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Comparison of the MIPPO technique and the modified Stoppa approach in the treatment of unstable anterior pelvic ring injuries: a retrospective cohort study

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Abstract

Background Anterior pelvic ring injuries have gradually become common. Using a minimally invasive technique to treat this injury may be feasible if the reduction and stability can be effectively achieved. We describe a percutaneous technique, minimally invasive percutaneous plate osteosynthesis (MIPPO), to fixate the anterior pelvis via establishing a subperiosteal tunnel between two limited incisions over the iliac crest(s) and pubic ramus in this research.

Methods A retrospective cohort study comparing the MIPPO technique ($n=60$) versus the modified Stoppa approach ($n=53$) for anterior pelvic ring injuries with posterior ring instability was performed from September 2016 to January 2023. The relative surgery variables, follow-up function evaluation, and complications were compared in two groups. The reduction quality of fracture was assessed according to the Matta criterion, and the functional score was evaluated using the Majeed score.

Results All patients completed follow-up, with an average interval of 39.90 ± 17.53 months (range 12–78). In the MIPPO technique group, the surgery interval and blood losses were lower compared to the modified Stoppa approach group ($P<0.05$). The mean procedure times and intraoperative blood losses were 69.56 ± 14.04 min/side (range 50–110) and 156.23 ± 49.75 mL/side (range 90–250) for unilateral anterior ring MIPPO fixation separately. All patients got a satisfactory reduction of the fracture. In the follow-up, earlier ambulation, shorter postoperative hospital stays, and lower complication rates were observed for patients using the MIPPO technique compared to the modified Stoppa approach ($P<0.05$). However, there is no statistical difference in these indicators including fracture union interval, full load time, the Majeed score, patient satisfaction level, and return to pre-injured work rate between the two groups.

Conclusion This clinical experience gives support for the use of the MIPPO technique to stabilize the anterior pelvis. This minimally invasive technique was an effective and safe surgery method and could obtain satisfactory function results, particularly fitting to part of patients with resistance using the modified Stoppa approach.

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Keywords Anterior pelvic ring injuries, Pubic ramus fractures, Anterior column fractures, MIPPO technique, Modified Stoppa approach

Introduction

Fractures of the anterior pelvic ring have been common due to high or low-energy trauma, with an incidence of 6.9/100,000/year in the total population [1–3]. In recent decades, if the posterior pelvic structures remain intact and stable, only surgical internal fixation for the pelvic anterior ring has been advocated as conservative treatment or external fixation has usually brought a range of complications, including chronic pain, sitting imbalance, sexual function impairment, and limb length inequality [4–9]. Internal fixation for anterior pelvis injuries can not only obtain better radiographic and clinical function outcomes but also reduce complications.

Common internal fixation methods for anterior ring injuries include the ilioinguinal approach [10], anterior subcutaneous pelvic internal fixator (INFIX) [11], anterior pelvic bridge [12], percutaneous screw fixation [13], and the modified Stoppa approach [14]. At present, the modified Stoppa approach has been widely used due to its advantages such as great surgical field, anatomical fracture reduction under direct vision, and mature manipulation. This method can get anatomical reduction and satisfactory clinical results. However, this approach also brings some shortcomings including iatrogenic neurovascular bundle injury during dissection, long operation procedures, intraarticular penetration of the screws, large trauma from surgery, and high occurrence of complications [15, 16]. Studies using minimally invasive methods to fixate anterior ring injuries have recently been described and discussed [12, 17, 18], which highlights the trend of anterior pelvis minimally invasive fixation in the future. In this research, we used the minimally invasive percutaneous plate osteosynthesis (MIPPO) technique to fixate anterior pelvis fracture through two limited incisions. We try to improve the fixation methods to reduce the patient's trauma from surgery and obtain an effective fixation as well as fast rehabilitation.

Our purpose is to compare the clinical outcomes of anterior pelvic ring fixation between the MIPPO technique and the modified Stoppa approach through a retrospective cohort study to estimate whether the MIPPO technique can obtain similar satisfactory outcomes as the modified Stoppa approach. Additionally, we describe this minimally invasive technique and its application, merit, and limitation according to our clinical experience.

Thus, we asked at a minimum follow-up of one year after the anterior pelvic ring injury fixation using the MIPPO technique, (1) whether the MIPPO technique can also obtain satisfactory outcomes like the modified Stoppa approach for anterior pelvis injuries? (2) What are the feasibility, merits, and limitations of the MIPPO technique? (3) Whether the MIPPO technique is safe and can be used as an option for anterior pelvic fixation?

Study Design

This is a retrospective cohort study and enrolled patients were divided into two groups. They were surgically treated using either the MIPPO technique or the modified Stoppa approach from September 2016 to January 2023 at our hospital, an academic tertiary referral center with a high-level trauma center. This study was approved by the Ethical Committee of Tongji Hospital, Tongji Medical College, Huazhong University of Science and Technology.

Patients

Between September 2016 to January 2023, 113 patients with anterior pelvic ring fractures with posterior ring instability were enrolled according to the inclusion criteria and exclusion criteria; and randomly divided into two groups including the MIPPO technique ($n=60$) or modified Stoppa approach ($n=53$). The average age of the patients was 48.88±13.92 years (range 18–78). They included seventy-three males (64.6%) and forty females (35.4%).

The mean injury severity score (ISS) was 15.76±6.97 points. The mechanism of injury included motor accident (sixty-eight patients, 60.2%), fall from height (twenty-five patients, 22.1%), struck by a heavy object (eight patients, 8.0%), fall from standing level (seven patients, 6.2%), and other (four patients, 3.5%). Additionally, all fracture types belonged to the type of Tile B or C1 [19]. All patients were surgically treated with an average waiting interval of 9.03±6.54 days from injury to surgery. The demographics of patients in two surgical groups were summarized, and the ratio of unilateral pubic ramus fractures was lower in the MIPPO technique compared to the modified Stoppa approach ($P<0.05$) (Table 1).

Inclusion criteria and exclusion criteria

The following characteristics were included: (1) anterior pelvic ring with more than 2.5 cm displacement; (2) anterior ring fractures combined with displaced anterior wall or column acetabular fractures; (3) unstable pelvic fractures belong to Tile B or C1; (4) closed fresh fractures; (5) patients aged 18 years or older.

The following characteristics were excluded: (1) anterior ring combined with iliac wing fractures; (2) severe displaced sacroiliac joint complex injury requiring surgical fixation. (3) combined posterior wall or column

Table 1 Patient demographics

Demographics	MIPPO (*n* = 60)	Modified Stoppa (*n* = 53)	t/χ2 value	*P* value
Gender (male/female)	35/25	38/15	2.20	0.138
Age (years)	48.90 ± 14.24	48.87 ± 13.69	0.01	0.990
Age (<55/ ≥55 years)	40/20	35/18	0.005	0.944
BMI (Kg/m^2)	22.11 ± 2.22	22.62 ± 3.46	-0.93	0.344
BMI (<24/ ≥24)	49/11	37/16	2.18	0.140
Type of pelvic fracture				0.297
Tile B1	2 (3.3%)	2 (3.8%)		
Tile B2.1/2.2	28 (46.7%)	34 (64.2%)		
Tile B3	9 (15.0%)	5 (9.4%)		
Tile C1	21 (35.0%)	12 (22.6%)		
Mechanism of injury				0.456
Motor accident	39 (65.0%)	29 (54.7%)		
Fall from height	11 (18.3%)	14 (26.4%)		
Struck by a heavy object	4 (6.7%)	5 (9.4%)		
Fall from standing level	5 (8.3%)	2 (3.8%)		
Other	1 (1.7%)	3 (5.7%)		
ISS score	16.37 ± 7.60	15.08 ± 6.18	0.98	0.328
Time from injury to surgery (days)	8.80 ± 5.81	9.28 ± 7.33	-0.39	0.697
Use of external fixator			1.28	0.258
Use	10 (16.7%)	5 (9.4%)		
Not	50 (83.3%)	48 (90.6%)		
Thrombosis formation (Yes/Not)	2 (3.3%)/58 (96.7%)	2 (3.8%)/51 (96.2%)	0.016	0.899
Deep vein thrombosis	1 (1.7%)	2 (3.8%)		
Pulmonary embolism	1 (1.7%)	0 (0)		
Pubic ramus fracture			5.67	0.017*
Unilateral	35 (58.3%)	42 (79.3%)		
Bilateral	25 (41.7%)	11 (20.8%)		
Concomitant anterior column fracture			0.001	0.976
Yes	27 (45.0%)	24 (45.3%)		
Not	33 (55.0%)	29 (54.7%)		
Follow-up (months)	38.90 ± 13.73	41.02 ± 21.15	-0.62	0.535

BMI, body mass index; ISS, injury severity score. *P<0.05 indicates a statistical difference

acetabular fractures requiring operative intervention; (4) only anterior wall or column acetabular fractures; (5) open or pathological fractures.

Surgical technique

Presurgical evaluation

Patients underwent presurgical X-ray film, CT scans (Fig. 1A-C), and three-dimensional reconstruction (Fig. 1D) of the pelvis. Moreover, arteriovenous color ultrasound examination and perioperative anticoagulation were routinely performed due to the patient's long period of immobilization which was susceptible to deep venous thrombosis of lower limbs and pulmonary embolism.

Minimally invasive percutaneous plate osteosynthesis (MIPPO) technique

The patient was placed in a supine position after general anesthesia was given. First, identified surgical landmarks and planned incisions were marked through the palpation of bone landmarks and pulse range of the femoral artery (Fig. 1E). Next, the surgical area and ipsilateral lower limb were disinfected (Fig. 1F).

A 3–5 cm medial incision was dissected over the pubic ramus area along the line from the pubic tubercle to near the iliopubic eminence (Fig. 1E (**3–4**) and Fig. 2A). The incision passed through the skin and subcutaneous fat to reach the external oblique aponeurosis. The incision edges were separated by surgical retractors to bluntly dissect and expose the spermatic cord or round ligament and its surrounding tissue (Fig. 2B). Notably, attention should be paid to avoid iatrogenic injury to the femoral nerve, femoral artery, femoral vein, and inguinal canal in this procedure. Such injury can be avoided by careful dissection and protection. Next, the round ligament was carefully stripped and pulled toward the superomedial side to expose the ligaments and periosteum of the superior pubic ramus. Then the ligaments on the surface

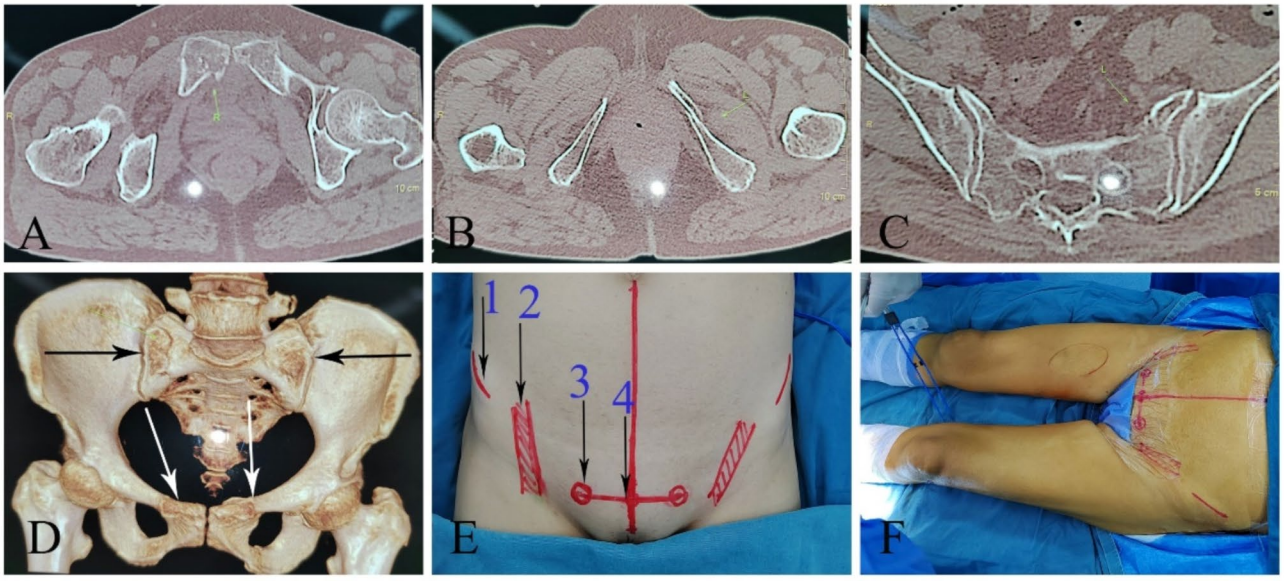

Fig. 1 **A-D**: (**A-C**) axial and (**D**) three-dimensional CT reconstruction pelvic radiographs showed bilateral pubic ramus fractures with anteroposterior displacement (white arrows) and sacroiliac joint injury (black arrow). **E**: Identified surgical landmarks and planned incisions. (**1**, ASIS; **2**, the pulse region of femoral artery, vein, and nerve; **3**, iliopubic eminence; **4**, pubic tubercle). **F**: The surgical manipulation area and ipsilateral lower limb of disinfection, draping, and affixed incision membrane. ASIS, anterosuperior iliac spine

of the pubis were cut and removed along the vertical axis, and other soft tissues and the associated periosteum were also stripped to fully expose the pubic ramus (Fig. 2C). A subperiosteal tunnel was established using a periosteal dissector to peel along the surface of the superior pubic ramus toward the acetabular anterior edge. Simultaneously, to minimize the resistance of stripping periosteum, the ipsilateral hip and knee were flexed to relax the iliopsoas muscle and the external iliac neurovascular bundle. The incision edges were separated with retractors to reveal the fracture site. Then, the superior pubic ramus or anterior column was restored with reduced bone-holders, bucking bar, or Kirschner wires which were used to provisionally fix if necessary. However, the wire's position should not hinder the placement of the steel plate. The incision was stuffed with gauze, and the lateral incision was continuously dissected.

A 3–5 cm lateral incision was made starting from the anterior superior iliac spine backwardly along the iliac crest (Fig. 1E (**1**)). The skin and subcutaneous tissues were carefully dissected. Then the attachment point of the iliacus was sharply dissected and pulled toward the medial side to expose the inner table of the iliac crest (Fig. 2D). In this lateral pull procedure, the caution was paid to avoid injury to the lateral femoral cutaneous nerve (LFCN) near the iliac crest (about 3 cm) [20]. A periosteal dissector was used to peel along the leading edge of the acetabulum toward the superior pubic ramus to further form and expand the subperiosteal tunnel allowing the steel plate to safely pass through, while flexion of the ipsilateral hip and knee (Fig. 2E, F). Notably, during the establishment of the tunnel, the periosteal dissector must be put underneath the periosteum to avoid damage to nerve and blood vessels that lead to bleeding (especially the corona mortis, the anastomotic branch between the inferior epigastric and the obturator vessel) [21].

After satisfactory fracture reposition was achieved and confirmed by a C-arm fluoroscopy, a ten to fourteen-hole locking reconstruction plate was shaped according to the pelvic structure (Fig. 2G-I). Next, under the condition of flexing the ipsilateral hip and knee, the shaped steel plate was inserted and placed through the tunnel underneath the periosteum on top of the pubic rami aligned from the acetabular anterior wall toward the inner table of the iliac crest (Fig. 3A). Two or three 3.5 mm locking screws were inserted into medial (Zone I of Nakatani classification [22], Fig. 3B-D) and lateral (Fig. 3E, F) ends of the steel plate while using C-arm fluoroscopy to check (Fig. 3G, H). Notably, the displaced fracture can be restored through the force of the shaped steel plate and screws sometimes. Adjusted the arc of the shaped steel plate and the screw can provide the downward pressure force and the upward pull force on the fracture to reach an indirect fracture reduction. Finally, the fascia and skin were carefully closed layer-by-layer to avoid injury to the inguinal canal and formation of the inguinal hernia, without placing drainage given the low amount of intraoperative bleeding and the limited incisions (Fig. 3I). The reduction quality of the fracture was evaluated through the X-ray radiograph after surgery (Fig. 3J). Finally, the pelvic ring remained stable after the anterior ring was fixed by the

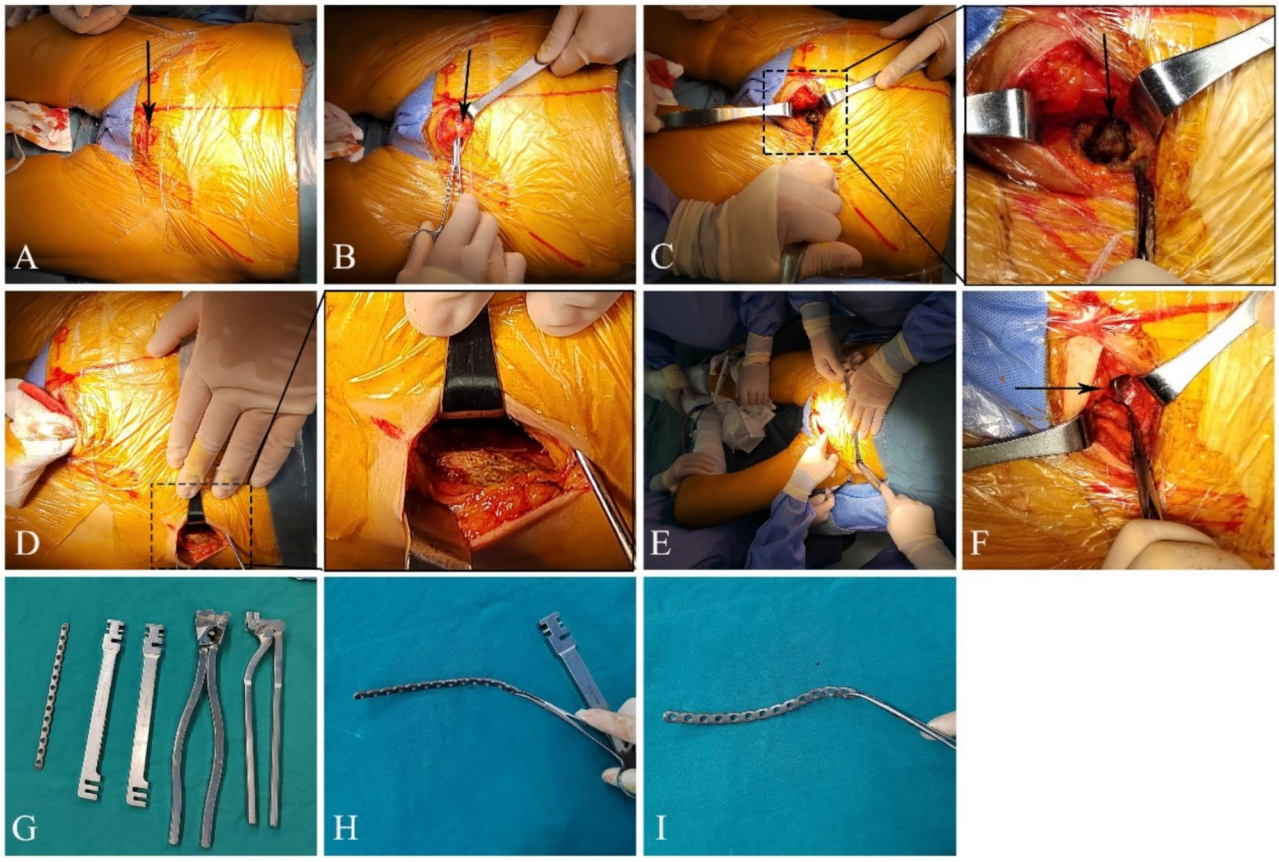

Fig. 2 **A**: Made a 3–5 cm medial incision from the pubic tubercle close to the iliopubic eminence. **B**: Incision of skin and subcutaneous tissue to expose the round ligament of the uterus and its surrounding tissue. **C**: Exposure of the superior ramus of the pubis by further dissection. **D**: Made a 3–5 cm lateral incision from ASIS along the iliac ala to expose the inner table of the iliac crest. **E**, **F**: A periosteal dissector was used to strip along the front edge of the acetabulum toward the superior pubic ramus to form a subperiosteal tunnel by flexing the ipsilateral hip and knee to relax the iliopsoas muscle and the external iliac neurovascular bundle. **G-I**: A reconstruction plate with thirteen holes was shaped according to the pelvic rim structure

squeeze-separation examination technique of the pelvis. Thus, the posterior ring fixation did not be performed.

Modified Stoppa approach

The patient was placed in a supine position on a radiolucent table after general anesthesia was given. The hips and knees were slightly flexed to relax the iliopsoas muscle. A midline incision (about 10–12 cm) from the umbilicus to symphysis was made, and the skin and subcutaneous fat were dissected to vertically expose and open the anterior rectus sheath. Then the preperitoneal space was carefully opened and bluntly cut until the exposure of pubic symphysis. The transverse abdominal muscle fibers were dissected from the peritoneal sac resulting in the latter being away from the fracture side. The common femoral artery/vein, and the spermatic cord or round ligament were anterolaterally pulled and carefully protected. The true pelvic ring was subperiosteally stripped and exposed along the superior edge of the superior pubic ramus near the symphysis to the lateral side. In this procedure, it should be noted that the corona mortis was cut after ligation if detected [21]. Then, the iliopectineal fascia was subperiosteally stripped to adequately expose the anterior ring fracture site.

The fracture reduction was achieved using the reduction clamps, bucking bars, or Kirschner wires to temporarily fixate. Next, the locking reconstruction steel plate was shaped and placed on the inner edge of the true pelvic entrance. Several 3.5 mm locking screws were appropriately fixed at both ends of the steel plate to achieve rigid and efficient fixation. The C-arm fluoroscopy was used to assess the placement of the steel plate and the length of the screws to ensure that these screws would not enter into the acetabulum. The integrity of the peritoneum was checked. Finally, the fascia recta, the fascia, and the skin were closely sutured, while a drainage tube was placed.

After the operation was finished, the surgical time was assessed from the incision of the skin to the suture of the wound, and the blood loss was evaluated based on the suction device and blood-soaked gauze.

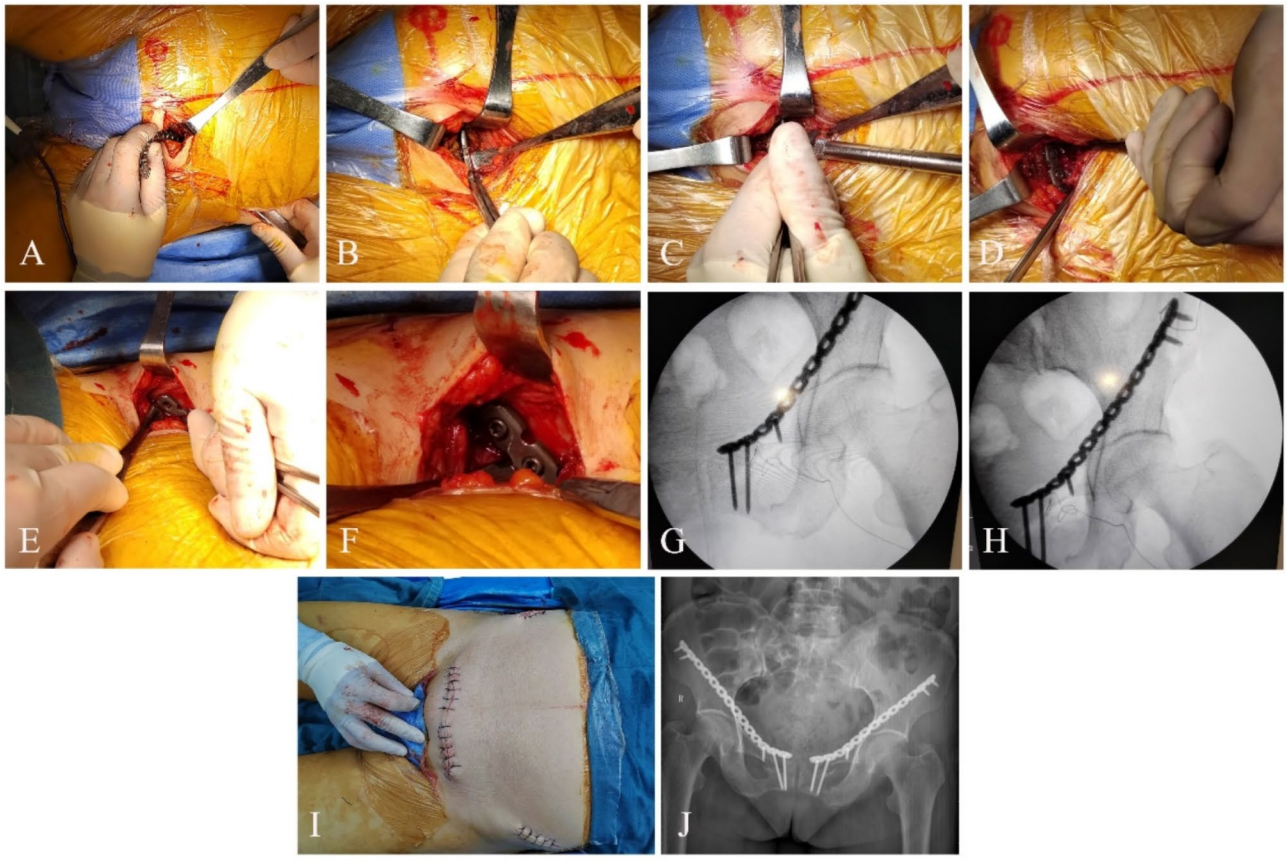

Fig. 3 **A**, **B**: Subperiosteal insertion of shaped steel plate on top of the pubic rami aligned from the acetabular anterior wall to the inner table of the iliac crest by flexing the ipsilateral hip and knee. **C-F**: After reduction, depth sounding and screw placement (Zone I of Nakatani classification) were performed in the medial and lateral incision. The steel plate's downward pressure force and the upward pull force of screws contributed to further fixation and reduction of the fracture. **G**, **H**: Intraoperative radiographs showed the displaced fracture was satisfactorily restored. Use of a similar surgical approach to fixate the right pubic ramus. The sacral fracture was conservatively treated because the posterior pelvis was stable after the anterior ring fixation. **I**: Suture the wound layer by layer. **J**: postsurgical AP pelvic radiograph showed a satisfactory fracture reduction

Postsurgical protocol

Antibiotics were given for two to three days following surgery. When the draining fluid was less than 30 mL per day for the patients with the modified Stoppa approach, the draining tube was removed. Patients were allowed to freely move bilateral lower limbs and gradually perform functional exercises such as moderately bending and straightening activities of the knee, but not to largely move the knee joint, sit up, and get off the ground. The patients were admitted to sit after two weeks, to walk using crutches in a protected situation after one month, and to walk at full weight after three months. However, all of these rehabilitation activities were dependent on the patient's condition such as wound healing, fracture healing, and functional recovery.

Reduction quality of the fracture evaluation

The reduction quality of the fracture was assessed using the Matta criterion [23] by measuring the maximal distance of fracture displacement at the postsurgical anteroposterior X-ray radiograph of the pelvis. The detailed classification of reduction quality involves the following: the distance of less than 4 mm was defined as excellent; the distance of 5–10 mm was defined as good; the distance of 11–20 mm was defined as fair; the distance of more than 20 mm was defined as poor.

Follow-up functional assessment

All patients were regularly followed up at one, three, six, and twelve months after surgery respectively. Moreover, pelvic X-rays and physical examinations were routinely performed each time to assess bone healing as well as functional recovery status.

During the follow-up process, the parameters including fracture union interval, full load time, the Majeed score, patient satisfaction level, return to pre-injured work rate, postoperative complications (including femoral nerve injury, obturator nerve palsy, sciatic nerve palsy, LFCN injury, deep infection, and superficial infection), and late complications (including chronic pain of the pelvis,

ectopic bone formation, hip joint arthritis, limited hip mobility, lateral inguinal hernia, plate/screws loosened, and walk with a limp), were assessed to evaluate patients' function outcomes. Moreover, the Majeed score was used to estimate the functional score of patients at the final follow-up [24]. This scoring method assesses five parts of the patients including pain (30 points), work (20 points), sitting (10 points), standing (36 points), and sexual function (4 points). Point 85–100 was graded as excellent, point 70–84 was graded as good, point 56–69 was graded as fair, and point 0–55 was graded as poor. In addition, we further simplify them as satisfactory or unsatisfactory. The excellent or good of the Majeed criterion was classified as satisfactory, while the fair or poor was classified as unsatisfactory.

Statistical analysis

The SPSS version of 25.0 (IBM Corp, Chicago) was used for statistical analysis. Continuous variables are presented as the mean ± standard deviation, which is compared using an independent-sample t-test. Categorical variables are presented as numbers and percentages, which are compared using the Chi-square test or nonparametric test. The value of $P<0.05$ is defined as a statistical difference.

Results

Patient demographics

All patients were followed up, with a mean time of 39.90 ± 17.53 months (range 12–78). Before surgery, one patient had a pulmonary embolism, as well as another patient had a deep vein thrombosis in the MIPPO technique group, and two patients had a deep vein thrombosis in the modified Stoppa approach group (Table 1). Moreover, the patient with pulmonary embolism was treated by thrombolysis before surgery, and a filter was placed for patients with deep vein thrombosis before the operation and was removed three or six months later.

Surgical relative statistic

The intraoperative variables of the two groups were summarized (Table 2). The duration of surgery for the MIPPO technique group was 95.95 ± 35.15 min and for the modified Stoppa approach group was 151.77 ± 39.81 min ($P<0.001$). Besides, the blood loss was 195.94 ± 75.68 mL in the MIPPO technique group and 314.96 ± 152.30 mL in the modified Stoppa approach group ($P<0.05$).

In the MIPPO technique group, thirty-five patients (58.3%) suffered unilateral pubic ramus fractures and they required only unilateral MIPPO fixation. Moreover, the mean procedure intervals and intraoperative blood losses were 69.56 ± 14.04 min/side (range 50–110) and 156.23 ± 49.75 mL/side (range 90–250), separately (Table 2). Moreover, twenty-seven patients (45.0%) suffered a pubic ramus fracture combined with an anterior column or wall fracture. They were simultaneously treated through the anterior ring MIPPO fixation, while getting an effective and strong fixation.

Follow-up outcomes and functional evaluation

Postoperatively, all patients in both groups obtained satisfactory fracture reduction evaluated by anteroposterior X-ray films, with a Matta's excellent/good rate of 100% (Table 3). During the follow-up, the postoperative hospital stays and ambulation time were shorter, while the complication rate was lower in the MIPPO technique group compared to the modified Stoppa approach group ($P<0.05$) (Table 3). All patients achieved the bone union, with a mean time of 12.15 ± 1.54 weeks for the MIPPO technique group and 12.66 ± 1.56 weeks for the modified Stoppa approach group, separately ($P>0.05$). Additionally, the average time for patients to fully bear weight is about 13 weeks in two groups ($P>0.05$).

At the final follow-up, functional results were evaluated by the Majeed standard in two groups (Table 3). The mean point was 87.58 ± 6.64 points for the MIPPO technique group and 85.09 ± 7.88 points for the modified Stoppa approach group ($P>0.05$). Further, the score was excellent in forty-six patients, good in eleven patients, and fair in three patients in the MIPPO technique group (Fig. 4), while excellent in thirty-four patients, good in fifteen patients, and fair in four patients in the modified Stoppa approach group (Fig. 5). More than 86.0% of patients returned to pre-injured work and felt satisfactory for function results in two groups. The secondary operation of hardware removal was performed for seven patients, three patients because of the plate or screws loosening (one patient in the MIPPO technique group, and two patients in the modified Stoppa approach group)

Table 2 Surgical statistics

Variables	MIPPO ($n=60$)	Modified Stoppa ($n=53$)	t/χ2 value	*P* value
Duration of surgery (min)	95.95 ± 35.15	151.77 ± 39.81	-7.71	<0.001*
Unilateral side	69.56 ± 14.04			
Blood losses (mL)	195.94 ± 75.68	314.96 ± 152.30	-5.16	<0.001*
Unilateral side	156.23 ± 49.75			
ASA score (I/II/III)	7/43/10	3/35/15	2.96	0.085

ASA, American society of anesthesiologists physical status. *$P<0.05$ indicates a statistical difference

Table 3 Follow-up and function results

Variables	MIPPO ($n=60$)	Modified Stoppa ($n=53$)	t/χ2 value	*P* value
Postoperative hospital stays (days)	7.98 ± 4.23	9.40 ± 2.27	-2.22	0.029*
Ambulation time (weeks)	5.40 ± 1.33	6.08 ± 1.97	-2.16	0.033*
Fracture union (weeks)	12.15 ± 1.54	12.66 ± 1.56	-1.75	0.083
Full load time (weeks)	13.15 ± 1.88	13.89 ± 1.99	-2.02	0.923
Matta criterion of reduction				1.000
Excellent	57 (95.0%)	49 (92.5%)		
Good	3 (5.0%)	4 (7.5%)		
Fair/poor	0 (0)	0 (0)		
Majeed score	87.58 ± 6.64	85.09 ± 7.88	1.82	0.071
Majeed criterion of function				0.376
Excellent	46 (76.7%)	34 (64.2%)		
Good	11 (18.3%)	15 (28.3%)		
Fair	3 (5.0%)	4 (7.5%)		
Patient satisfaction level				0.704
Satisfactory	57 (95.0%)	49 (92.5%)		
Unsatisfactory	3 (5.0%)	4 (7.5%)		
Plate removal				1.000
Yes	4 (6.7%)	3 (5.7%)		
Not	56 (93.3%)	50 (94.3%)		
Return to pre-injured work			0.06	0.804
Return	53 (88.3%)	46 (86.8%)		
Not	7 (11.7%)	7 (13.2%)		
Complications			4.63	0.043*
Yes	9 (15.0%)	17 (32.1%)		
Not	51 (85.0%)	36 (67.9%)		

*$P<0.05$ indicates statistical difference

(Table 4), and four female patients due to their concern for impaired sexual activity and fertility in two groups.

Complications

The complication rate for the MIPPO technique group was lower than the modified Stoppa approach group (15.0% vs. 32.1%), and there was a significant statistical difference between the two groups ($P<0.05$) (Table 3). The incidence of postoperative complications (including femoral nerve injury, obturator nerve palsy, sciatic nerve palsy, LFCN injury, deep infection, and superficial infection) and late complications (including chronic pain of the pelvis, ectopic bone formation, hip joint arthritis, limited hip mobility, lateral inguinal hernia, plate/screws loosened, and walk with a limp), was low in the MIPPO technique (Table 4). Therefore, the MIPPO technique is safe during operation and achieves good clinical outcomes. Generally, no fracture delayed/non-union or plate broken occurred in both groups.

Discussion

When the pelvis suffers from violent forces, the pelvic anterior or posterior ring fracture occurs resulting in pelvic instability [25]. This injury of high energy usually causes hemodynamic instability and other multiple injuries [26]. The pelvic anterior ring injury is susceptible to occur due to the weakness of the surrounding ligament structures [1]. Presently, most authors have advocated using internal fixation to fixate the anterior pelvis fracture because conservative therapy is limited and brings many adverse events [1, 9, 27]. Hence, pelvic stability should be reduced early if the patient's condition is admitted because excellent reduction quality of the fracture can improve later clinical outcomes [28].

Surgical methods for anterior pelvis fixation include steel plate fixation, cancellous bone screw fixation, and an external fixator built under the skin. The ilioinguinal approach was a traditional method for anterior pelvis fixation. This method can greatly expose the surgical field, which contributes to fracture reduction under direct visualization. However, the use of this approach gradually decreased due to large trauma from surgery, many complications following the operation, and the difficulty of manipulation [10, 29]. In contrast, the MIPPO technique used a percutaneous fixation through two limited incisions to fix fractures. It is a more minimally invasive method and brings less trauma as well as pain to patients compared to the ilioinguinal approach. In 1995, Routt et al. [30] proposed a novel technique, retrograde superior pubic screw fixation, to treat anterior pelvic ring disruptions. Moreover, relative reports of this minimally invasive method have risen. Although this approach can

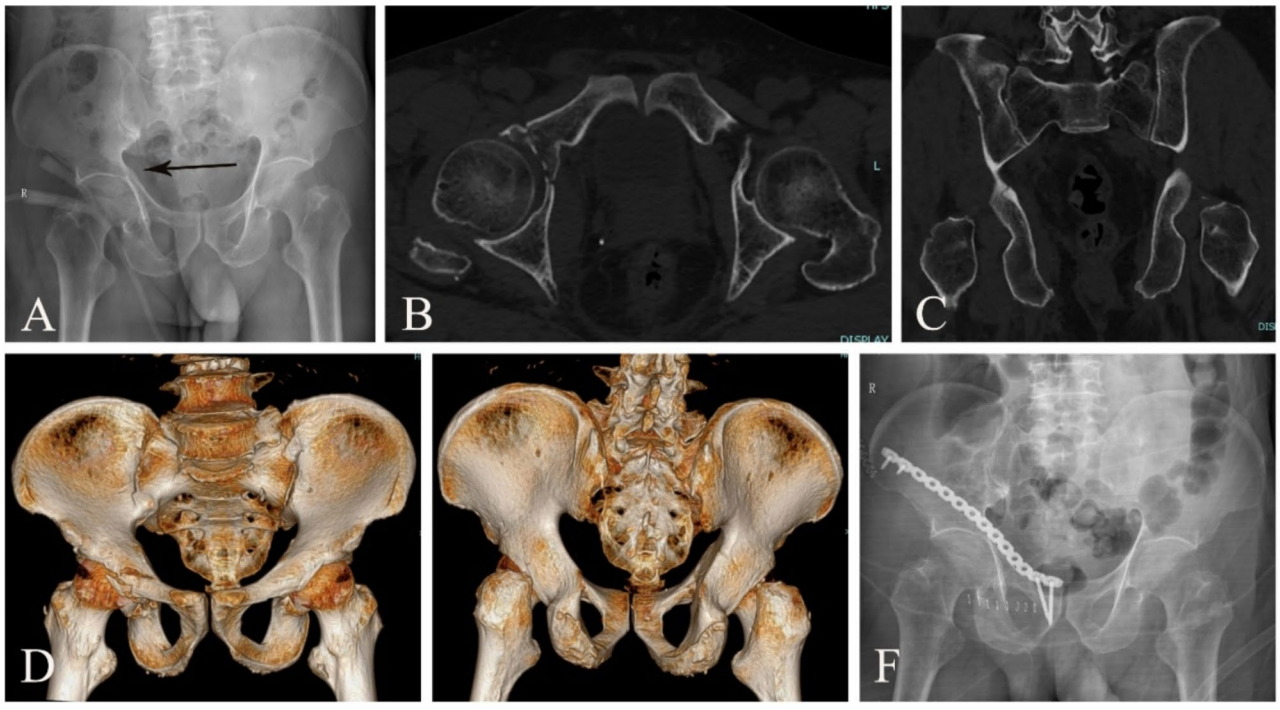

Fig. 4 An elderly male patient with right superior and inferior ramus of the pubis, acetabular anterior column, and left sacroiliac joint injuries sustained from a motor collision was surgically treated via the left MIPPO approach. **A-E**: (**A**) Presurgical AP radiograph, (**B**) axial view, (**C**) coronal view, and (**D**, **E**) three-dimensional CT reconstruction showed separation and displacement of the fracture fragment. **F**: Postoperative AP radiograph demonstrated satisfactory restoration of the fracture

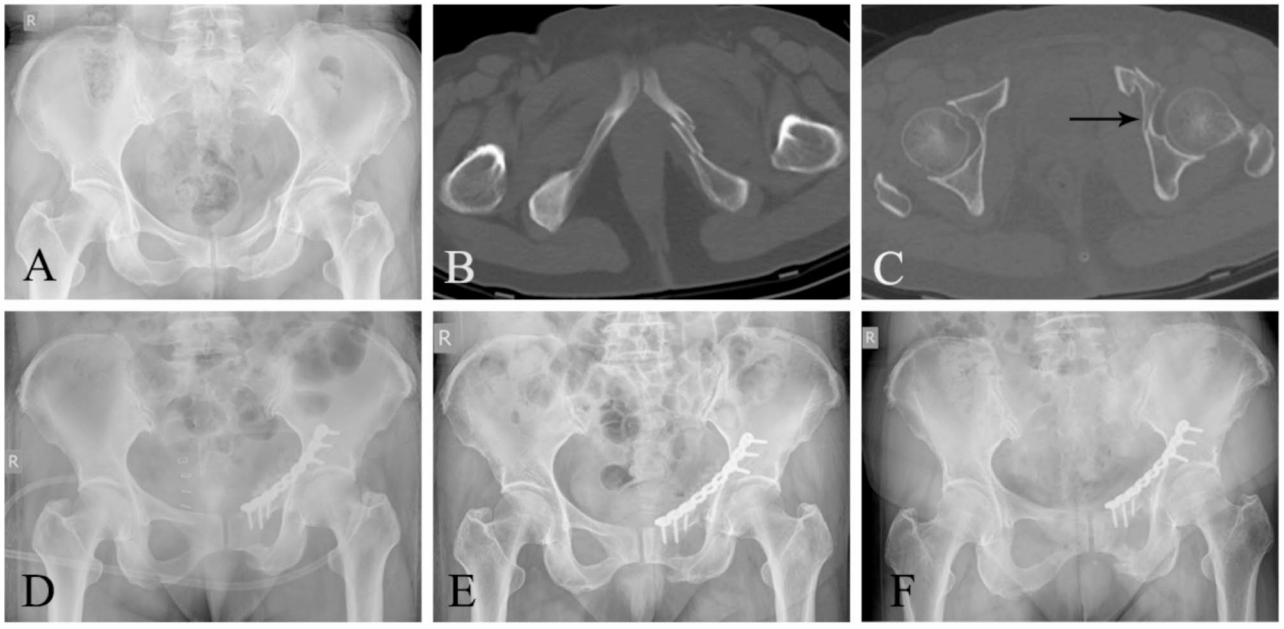

Fig. 5 An elderly female patient with left superior and inferior ramus of the pubis, and acetabular anterior column fractures caused by a motor collision was treated through the modified Stoppa approach. **A**: Presurgical AP radiograph. **B**, **C**: axial view. **D**: Postoperative AP radiograph after four days. **E**: X-ray radiograph after one month. **F**: X-ray radiograph showed the fracture union after three months

Table 4 Complications of postoperative anterior pelvic fractures

Complications	MIPPO (*n* = 60)	Modified Stoppa (*n* = 53)	Management
Incidence rate	9 (15.0%)	17 (32.1%)	
postoperative complications			
Femoral nerve injury	0 (0)	1 (1.9%)	Recovered in 8 months
Obturator nerve palsy	0 (0)	1 (1.9%)	Partial recovery
Sciatic nerve palsy	0 (0)	1 (1.9%)	Recovered in 1 month
LFCN injury	1 (1.7%)	2 (3.8%)	Recovered in 6–12 months in two patients and partial recovery in another patient
Deep infection	0 (0)	1 (1.9%)	Debridement and antibiotics
Superficial infection	1 (1.7%)	2 (3.8%)	Dressing and antibiotics
Late complications			
Chronic pain of the pelvis	2 (33.3%)	2 (3.8%)	Physical therapy or oral obtundent
Ectopic bone formation	1 (1.7%)	1 (1.9%)	Conservative treatment without limited range of motion
Hip joint arthritis	1 (1.7%)	1 (1.9%)	Conservative treatment
Limited hip mobility	1 (1.7%)	1 (1.9%)	Rehabilitation training
Lateral inguinal hernia	0 (0)	1 (1.9%)	Repaired surgically
Plate/screws loosened	1 (1.7%)	2 (3.8%)	Removed
Walk with a limp	1 (1.7%)	1 (1.9%)	Rehabilitation training

LFCN, lateral femoral cutaneous nerve

reduce the duration of surgery and blood loss, it also existed shortcomings such as reduction loss, screw loosening, and the necessity of a secondary revised operation [13, 31]. Hence, its wide use is limited. Anterior subcutaneous pelvic internal fixator (INFIX) is based on the same principle as the external fixator, and their difference lies in the implant of INFIX under the skin [11]. This approach has adopted the indirect restoration for the anterior pelvis fixation. Therefore, the possibility of micro-movement in the fracture site may affect fracture healing. The common complications of this technique have included heterotrophic ossification (35%), irritation of the LFCN (30%), and internal fixation failure [32, 33]. Some studies have proposed another subcutaneous method [12, 34, 35]. A steel plate or a spinal rod is placed through a subcutaneous tunnel under the skin and over neurovascular structures, and fixation into the iliac crest and pubic ramus is reached to maintain pelvic stability. Even though this approach can avoid damage to nerve and blood vessels, it results in the patient's discomfort due to the plate or spinal rod is palpable. Moreover, the steel plate or spinal rod is not tightly attached to the fracture and the arm of force is large. Hence, the instability of internal fixation and the micro-movement in the fracture fragment may exist, which will interfere with the fracture healing and reduction loss. At present, the perspective that steel plate fixation can provide better stability than other fixation methods is accepted, because it firmly captures the fracture to avoid fracture re-displacement and provide large fixation strength [31].

The modified Stoppa approach has commonly been used and viewed as the therapy standard for anterior pelvic ring fixation, since Cole et al. [14] introduced this surgery in 1994. The therapy principles of the modified Stoppa approach primarily underline the anatomical reduction of the fracture and strong internal fixation with steel plates and screws. This approach can provide a large surgery field under direct visualization, which is helpful for accurate fracture reduction, adequate steel plate placement, and getting satisfactory clinical outcomes [14, 15, 36, 37]. Bible et al. [38] dissect ten cadavers using the modified Stoppa approach to quantify and describe the extent of the bony pelvis exposed. The results indicated this approach allows for exposure of 79% of the inner true bony pelvis including the entire pelvic brim and 80% of the quadrilateral surface, which can provide adequate anterior pelvic exposure for clamp and steel plate placement. Despite this approach having the abovementioned merits, some shortcomings exist following surgery. For instance, extensive dissection and stripping disrupt the surrounding blood supply and prolong the operation interval during the exposure and reduction of the fracture [14, 15]. This procedure greatly disrupts the surrounding blood, which may affect wound healing and bring huge pain to patients. Moreover, other complications include the iatrogenic femoral nerve or vascular injury during surgery, and wound infection [36, 39]. However, despite these limitations exist, it is proved that the modified Stoppa approach can indeed obtain satisfactory clinical rehabilitation. Thus, the modified Stoppa approach is viewed as a reference to assess whether the clinical functional outcomes of the MIPPO technique are excellent as it in this study.

The MIPPO technique was initiatively used for femoral shaft fracture fixation through two limited incisions and a percutaneous indirect reduction method [40, 41]. Based on this concept, we have begun to use minimally invasive methods for anterior pelvis fixation since 2013.

With respect to the steel plate placement, we fixated one end of the steel plate to the pubic ramus on one side of the pubic symphysis, and the other end of the plate to the pelvic medial border (outside of the arcuate line) toward the inner table of iliac wing, which differs from the traditional anterior pelvis fixation that fixated the latter to the arcuate line. Finally, a satisfactory and stable fixation was achieved by using several screws to fixate the steel plate to both ends of the fracture. In this study, the clinical outcomes of the MIPPO technique were demonstrated. The potential benefits of the MIPPO technique include minimal surgical trauma, relatively short duration of operation, and less intraoperative blood loss, while less complications and faster postoperative recovery.

Considering the surgical manipulation, our study indicated the MIPPO technique had a shorter operation time and lower bleeding volume compared to the modified Stoppa approach. This illustrated that the surgical trauma of the MIPPO technique was less. Long-time surgical procedure with much blood loss means high pressure for the cardio-vascular system and may cause some dangerous conditions such as hypothermia and coagulopathy for the elderly in particular. Hence, a fast and minimally invasive surgical procedure can effectively decrease the secondary trauma from the operation. The modified Stoppa approach needed to perform extensive soft tissue dissection for exposure of the fracture, which results in severe trauma for patients and continuous bleeding in the surgical wound. Secondly, the surgical exposure procedure of this approach took a long time to avoid neurovascular bundles (femoral nerve, femoral artery, and femoral vein, etc.), abdominal cavity, and urinary bladder injury. Notably, the corona mortis, the anastomotic branch between the inferior epigastric and the obturator vessel, needed to be cautiously cut and ligated. Thirdly, this approach required orthopaedic surgeons to grasp skilled knowledge of anatomy, and needed a long learning curve that brings anxiety to young surgeons. However, for the MIPPO technique, it needs to make two small incisions (about 3–5 cm), and passes through the subperiosteum of the anterior pelvic ring to establish a tunnel, which greatly reduces the surgical exposure. Next, a shaped steel plate was placed on top of the pubic rami aligned from the acetabular anterior wall toward the inner table of the iliac crest. The modification of plate placement can efficaciously avoid dissecting the neurovascular structures. The steel plate can safely pass through the subperiosteal tunnel, and avoid injuring the corona mortis. Du et al. [21] also studied the location relationship between the vessel and the steel plate placement to evaluate the safety of the corona mortis when the minimally invasive plate insertion in the treatment of anterior pelvis fracture. They concluded the maximum vertical distance between the corona mortis and the pubis was 12.6±3.0 mm, which allowed the plate and bone exfoliator safely passed during subperiosteal stripping. The above-mentioned modifications reduced the operational trauma and time.

At the follow-up period, postoperative hospital stays and ambulation time in the MIPPO technique group were shorter compared to the modified Stoppa approach. The potential cause may be the modified Stoppa approach exerting extensively open surgical trauma and great pain to patients, which contributes to the patients being afraid of early movement after surgery, and the postoperative rehabilitation exercise being delayed until the pain reduces. Conversely, the MIPPO technique adopts a percutaneous fixation through the dissection of two limited incisions, and generates less trauma and pain, which promotes the patient's early mobilization and recovery procedure. We also confirmed this cause by inquiring about the patients during hospitalization and the outpatient clinic. Regretfully, the pain scores of patients were not systematically recorded following surgery in two groups due to the essence of this retrospective study. Recently, the incidence of pelvic fractures has been raised among the elderly due to the fragility of bone quality [3, 42]. Consequently, the use of the minimally invasive technique results in early goes into the field and fast recovery, which contributes to reduce hospitalization complications such as pneumonia, urinary infection, and pressure sores, etc. There are thirty-eight patients (≥55 years) in our study and all of them got satisfactory outcomes. Finally, two groups of patients obtained satisfactory reduction quality of the fracture (100%) and functional scores. Most of the patients were satisfactory for functional recovery and returned to the pre-injured job and level of mobility after discharge.

The complication rate in the MIPPO technique group (15.0%) was lower than in the modified Stoppa approach (32.1%). One patient occurred the LFCN damage in the MIPPO technique group. The LFCN injury might be caused during the dissection of the lateral incision (the inner table of the ilium). Additionally, the modified Stoppa approach group included the occurrence of lateral inguinal hernia, deep wound infection, chronic pain, and nerve injury (the femoral nerve, obturator nerve, sciatic nerve, and LFCN damage). The modified Stoppa approach was susceptible to iatrogenic nerve or vessel injury and wound infection due to extensive dissection in the surgical area, which interferes with postoperative care and the patient's recovery. Hence, potential benefits of the MIPPO technique anterior pelvis fixation included decreased complications and faster recovery.

The limitations of this study exist. Firstly, the essence of the retrospective study may result in the presence of patient choice bias. Secondly, our analysis is based on the clinical data to evaluate the stability of fixation of two methods, lacking the support of the biomechanical

studies. Thirdly, the MIPPO technique has a limited treatment for Tile C2 or C3 pelvic fractures and severely displaced anterior wall or column acetabular fractures, whereas the modified Stoppa approach can effectively fix such fractures. Thus, Large and prospective controlled studies, as well as relative biomechanical studies will be needed in the future.

Conclusion

In conclusion, the MIPPO technique for the treatment of anterior pelvic ring fracture provides effective clinical results. This minimally invasive technique has advantages including little bleeding, short operation procedure, few complications, and fast rehabilitation. Hence, the MIPPO technique provides a new surgical option for anterior pelvis fixation, particularly fitting to part patients with resistance using the modified Stoppa approach.

Supplementary Information

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Supplementary Material 1

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Author contributions
Jianwen Li is the first author, and Weikai Zhang and Hui Huang are the corresponding authors. Dr. Hui Huang and Dr. Weikai Zhang designed this study. Jianwen Li, Lingxiao He, and Meipeng Zhu gathered relative clinical data. Moreover, Jianwen Li and Meipeng Zhu analyzed the data, while Jianwen Li and Lingxiao He wrote the paper. Finally, Dr. Hui Huang, Dr. Weikai Zhang, and Dr. Chengyan Xia reviewed and revised the paper.

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Data availability
The data analysed during the current study are not publicly available due to limitations of ethical approval involving the patient data and anonymity but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This study was approved by the Ethical Committee of Tongji Hospital, Tongji Medical College, Huazhong University of Science and Technology (registration-number: TJ-IRB20220625). All methods were performed in accordance with the Declaration of Helsinki. Written informed consent was obtained from all study participants and/or family members.

Consent for publication
Not applicable.**Competing interests**.

Competing interests
The authors declare no competing interests.

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