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CASE REPORT

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TiRobot ForcePro Superior combined with suture-button plates for minimally invasive treatment of an acetabular both-column fracture - a case report

Dai Yonghong[1] and Zeng Yanhui[1,2*]

Abstract

Background The acetabulum exhibits an irregular anatomical structure with a dense concentration of critical blood vessels and nerves in its vicinity. Acetabular fractures accompanied by periarticular soft tissue injuries may lead to life-threatening complications. The Letournel-Judet classification system is currently the widely adopted standard for categorizing acetabular fractures, with the both-column fracture type recognized as the most complex pattern within this framework. Open reduction and internal fixation remains the gold standard for its management. The minimally invasive closed reduction of acetabular both-column fractures with significant displacement remains an unresolved global challenge in orthopedic surgery. Our surgical team has developed an innovative approach that provides a novel solution to this complex clinical problem. Therefore, this article was compiled to provide a comprehensive description of this surgical technique, thereby offering novel insights for the orthopedic surgeons.

Case presentation A 33-year-old male patient sustained a left-sided acetabular both-column fracture due to a high-altitude fall. Under the guidance of the TiRobot ForcePro Superior, we first established a bony channel, then passed a suture-button plate through the quadrilateral plate of the acetabulum. Subsequently, high-strength sutures were tightened using a suture tensioner to achieve compression reduction of the fracture fragments. Following reduction, screws were inserted with robotic assistance via the TiRobot ForcePro Superior to achieve rigid fixation of the fracture site. The patient underwent an 11-month follow-up. Radiographic evidence of bony consolidation was confirmed at the 4th postoperative month, with no traumatic arthritis observed throughout the follow-up period. Pelvic function demonstrated excellent recovery, achieving a Majeed Pelvic Function Score of 92 points. There was virtually no difference in the patient's function regarding sitting, walking, standing, and sexual activity compared to pre-injury, and no gait alteration was observed.

Conclusions With the assistance of robot-aided surgery combined with suture-button plates, our surgical team successfully achieved minimally invasive closed reduction and internal fixation for an acetabular both-column fracture. This innovative surgical approach provides a novel strategy for the minimally invasive management of acetabular both-column fractures.

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Keywords Acetabular both-column fracture, Navigation; innovation, Suture-button plate, TiRobot forcepro superior

Background

Acetabular fractures, accounting for approximately 3.73% of all skeletal fractures, are predominantly caused by high-energy trauma such as falls from heights or traffic accidents [1]. In elderly patients with osteoporosis, these fractures often result from low-energy injuries. As complex intra-articular fractures, anatomical reduction and stable fixation of acetabular fractures remain the primary goals for orthopedic surgeons while also posing significant challenges [2–7]. Among all acetabular fracture types, both-column fractures are both the most surgically demanding and the most prevalent, constituting approximately 21.2% of cases [6]. A both-column fracture is defined by the loss of continuity between fracture fragments and the axial skeleton (i.e., disconnection from the sacroiliac joint), resulting in separation of the anterior and posterior columns from the axial bone and creating a "floating acetabulum" [8, 9]. The displacement of the acetabular dome disrupts anatomical landmarks, making reduction and fixation exceptionally complex. Traditional surgical approaches—including the ilioinguinal, modified Stoppa, lateral rectus abdominis, Kocher-Langenbeck, and combined anterior-posterior approaches—rely on open reduction and internal fixation [2, 6, 10]. However, extensive open procedures are associated with significant surgical trauma and suboptimal outcomes.

The advent of navigational robotic systems, with their precise spatial positioning capabilities, has provided a powerful tool for minimally invasive acetabular fracture management [11–16]. In the treatment of acetabular fractures, the initial step is reduction. Without proper reduction of the fracture, there can be no screw trajectory, rendering the use of navigated robotic-assisted screw fixation impossible. The deep anatomical location of the acetabulum makes closed reduction exceptionally challenging. Current navigation robotic systems lack the capability for fracture reduction, significantly limiting their widespread application in the treatment of acetabular fractures. Our surgical team ingeniously combined the suture-button plates with the navigation robot, offering a novel approach for achieving minimally invasive closed reduction of acetabular fractures.

Case presentation

The robotic system utilized in our study was the TiRobot ForcePro Superior(Fig. 1), manufactured by Beijing TINAVI Medical Technologies Co., Ltd. (China). Subsequently, we provided a detailed description of this surgical approach through this case report.

A 33-year-old male patient (body mass index: 24.22 kg/m²) sustained left-sided comminuted fractures of the acetabulum, superior/inferior pubic rami, ischial ramus, and iliac wing, along with an avulsion fracture of the posteromedial border of the left ischial body, fractures of the 5th sacral and 1st coccygeal vertebrae, and a left femoral head fracture (Fig. 2A) following a high-energy fall. According to the Letournel-Judet classification, the fracture was categorized as a both-column fracture. When classified using the acetabular quadrilateral plate fracture APQ classification system, it was identified as an APQ type 2 fracture. The patient's Injury Severity Score (ISS) was 41, indicating a severe injury. Significant displacement of the acetabular articular surface was observed radiographically. The patient presented with multiple associated injuries, including rib fractures, L2 vertebral burst fracture, left L2 transverse process fracture, L1 spinous process fracture, bilateral pulmonary contusions, splenic contusion, bilateral pleural effusions, hypoalbuminemia, and moderate anemia. Notably, the patient had previously undergone left internal iliac artery embolization at an external institution to control active hemorrhage secondary to arterial injury, resulting in retained intravascular embolic material. The interval from injury to surgical intervention was 8 days. The operative protocol is systematically illustrated in Figs. 2B-D. The technical sequence proceeded as follows:

a. An image tracker was mounted onto the C-arm image intensifier, and a sterile working environment was established for both the robotic system and the C-arm. The C-arm console was interfaced with the robotic main unit to facilitate subsequent transmission of three-dimensional patient pelvic data.
b. Given the patient's presentation with the most severe acetabular fracture pattern and the potential risk of robotic surgical failure, sterile draping was performed in accordance with open reduction and internal fixation protocols.
c. The patient tracker was rigidly fixed to the osseous pelvic structure to prevent relative displacement between the two, as any movement would compromise the accuracy of robotic navigation.
d. Three-dimensional imaging data of the patient's pelvic acetabulum were acquired and uploaded to the robotic surgical planning platform.
e. A screw trajectory penetrating the quadrilateral plate was preoperatively planned on the platform to establish an osseous channel for suture-button plate placement.
f. After the robotic arm was positioned according to the preoperative plan, the orthopedic surgeon

Fig. 1 TiRobot ForcePro Superior (TFS)

inserted a sleeve into the robotic guide and advanced a 2.5-mm Kirschner wire through the sleeve.

g. A 5.5-mm cannulated drill was then used to ream the channel for plate insertion.
h. The plate (micro condylar compression locking plate, Shandong Weigao Orthopedic Materials Co., Ltd., China) was trimmed and polished to facilitate smooth passage through the prepared osseous channel.
i. High-strength sutures were threaded through the plate, and a thinner white suture was knotted to the plate as a safety measure to prevent accidental migration of the plate into the pelvic cavity during traction, though it did not directly participate in fracture reduction.
j. Using long, slender forceps, the plate was advanced through the osseous channel across the quadrilateral plate.
k. A Kirschner wire was inserted retrograde through the sleeve to stabilize one end of the plate while traction was applied to the contralateral suture, enabling plate rotation for optimal bone contact.
l. An additional lateral plate was positioned and secured with a sleeve.
m. The high-strength sutures were connected to a line tensioner, and incremental traction was applied to achieve fracture reduction.
n. Three-dimensional imaging confirmed satisfactory reduction.
o. Two additional quadrilateral plate-penetrating screw trajectories were planned, and two supplementary plates were inserted using the aforementioned technique to augment reduction stability.
p. Following fracture reduction, an anterograde superior pubic ramus screw, an acetabular dome screw, an LC-2 screw, and an iliosciatic screw were planned and inserted for definitive fracture fixation. The acetabular dome screw (6.5-mm diameter) was manufactured by Synthes GmbH (Switzerland), while the remaining three screws (6.5-mm diameter) were

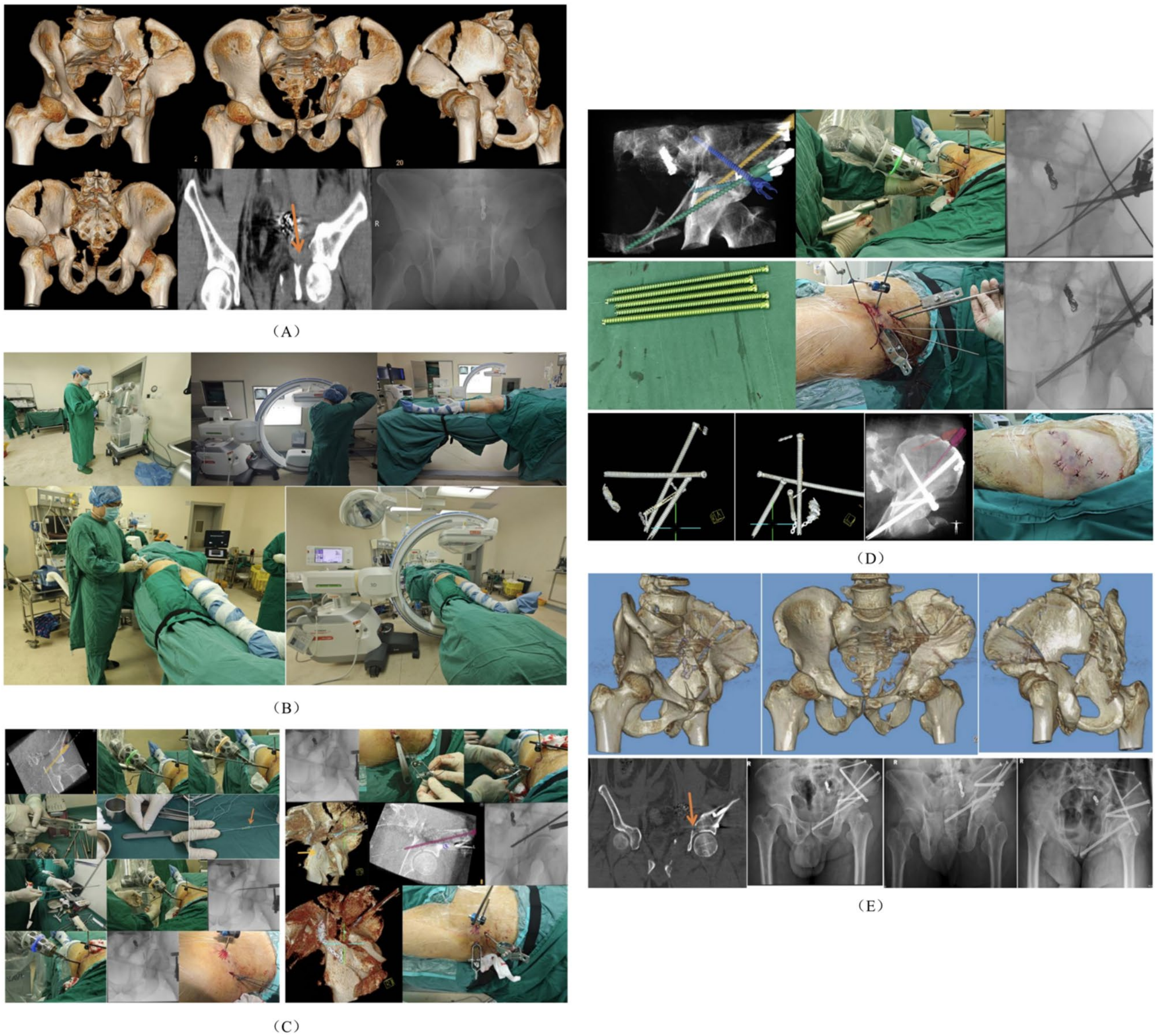


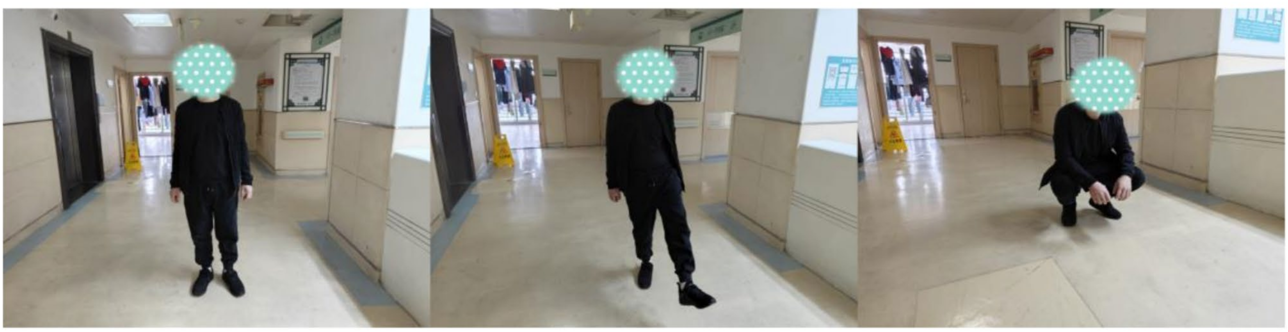
Fig. 2 Comprehensive surgical workflow illustration (**A**) Preoperative pelvic CT and X-ray; (**B**) Preoperative preparation; (**C**) Intraoperative reduction; (**D**) Intraoperative minimally invasive screw fixation; (**E**) Postoperative pelvic CT and X-ray

produced by Tianjin Zhengtian Medical Devices Co., Ltd. (China).

q. After robotic arm repositioning, guidewires were advanced through the sleeves.
r. The position of the guide pin was verified, and once its position was satisfactory, a cannulated screw was inserted, followed by verification of the screw position.
s. Spatial relationships between screws and plates are illustrated in Fig. 2D.
t. Two additional 4.5-mm iliac wing screws (Tianjin Zhengtian Medical Devices Co., Ltd., China) were inserted to stabilize the iliac wing.
u. Following implant placement, surgical incisions were closed, with the largest incision measuring 2.5 cm in length. Total intraoperative blood loss was 100 mL, and operative duration was 293 min.
v. The three-dimensional reconstructed CT and X-rays on the second postoperative day showed that the fracture displacement had been significantly reduced, the position of the internal fixation was satisfactory, and the integrity and smoothness of the acetabular joint surface had been restored, achieving an ideal clinical outcome (Fig. 2E).

We conducted a follow-up of 11 months for this patient. The fracture healed at 4 months postoperatively, and no traumatic arthritis occurred (Fig. 3A). The patient's pelvic function recovered well, with a Majeed pelvic function score of 92 (Fig. 3B). There was virtually no difference in

(A)



(B)

Fig. 3 The postoperative recovery status of the patient was demonstrated. (**A**) The pelvic X-ray taken at the fourth postoperative month indicated that the fracture had healed; (**B**) At the 11th postoperative month, the patient exhibited favorable recovery of pelvic function

the patient's function regarding sitting, walking, standing, and sexual activity compared to pre-injury, and no gait alteration was observed.

Discussion and conclusions

For significantly displaced acetabular both-column fractures, conservative treatment is highly prone to complications such as post-traumatic arthritis, femoral head necrosis, and joint stiffness [3]. The quality of fracture reduction is a critical factor in determining the surgical treatment outcomes for acetabular both-column fractures [17, 18]. The treatment objectives for both-column fractures are to restore the integrity and congruity of the acetabular joint surface and to achieve stable fixation of the fracture to reestablish the biomechanical stability of the acetabulum [19]. For acetabular both-column fractures involving pelvic ring disruption, greater emphasis is placed on pelvic ring stability rather than anatomical reduction. In this particular case, the primary focus involves achieving anatomical reduction of the acetabular quadrilateral plate to restore articular surface integrity and congruity. The well-established surgical protocol employs approaches including pararectus/lateral, high ilioinguinal, modified Stoppa, or extended two-window ilioinguinal exposures [20–25]. Fracture fixation combines frame stabilization (partial/complete containment) with quadrilateral plate-specific techniques: cannulated screws, dynamic anterior plate-screw constructs (staple fixation), wire cerclage, containment plates (puboischial/ilioischial plates), patient-specific 3D-printed plates, or dedicated quadrilateral plate anatomical fixation systems [26–36]. However, this approach entails extensive soft tissue compromise, significant intraoperative blood loss, and elevated risk of surgical site infections. Our surgical team performed robot-assisted minimally invasive closed reduction utilizing suture-button plates, which significantly reduced operative trauma and provided a novel approach for the minimally invasive treatment of acetabular both-column fractures.

However, this surgical approach is not without its limitations. As it involves closed reduction, the continued rotation of the spool after achieving complete fracture apposition without immediate fluoroscopic verification of the reduction status may result in the rupture of the high-strength suture. To address this, our reduction strategy involves rotating the spool incrementally and performing fluoroscopic verification after each rotation. Although this approach increases radiation exposure, it offers greater benefits to the patient compared to the substantial trauma caused by open surgery. To mitigate the risk of accidental migration of a ruptured high-strength suture into the pelvic cavity, we introduced an additional high-strength suture that passes through the plate and is secured with a knot. This supplementary suture does not participate in the traction reduction process, thereby eliminating the possibility of rupture and effectively preventing the unintended migration of the plate into the pelvic cavity.

In the future, we plan to further refine the surgical instruments and develop standardized procedures to enhance the operability and reproducibility of this type of surgery, thereby benefiting more patients.

Abbreviations

TFS TiRobot ForcePro Superior

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Not applicable.

Author contributions

Dai Yonghong and Zeng Yanhui contributed to research implementation and article writing.

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Data availability

All data generated or analysed during this study are included in this published article.

Declarations

Ethics approval and consent to participate

This study was conducted in full compliance with the Declaration of Helsinki. Informed consent was obtained from all individual participants included in the study. This research protocol received official approval from the Medical Ethics Committee of Foshan Hospital of Traditional Chinese Medicine (No: QX[2022]001).

Consent for publication

Written informed consent was obtained from the patient for publication of this case report.

Competing interests

The authors declare no competing interests.

Clinical trial number

Not applicable.

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