

Minimally Invasive Treatment of Pelvic Fractures With Titanium Elastic Nailing: an Innovative Technology

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Research article

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Abstract

Background: Minimally invasive treatment has become the most popular and effective method for the treatment of pelvic fractures. The aim of this study was to evaluate the safety and efficacy of a new technique, titanium elastic nailing (TEN), for the minimally invasive treatment of pelvic fractures.

Methods: 18 patients with pelvic fractures were referred to us between March 2020 to November 2020, including 13 males and 5 females. The pelvic fractures were temporarily fixed by pelvic fixation belt accompanied with the traction from lower limb bone. The anterior pelvic ring injury (superior ramus of pubis) and ilium fracture were all treated with closed reduction and intramedullary fixation with minimally invasive TEN. Intraoperative C-arm, including pelvic anteroposterior, pelvic outlet, inlet and ilium oblique view) and O-arm fluoroscopy (intraoperative CT) were employed to determine the reduction of fractures and the location of elastic titanium nails in the bone channel.

Results: By adopting closed reduction and minimally invasive incision, the pelvic fractures could be safely fixed by placing the elastic titanium nail in the osseous medullary cavity channels of the pelvis. Postoperative investigation indicated that the wounds of all the patients were healed in the first stage, without any occurrence of complications such as nerve, blood vessel and important tissue structure injuries. The patients recovered quickly after the operation and could perform functional exercise in the early stage.

Conclusion: TEN can be used for the minimally invasive treatment of pelvic fractures. This novel technique has no obvious complications and worthwhile to use in clinic practice.

Introduction

Pelvic fractures are generally caused by high-energy injuries, accounting for 3% – 8% of the total body fractures. Among them, the unstable pelvic fractures that damage the anterior or posterior rings, should be reduced and fixed as soon as possible to restore the stability of the pelvis [1–2]. The traditional open reduction and internal fixation is the most classic operation method for these pelvic fractures requiring surgical treatments [3]. However, it has several disadvantages, as it needs long operation time and often leads to large amount of bleeding and trauma. Recently, with the progress of minimally invasive technology and the popularization of Biological Osteosynthesis (BO) concept, minimally invasive pelvic surgery is increasingly employed in clinic practice [5, 6].

At present, closed reduction and cannulated screw internal fixation has gradually become the main surgical fixation method for pelvic anterior ring injury, iliac bone fracture and sacral fracture, but it has some limitations and contraindications. For example, the screws easily cut out because of the large physiological radian of ilium and superior pubis and the narrow medullary cavity, which damages the surrounding tissue and eventually leads to the failure of fixation. For patients with severe osteoporosis, the screw easily loses the holding force, which leads to the failure of fixation [7–9].

In recent years, with the popularization of elastic titanium nail, patients with pelvic fractures have new choices. Elastic titanium nail has good biomechanical properties such as elastic fixation, axial stability, transverse stability, bending stability, and anti-rotation stability [11]. Thus, we carried out elastic titanium nail through intramedullary fixation for the treatment of pelvic fractures in our study. We found that this method was particularly suitable for patients with critical weakness and multiple organ injury. It is a novel technique for the treatment of pelvic fracture, which is safe, could avoid injuries and second open surgery, and promotes the early recovery of the patients.

Materials And Methods

Ethics statement

This retrospective study was approved by the Ethics Committee of Shenzhen People's Hospital at Jinan University. All volunteers gave informed consent prior to participating in the study.

Case inclusion criteria and exclusion criteria

Case inclusion criteria: Patients had age range from 18 to 70 years, had no serious underlying diseases or complications except those who had complications but were relieved after treatment, and were able to tolerate anesthesia and surgery; The fractures of these should be fresh, closed ilium fractures, and Type B1-3 or C1-3 pelvic fractures based on AO (Arbeitsgemeinschaft für Osteosynthesefragen) classification; The degree of fracture displacement should mild, or the displacement should be almost reduced after lower extremity traction and closed reduction.

Case exclusion criteria: Patients were younger than 18 years or older than 70 years, or with serious underlying diseases or complications, or unable to tolerate anesthesia and surgery; Patients had late sequelae of pelvic fractures or open pelvic fractures; Patients had severe fracture displacement, or had displacement that were unable to be reduced after lower limb traction and closed reduction.

General information

A total of 18 patients with pelvic fractures were included in this study, including 13 males and 5 females; the age ranged from 18 to 70 years, with an average of 38.4 years; The group included 7 cases of Type A2, 3 cases of Type B1, 5 cases of Type B2, 2 cases of Type C1, and 1 case of type C2 patients based on the AO classification of pelvic fractures (Fig. 1, Table 1). The causes of injury were as following: 11 cases were injured by traffic accidents, 5 cases by falling from high place and 2 cases by crushing with heavy objects (Table 2). After admission, patients received complete preoperative examination and lower limb traction for reduction fracture if necessary. The anterior pelvic ring (superior pubic branch) and iliac fractures were treated with minimally invasive closed reduction and titanium elastic nail fixation. During the operation, the status of fracture reduction and the position of the elastic titanium nail in the bone channel were determined by C-arm and O-arm fluoroscopy. The elastic titanium nail was purchased from Smith & nephew company (USA), with size of 3.0-3.5 mm.

Table 1. Fracture classification of the patients in our study based on the AO classification ^[12]

AO classification	Number of patients
A2.2	3
A2.3	4
B1.1	3
B2.1	5
C 1.1	1
C1.3	1
C 2	1

Surgical methods

All patients were given general anesthesia with tracheal intubation, and the patients were placed on the supine position. The surgeon stood on the opposite side of the patient's operation side, and the C-arm X-ray machine ball tube was placed on the surgical side of the patient. According to the preoperative X-ray films and CT images of the patient, closed manual reduction was performed on the pubic branch for the anterior pelvic ring and iliac bone fractures. Firstly, the affected hip joint was abducted and circumflexed under slight traction. Then the affected hip joint was rotated inward, and the iliac wing was pressed manually to reduce the bone fracture end. The fracture reduction was confirmed by C-arm fluoroscopy. Disinfection and sterile towel were applied after satisfactory reduction.

Fracture of anterior pelvic ring

First, a longitudinal incision of 1–2 cm was made from the upper edge of the pubic symphysis. The skin and subcutaneous tissue was cut open, and the soft tissue was gently and bluntly separated until about 1 cm below the pubic symphysis. The entry point and direction was determined by opening the road, which was realized by fixing a fixed point and entering the open cone slightly lower from the ipsilateral angle of the pubic symphysis and at an angle of 30–45 degrees. Then, after confirming the satisfactory opening and direction by C-arm fluoroscopy, the 3.0 mm elastic titanium nail was prebent according to the radian of the superior pubic ramus based on the CT reconstruction preoperatively. The direction of the elastic titanium nail tip was kept consistent with the longitudinal axis of the pelvic ring. After the tip reached the fracture end, an assistant held the patient's pelvic region from the surgical side and kept a good reduction of the fracture end. Under the view of fluoroscopy, the operator adjusted the moving direction of the titanium nail continuously by rotating the handle, making the elastic nail reaching above the anterior inferior iliac spine through the fracture end, which was the best position for the nail tip. Figure 2 showed that a 3.0 mm elastic nail was placed in the left superior pubic branch of the patient, and

another 3.0 mm elastic nail was placed on the right side in a same way (Fig. 2A-E). CT images confirmed that the elastic titanium nails were located in the pelvic bone marrow cavity in a good position (Fig. 2F-I).

Iliac fracture

First of all, a small incision of 1–2 cm was made longitudinally from the lower edge of the anterior inferior iliac spine, and soft tissue was bluntly separated. The road was opened to determine the entry point and direction as the screw was inserted under the iliac bone and placed in the direction of the iliac bone fracture. After confirming that the fracture reduction position was satisfactory by C-arm fluoroscopy observation, a 3.0 mm elastic intramedullary nail was pre-bent according to the physiological shape of the right iliac bone based on preoperative CT reconstruction. Then the nail was inserted along the internal plate of the iliac bone. The direction of nail tip was kept the same as the vertical axis of the right ilium. An assistant held the good reduction of the ilium fracture from the operation side after the tip reached the ilium fracture end. The surgeon adjusted the moving direction of the nail continuously by rotating the handle, making the elastic nail reaching the upper end of the ilium through the fracture end, which was the best position for the nail tip. Figure 2B showed that a 3.0 mm elastic nail was inserted into the right iliac bone of the patient (Fig. 2).

Evaluation criteria of curative effect

The criteria for evaluating the efficacy of the surgery included following parameters. First, we measured the length of both lower limbs. Second, we evaluated the pain grade according to the visual analogue scale (VAS). Third, we evaluated the quality of pelvic fracture reduction according to the Matta standard [12]. Forth, the function of the lower limb was evaluated according to the Majeed pelvic fracture quantitative score system during follow-up [13]. Also, at the last follow-up, the patients were evaluated according to the Poste and modified Merle D'Aubigne score standards [14]. Besides, the incidence of complications was recorded.

Results

By using closed reduction and minimally invasive incision, elastic titanium nail can be safely placed in the pelvic bone marrow cavity channel and fix the pelvic fracture. The insertion time of each elastic intramedullary nail was 15–45 min, with an average of 18.5 min. The average length of each operation was 112.5 (62–135) min. The times fluoroscopy imaging for each nail were 4–11 times, with an average of 6 times. The intraoperative blood loss was 25–200 ml, with an average of 70 ml. No blood transfusion was given for any patients. The mean follow-up period was 6.6 (1–8) months (Table 2).

Table 2. Demographics and clinical characteristics of the patients

Number of patients	18
Sex (male/female)	13/5
Age (average, range)	38.4 years (18–70 years)
Interval between injury and surgery (average, range)	5.6 days (1-16 days)
Fracture mechanism (traffic accident: accidental fall: injury caused by heavy object)	11(61.1%): 5(27.8%): 2(11.1%)
Duration of operation(average, range)	112.5 min (62~135min)
Mean bleeding volume	70 ml (25~200ml)
Duration of follow-up (average, range)	6.6 months (1–8 months)

The average VAS score of 18 patients in this study was 7.0 before operation and down to 2.0 after operation. The postoperative pain was significantly reduced. No complications occurred, such as injuries of nerve, blood vessel and important tissue structure, infection, broken nail, fracture nonunion and other complications.

The X-ray film and CT of the typical patient showed that the elastic titanium nail was in good position on the second day after operation, and all nails were located in the bone marrow cavity of acetabulum. Besides, the images indicated that the internal fixation was stable, and the fracture end had no obvious displacement (Fig. 3).

All patients were followed up for 3 months after the operation. After three months, the X-ray film of typical patient 1 showed that the elastic intramedullary nail was in good position, the internal fixation was stable, the fracture end was in a good position, and the fracture end had callus growth (Fig. 4A-B, D-E). Besides, the hip joint function was good, and they could squat down and do some weight-bearing exercises (Fig. 4C, F).

Discussion

Pelvic fracture has been a challenge for orthopaedic surgeons due to the complex anatomical structure. Traditional open reduction and internal fixation with bone plate can usually obtain good reduction and strong internal fixation, but it has many disadvantages, such as huge trauma, large amount of bleeding, damages on the surrounding important blood vessels, nerves and organs structure, and relatively high

risk of operation. Due to high-energy injury, most patients often have severe multiple injuries. So if selecting open reduction, the trauma will be further aggravated [15, 16]. In recent years, with the development of navigation technology and various reduction tools, minimally invasive percutaneous screw fixation has gradually become a more meaningful treatment method and popular for pelvic fractures. This technique has several advantages over the traditional open reduction and internal fixation, as it causes small trauma and minimal bleeding, needs short operation time, results in stable and reliable internal fixation, and has achieved good clinical effect [17–19].

However, there are still several challenges for the treatment of pelvic fractures with percutaneous screw fixation. First, the physiological radius of pubic branch is large while the medullary cavity is narrow. Second, the cannulated screw cannot perfectly conform to the physiological structure and mechanical characteristics of the superior pubic branch due to curved structure of the anterior pelvic ring. Third, comminuted fractures of the superior ramus of the pubis and proximal iliopubic tuberosity are difficult to be fixed with hollow screws [20].

Therefore, in order to solve the above mentioned problems, a better fixation method or a new type of implant is needed. In recent years, the wide application of elastic titanium nail in limb fracture provides us a new idea for the treatment of pelvic fracture. Elastic titanium nail has several excellent biomechanical characteristics as it can provide elastic fixation, has axial, transverse, bending and anti-rotation stability, and meets with BO theory particularly, which makes it suitable for the treatment of pelvic fractures [11]. Based on the large number of applications of elastic titanium nail in our study group, we concluded that this method had several advantages as following. First, the elastic titanium nail has good biocompatibility, strong fatigue and corrosion resistance, and interferes little to the bone tissue. Second, the elastic titanium nail has small diameter, which allows it freely passing through the long and thin superior pubic branch and the bony medullary cavity of the flat ilium, damaging little to the intramedullary bone and protecting the blood supply of the fracture end to maximum extent. Third, the elastic titanium nail has excellent plasticity, which makes it perfectly fitting the physiological and anatomical structure of pelvic ring, and easily crossing through the bone marrow cavity. Besides, the hook on the elastic nail head can well anchor the bone, which can effectively resist the rotation and displacement of the fracture end. Fourth, this surgery is easy to operate, needs no repeated procedures, requires no specific angle for the inserting needle, and is suitable for most of the fractures on the anterior pelvic ring and iliac bone. Fifth, the elastic titanium nail is bended in the medullary cavity and can form an elastic moment in the long bone [21]. Sixth, the micro motion of fracture end resulting from the elastic fixation could benefit the fracture healing [22].

Our group has conducted a relatively large-scale clinical study of the minimally invasive elastic titanium nail intramedullary fixation for the first time. The following skills could be helpful to increase the success rate of the operation. First, the operation plan should be individualized by carefully analyzing the imaging data of patients before operation. Based on the data, surgeons could observe the status of the fracture displacement, make the order of conservative reduction, investigate the bone channel of pelvic anterior and posterior column, and determine the direction of elastic titanium nail insertion. Second, surgeons

should have good knowledge of placing and steering skills with the elastic titanium nail. Third, clear fluoroscopic image is needed during the operation to accurately investigate the fracture reduction and observe the position of the inserted elastic titanium nail. Forth, the tail of the elastic titanium nail should be placed above the level of the anterior inferior iliac spine on the same side, so that the head end, tail end and acetabular wall of the elastic titanium nail form a "three-point support" structure. The tail cap is routinely placed and screwed into the bone canal for internal fixation. It can provide additional axial stability, avoid shortening and soft tissue irritation, and benefit the removal of the implant. Fifth, the tip of the elastic titanium nail should hook the bone cortex of the medial iliac bone above the level of anterior inferior iliac spine, which could increase the anchoring force of the elastic titanium nail. Sixth, elastic titanium nails with size 3.0 mm or 3.5 mm are suggested for this operation. As large nails are difficult to be shaped and inserted into the medullary cavity, or it will damage the medullary cavity. Meanwhile, small nails are easily bended and deformed, which couldn't maintain the stability of fixation at the fracture end, finally increasing the risk of screw withdrawal and breakage.

Our study has several limitations. First, the elastic titanium nail has no compression effect as the lag screw, which limits its application on the treatment of pelvic posterior column fracture. Second, the technical request is relatively high, and the learning curve is long. Third, the request for intraoperative fluoroscopy imaging is high. Forth, we didn't perform the biomechanical study at present, and we will start relevant research in the future. Fifth, the number of cases included is small, so statistical analysis couldn't be proceeded. We are collecting more cases and hope to have enough clinical data for statistical analysis in the near future. Sixth, longer follow-up is needed for more comprehensive study.

Conclusion

After our preliminary clinical study, closed reduction and minimally invasive elastic titanium nail intramedullary fixation has a good therapeutic effect on the treatment of pelvic fractures, which should be widely applied under the permission of indications. However, further research and exploration are still needed.

Abbreviations

TEN: Titanium Elastic Nailing; AO: Arbeitsgemeinschaft für Osteosynthesefragen; BO: Biological Osteosynthesis; VAS: Visual Analogue Scale;

Declarations

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Authors' contributions

ZFJ did the surgery, collected the data, analyzed the data, drafted the manuscript, and carried out the follow-ups. WXL, JDL and JYD conceived of the study, participated in its design and coordination, and helped to draft the manuscript. XJH was responsible for the whole project, designed the study and supervised the study. All authors read and approved the final manuscript.

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Availability of data and materials

All the data and materials can be found in the manuscript.

Ethics approval and consent to participate

The study was approved by the ethics committee at Shenzhen People's Hospital and was conducted in accordance with the Protocol of Helsinki. Informed consent was signed by the relatives of the patients.

Consent for publication

All individual persons consented for their data to be published.

Competing interests

The authors declare that they have no competing interests.

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Figures

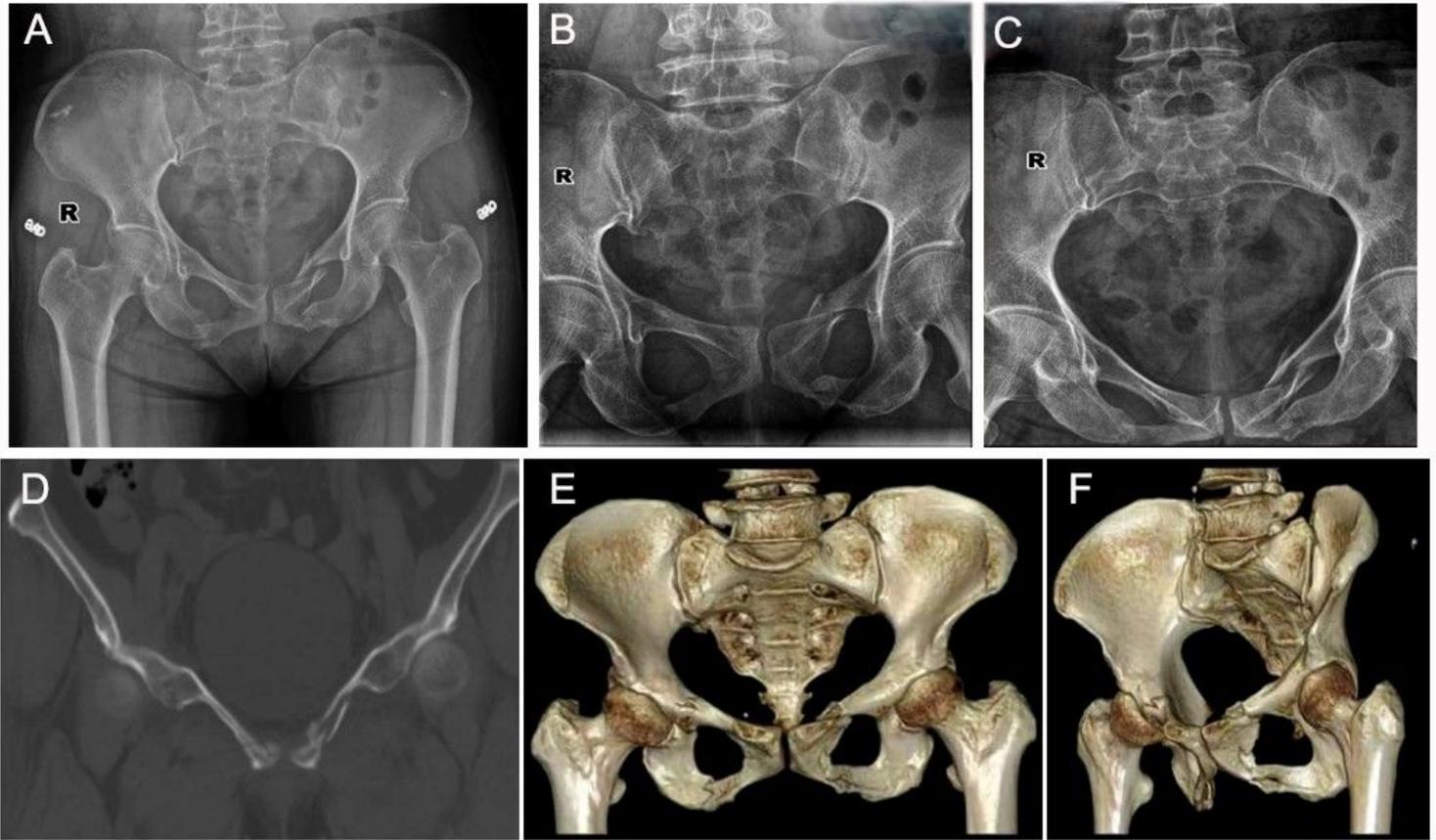


Figure 1

Preoperative observation of a 55-year-old female patient with pelvic fracture caused by traffic injury. Preoperative X-ray (A-C) and CT three-dimensional reconstruction images (D-F) showed that she had right iliac bone fracture, bilateral upper and lower pubic branches fractures, and bilateral ischial ramus fractures. The fracture displacement was obvious. Tile classification was Type B3 fracture.

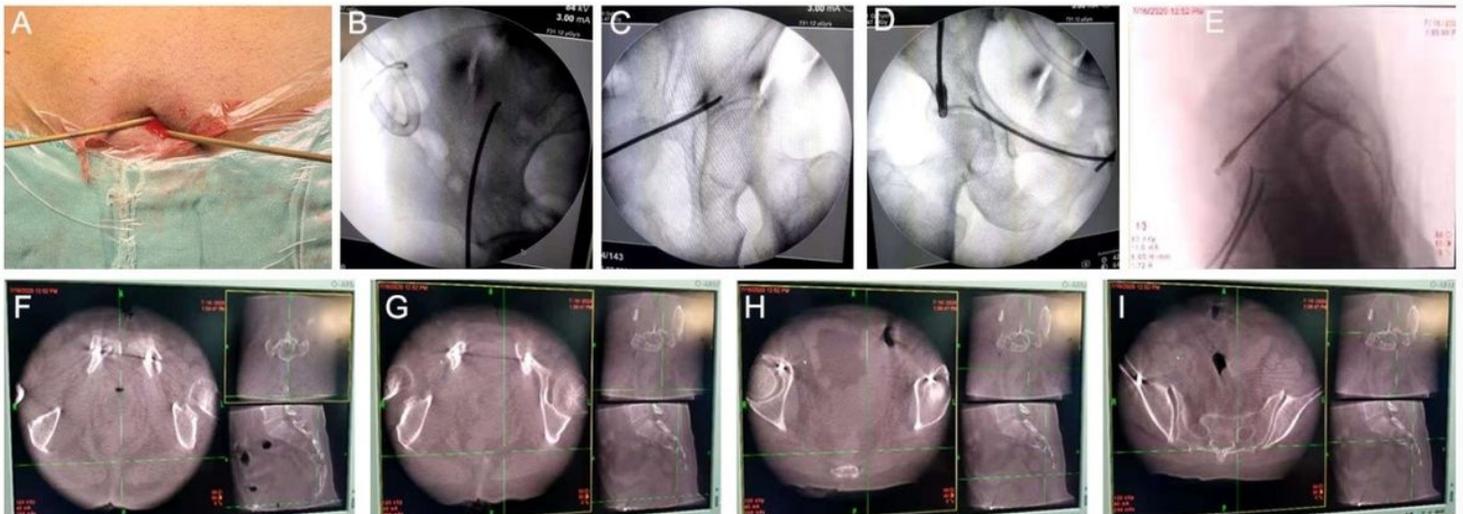


Figure 2

Images of intraoperative operation and fluoroscopy of elastic titanium nailing for the treatment of pelvic fracture. A, The longitudinal incision on the middle of pubic symphysis, length about 1 cm. B, A 3.0 cm elastic titanium nail fixing the fracture end of right iliac bone. C, A 3.0 cm elastic titanium nail fixing the fracture end of the left superior pubic ramus. D, A 3.0 cm elastic titanium nail fixing the fracture end of the right superior pubic branch. E, The lateral view showing that the elastic titanium nail was in a good position. F-I, O-arm fluoroscopy images indicating that the elastic intramedullary nail was in the pelvic bone marrow cavity channel during the operation.

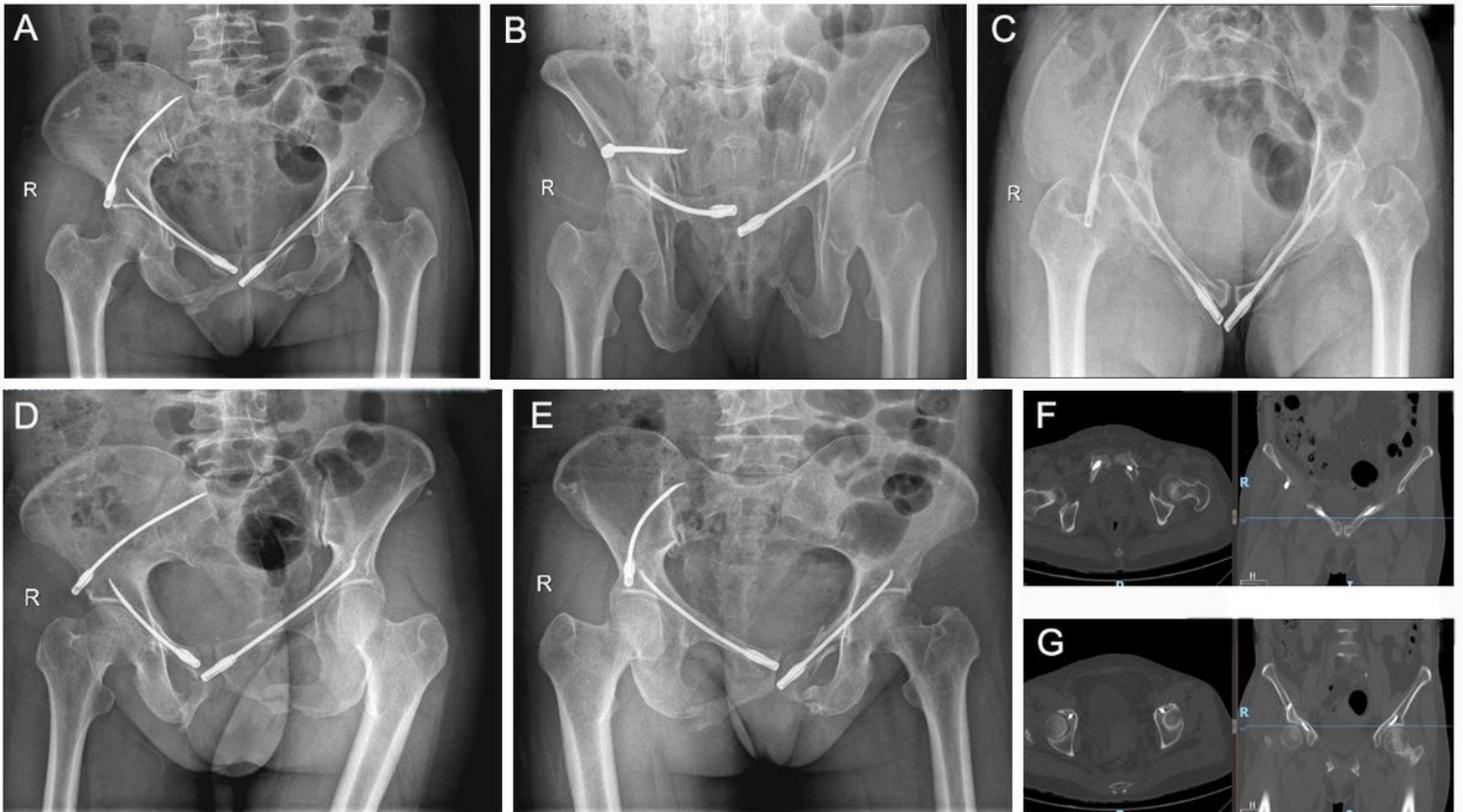


Figure 3

The X-rays image of the typical patient on the second day after surgery. A-E, The X-ray images indicated that the fracture end of the right iliac bone and bilateral pubic branches were well re-set and the elastic titanium nail was in good position. F-G, The X-ray images indicated the good reduction of the right ilium and bilateral pubic ramus fracture ends, and the good position of the elastic titanium nail.

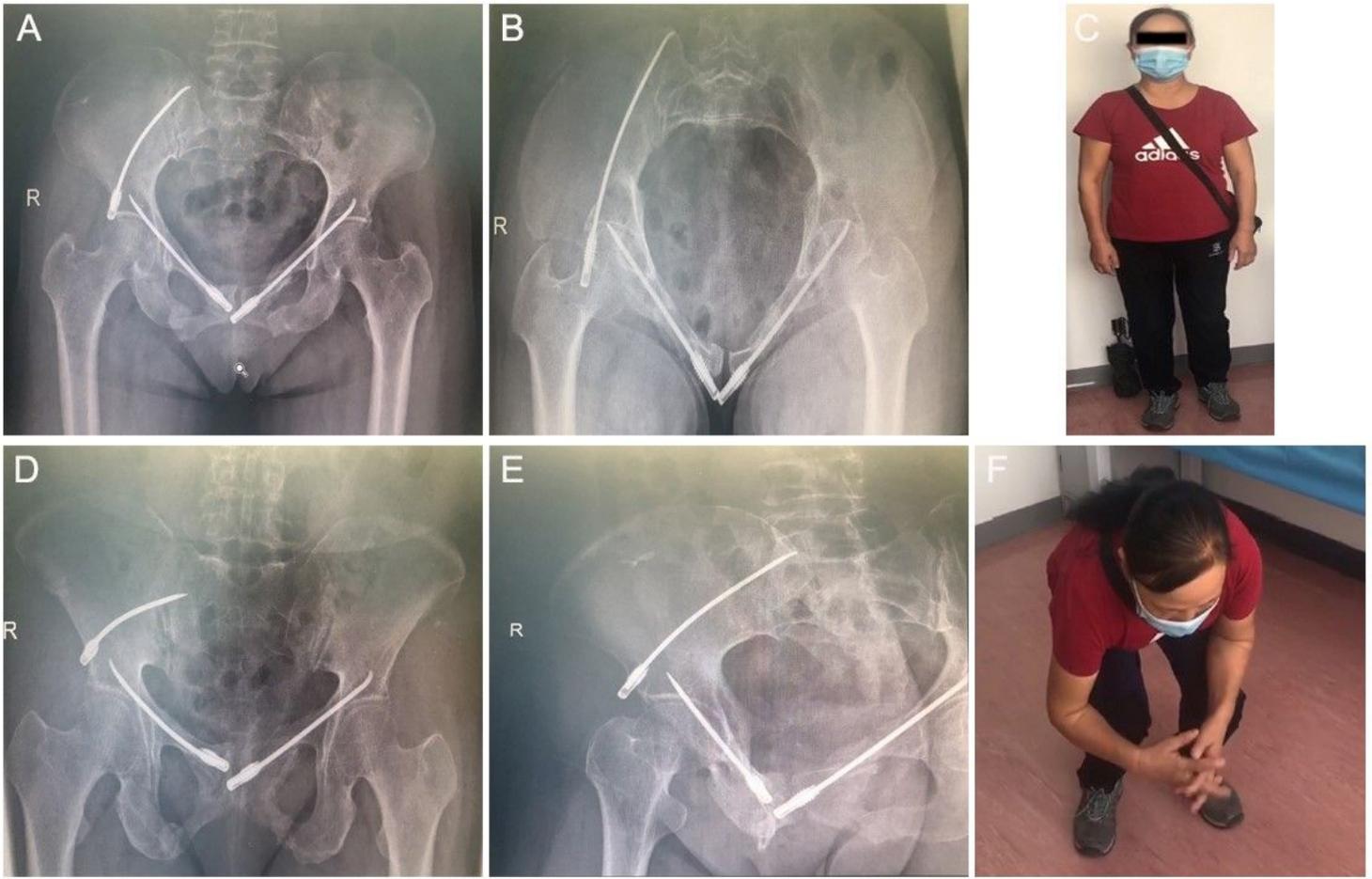


Figure 4

The X-Ray images of the typical patient three months after surgery. A-B-D-E, X-ray images showed that the fractures ends of the right iliac bone and bilateral pubic branches healed and the elastic titanium nail was in good position. C, F, Three months after the operation, the gross functional position photos of the patients showed the good functional recovery, satisfactory hip joint function recovery, and no obvious limitation of movement. According to the Majeed pelvic function score system, the curative effect was excellent.