 3.29(0.81)</td>
<td>3.86(0.94)</td>
<td>0.57(0.05 to 1.09)</td>
<td>.0331</td>
<td>0.66</td>
</tr>
<tr>
<td></td>
<td>4 week posttreatment 1.67(0.76)</td>
<td>2.73(1.03)</td>
<td>1.06(0.52 to 1.61)</td>
<td>.0003</td>
<td>1.18</td>
</tr>
<tr>
<td></td>
<td>12 week posttreatment 0.63(0.65)</td>
<td>1.00(0.76)</td>
<td>0.38(0.05 to 0.79)</td>
<td>.0791</td>
<td>0.53</td>
</tr>
<tr>
<td></td>
<td>24 week posttreatment 0.38(0.49)</td>
<td>0.36(0.49)</td>
<td>-0.01(-0.30 to 0.28)</td>
<td>.9382</td>
<td>-0.02</td>
</tr>
<tr>
<td></td>
<td>Majeed score (SD)</td>
<td>51.54(2.26)</td>
<td>39.32(1.87)</td>
<td>&lt;.0001</td>
<td>-5.87</td>
</tr>
<tr>
<td></td>
<td>1 week posttreatment 70.46(2.19)</td>
<td>61.73(3.06)</td>
<td>-12.22(-13.45 to -10.99)</td>
<td>&lt;.0001</td>
<td>-3.31</td>
</tr>
<tr>
<td></td>
<td>4 week posttreatment 80.75(2.71)</td>
<td>70.50(4.22)</td>
<td>-8.73(-10.33 to -7.13)</td>
<td>&lt;.0001</td>
<td>-2.92</td>
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<tr>
<td></td>
<td>12 week posttreatment 81.09(2.78)</td>
<td>71.27(4.44)</td>
<td>-10.25(-12.39 to -8.11)</td>
<td>&lt;.0001</td>
<td>-2.67</td>
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<tr>
<td></td>
<td>24 week posttreatment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: Matta’s criteria, Imaging evaluation of reduction quality after internal fixation of pelvic fractures (indicating the size of the fracture gap or step off); SD, Standard deviation; CI, confidence interval; VAS score, Visual analogue scale score; Majeed score, Majeed pelvic outcome score (a functional scoring system specifically developed for pelvic injuries, with an overall value of 100 points); a Effect sizes are listed as Cohen’s d.

Accuracy of Screw Placement

According to the Gras criteria of the affected pelvic fractures, the 51 screws implanted in the RA group were classified as follows: class I (41), class II (10), and class III (0); the accuracy rate of the implants was 100% (Accuracy of screw placement = [number of screws of class I + number of screws of class II]/total number of implanted screws × 100%). Thirty-nine screws implanted in the FH group, 22 screws were defined class I, class II (12), and class III (5). The accuracy rate of the implants was 87.18% (χ2 =
There was a statistically significant difference between the two groups, as seen in Table 2 and Fig. 3(A). This means that TiRobot-assisted screw implantation had more accuracy.

Visual analog Scale (VAS)

The VAS score at 1 week, 4 weeks, 3 months and 6 months after treatment were lower than the preoperative scores of the same group. At 1 week after treatment, the VAS of RA group was 3.29 ± 0.81 points, which was lower than that of RH group (3.86 ± 0.94 points) (p = .0331). VAS score at 4 weeks after treatment was 1.67 ± 0.76 points in RA group, which was lower than 2.73 ± 1.03 points in RH group (p = .0003). There was no significant difference in VAS scores between the two groups after 12 weeks of follow-up. Both group (p > .05), Table 3 for details. The changes of VAS scores between 2 groups was shown in Fig. 4(A).

Pelvic function recovery

There was no significant difference in Majeed scores between the two groups preoperation (Table 1). Majeed score at 1 week, 4 weeks, 12 weeks and 24 weeks after treatment were higher than those preoperation in the same group (all p < .05). Notably, the Majeed score of the RA group was higher than that of the FH group at all time points during the follow-up period. There was a statistically significant difference between the two groups (all p < .0001), as seen in Table 2. The changes of Majeed scores between 2 groups was shown in Fig. 4(B).

Discussion

Despite the increasing incidence of FFP in the elderly population, evidence on the most appropriate treatment for FFP remains limited. The frailty of these elderly patients, which suffer FFP, requires specific, less invasive treatment algorithms. Indeed, elderly FFP that require fixation are a challenge for orthopedic surgeons. Robot-assisted minimally invasive fixation of pelvic fractures is now well established and has been accepted by an increasing number of orthopaedic surgeons and promoted in clinical practice. Using TiRobot-assisted channel screw placement fixation for patients with FFP is undertaken in this study.

Efficacy and safety of TiRobot-assisted surgery

In this study, the TiRobot system successfully assisted channel screw fixation of FFP with intuitive surgical path planning. Indeed, according to the concept of minimally invasive stabilization, screw implantation fixation is a safe surgical procedure for stabilizing FFP. During the 24 weeks of follow-up, there were no complications such as wound infection, vascular or nerve injury, screw loosening, secondary screw displacement, malunion, or nonunion in our study. Similar to other studies\textsuperscript{18–23}, we found that compared with conventional freehand operation, TiRobot-assisted surgery has obvious advantages in fracture reduction, accuracy, stability, early pain relief and rapid recovery.

The Matta score of fracture reduction quality after treatment in the RA group was 91.67%, which was much higher than that in the FH group (72.73%). The high rate of good reduction was mainly due to the
fact that we used the TiRobot system to plan indirect barrier reduction of the broken end of the fracture with different diameters of the guide needle channel and the screw channel, achieving the integration of the minimally invasive concept and indirect reduction, which was the first attempt to treat pelvic fractures with channel screws. In fact, there is no consensus on whether robot-assisted surgery can effectively adjust fracture reduction in FFP treatment. Recently, a study by Han et al. came to a different conclusion, arguing that robot-assisted surgery does not affect reduction rates $^{24}$. Due to the relative lack of relevant research data, it can not provide reference for our results. Nevertheless, we believe that the use of TiRobot-assisted is beneficial for fracture reduction in FFP patients.

According to the Gras criteria of the affected pelvic fractures, the accuracy of channel screw placement in RA group was 100% (24/24), much higher than 87.18% in FH group. In the treatment of elderly FFP with the assistance of the second-generation TiRobot (Tianji 2.0 system automatic execution mode), we carried out the micro-adjustment of the whole process of intraoperative needle implantation, thus achieving accurate and reliable screw placement. In the actual operation process, the procedure reduced the risk of decreasing the holding force of the channel screw after repeated freehand adjustment, and also avoided the slight swing of the guide needle of the X-ray navigation sleeve of the O-arm with the fluctuation of breathing and pulse. Precise positioning, accurate placement and stable fixation are the main goals of internal fixation of pelvic fractures using the medical screws. Based on our results, compared with manual surgery, TiRobot-assisted surgery is more conducive to achieving this goal. Supporting this notion, is the fact that Gras classification measurements show a 100% screw implantation accuracy rate.

In this study, preoperative mean pain levels were similar between the two groups, with no significant difference. From the first week of postoperative follow-up, VAS scores showed statistical difference between the two groups, and the pain level in the RA group was significantly lower than that in the FH group. It was not until 24 weeks after surgery that the pain scores of the two groups were nearly consistent. The VAS score in the RA group decreased from 4.5 before surgery to 2.1, which goes in line with other studies, where the VAS score varies from 0.36 to 3.4$^{25-30}$. Follow-up VAS scores indicated that TiRobotic-assisted surgery was more effective in relieving early pain in FFP patients. It is true that TiRobotic-assisted surgery achieves the goal of early pain relief for FFP patients. On the other hand, it reduces the incidence of cardiovascular and cerebrovascular events caused by pain stimulation and promotes the functional recovery of lower limbs.

As an important parameter value for evaluating the recovery of pelvic function after surgery, we found that Majeed scores in the RA group were higher than those in the FH group at each follow-up time point (1 week, 1 month, 3 months, 6 months). At the last follow-up, the Majeed scores of the two groups were 81.09 (SD 2.78) vs. 71.27 (SD 4.44). The results of this study suggest that robotic surgery for the treatment of osteoporotic pelvic fractures in the elderly contributes to early recovery of pelvic function. In other words, it may provide a strong guarantee for the rapid and comprehensive recovery of FFP patients. A recent study from China has shown that Robot-assisted surgery has clear advantages in accuracy, stability, and reducing intraoperative radiation exposure, but there is no final conclusion about functional
recovery. We believe that our findings can be used as an update and supplement to the above conclusions.

**Advantages of TiRobot-assisted surgery for FFP**

Elderly FFP is an indication for TiRobot-assisted channel screw fixation. In fact, the final outcomes turned out that TiRobot-assisted surgery in the treatment of elderly FFP is superior to conventional manual surgery in fracture reduction, screw implantation fixation accuracy, early postoperative pain relief, pelvic function recovery and other aspects. Its main advantages can be summarized as follows. The first advantage is precise positioning and accurate placement of the screws. The robot provides precise spatial positioning and stable path navigation for screw placement. Through the movement of the robotic arm, the guide screw is accurately, safely and stably placed at the anatomical site. The second advantage is programmed surgery. The process only needs to capture 3D images, complete path planning and drilling positioning. By following the procedure, the guide needle can be inserted precisely in the planned position. The use of 3D intraoperative imaging had allowed us to assess complex anatomies, perform surgery on displaced fractures, and obtain real-time data during and after fracture reduction. That data, in turn, was used for robotic insertion of implants. Indeed, the use of intraoperative 3D imaging has been shown to improve channel screw placement. The third advantage is its correction function. Once the actual path of the guide pin is found to deviate from the planned path, the fine-tuning function of the software can be used to adjust the Angle of the robot arm, thus effectively ensuring the safety of the operation. The fourth advantage is the reduction of radiation damage. Compared with manual screw insertion, the robotic procedure significantly reduces the cumulative intraoperative radiation dosage.

**Precautions and improvements of TiRobot-assisted surgical procedure**

The second generation of Tianji orthopedic robot assisted treatment of elderly FFP patients has the advantages of precision, minimally invasive and intelligent, paving the way for the treatment of elderly FFP, but there will be some problems in the specific implementation process. We need to solve these problems in order to be able to give full play to the advantages of orthopedic robots, avoiding or reducing repeated fluoroscopy, poor reduction, screw implantation errors, etc. First, we used a C-arm to capture 3D images. Intraoperative images of the sacroiliac, anterior column, and bilateral pelvic structures may not be obtained at the same time, so the patient may not be located in the center of the carbon fiber fluoroscopy bed. Reasonable arrangements should be made according to the patient's injured site, screw placement planning, C-arm placement, etc., so as to obtain the bone structure of the effective surgical area, and to arrange screw planning and placement of the anterior and posterior pelvic rings. Of course, if the hospital has advanced equipment, the O-arm navigation system can present high-definition three-dimensional images for the surgeon, clearly showing the degree of fracture reduction, whether the articular surface is flat, and whether the screw position and length are accurate, so that the surgery is more minimally invasive, accurate and intelligent. It improves surgical safety and reduces doctor-patient radiation exposure, laying the foundation for obtaining satisfactory curative effect. Second, for Tianji
orthopedic robot, keeping the human tracer (Track) relatively stable with the target bone structure of the patient is the premise of the accuracy of the channel screw, and ensuring the correct real-time correlation of the human tracer, fracture target bone structure, optical tracking camera and robotic arm tracking during surgical operation is the key to the robot to complete the screw placement according to the plan. Finally, osteoporotic pelvic fractures are characterized by thinner than normal cortical bone and more irregular pelvic structure. Therefore, the risk of deviating from the set entry point, penetrating the contralateral cortex, and damaging blood vessels and nerves is higher than that of normal bone tissue. The intraoperative procedure requires blunt separation to the bone surface, not to the smooth bone cortex. The principle of “fast drilling and slow entry” should be observed to avoid excessive resistance into the needle; Follow the principle of "let nature take its course" through the cancellous bone screw channel. The length of the insertion guide needle: the distance between the tip of the handheld electric drill and the end of the guide sleeve is planned according to the image to limit the depth of the guide needle, so as to avoid the risk of penetrating the contralateral cortex of bone and damaging blood vessels, nerves and other organs.

**Study Limitation**

First, the retrospective nature of this study is a limitation. Second, only a small sample size was reported in this study. Third, the follow-up period in this study was relatively short. In addition, the study did not examine biomechanics. Future multicenter, large sample prospective studies are needed and guidelines for robot-assisted minimally invasive pelvic fracture treatment are developed.

**Conclusions**

Minimally invasive screw fixation is an acceptable treatment for FFP in the elderly patients. The TiRobot-assisted surgery provides precise spatial positioning and stable path navigation for screw placement of elderly patients with FFP, which overcomes the shortcomings of the conventional manual surgery methods, such as unstable manual operation and more radiation damage. It can achieve satisfactory clinical results with good fracture reduction, higher accuracy, less invasion, early pain relief and rapid recovery of patients after operation, suggesting it is a better method for minimally invasive treatment of elderly patients with FFP. Based on our findings, the TiRobot-assisted surgery has great clinical application value on the treatment of elderly FFP patients.

**Declarations**

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**Authors’ contributions**
BRX and XBQ designed this study, prepared the manuscript, tables and figures and have read and approved the final manuscript. XXH and YDZ collected and/or rated the data, read and approved the final manuscript.

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**Availability of data and materials**

The patients’ dataset are confidential and are privately held for patients confidentiality safeguard. As such, the datasets generated and/or analysed during the current study are not publicly available but are available from the corresponding author on reasonable request.

**Ethics approval and consent to participate**

This study was approved by the medical ethics review board of Cangzhou Hospital of integrated traditional Chinese medicine and Western medicine.

All methods in the study were carried out in accordance with the Helsinki guidelines and declaration.

All procedures were undertaken by the senior author after obtaining informed consent for all patients.

**Consent for publication**

Participate in our study involving human subjects,signed informed consent was obtained from all participants.

**Competing interests**

No competing interest to report.

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References


**Figures**
Figure 1

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Figure 2

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Figure 3

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Figure 4

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