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Application of a posterior anatomical integrated locking compression plate in the treatment of posterior wall acetabular fractures

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Abstract

Background Traditional fixation methods for posterior wall acetabular fractures (PWAFs) typically require the utilization of multiple plates and intraoperative plate contouring, which are technically demanding and carry the risk of intra-articular screw penetration. A novel posterior anatomical integrated locking compression plate (PAILCP) has been designed to optimize these shortcomings. This study aims to evaluate the feasibility and effectiveness of the PAILCP fixation method for the surgical management of PWAFs.

Methods A total of 48 patients with PWAFs who were treated surgically in our department between January 2018 and December 2022 were selected for retrospective analysis. The 48 patients were classified into groups A (PAILCP fixation, $n = 25$) and B (traditional fixation, $n = 23$) according to different fixation methods. Fracture reduction quality, number of utilized plates, blood loss, surgical time, instrumentation time, hip function, and complications were compared between the two groups.

Results A total of 25 PAILCPs were used in group A, while 34 mini-T plates and 29 reconstruction plates were employed in group B. Compared to the patients in group B, those in group A had significantly shorter instrumentation time (−16 min) and surgical time (−23 min) as well as lower blood loss (−123 ml). However, no significant differences were observed in fracture reduction quality and hip function between the two groups. Additionally, the complication rate was slightly lower in group A (3/25 patients) than in group B (6/23); however, this difference was not statistically significant. Finally, follow-up examination revealed no main plate breakage, miniplate displacement, screw loosening, or intra-articular screw penetration in all patients.

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Conclusion The surgical treatment of PWAFs using the PAILCP fixation method results in shorter instrumentation and surgical time and lower blood loss than the traditional fixation method. Thus, the PAILCP fixation method is a promising alternative for PWAFs management, offering enhanced surgical ease and safety.

Keywords Posterior wall, Acetabular fracture, Anatomical, Integrated, Fixation method

Background

Posterior wall acetabular fractures (PWAFs) are the most common acetabular fracture pattern, accounting for 35–47% of all fractures in this region [1–3]. Despite the high incidence of PWAFs, these fractures still have poor outcome rates of up to 32% [1]. Most PWAFs are multifragmentary or have areas of impaction, whereas only 30% involve a single large fragment [4]. Considering that PWAFs are intra-articular fractures, selecting an appropriate fixation method is critical for achieving anatomical reduction and rigid fixation.

Classical fixation methods such as lag screw [3], reconstruction plate [5], and a combination of both [6, 7] have been confirmed to be effective for PWAFs with a single large fragment. Additional spring plates such as 1/3 tubular plates [8], mini-T plates [6, 7, 9], and mesh/box locking plates [10] may be required for the augmented fixation of acetabular rim fragments in cases of comminution. Moreover, combined posterior column fractures necessitate additional fixation with reconstruction plates [11]. These fixation methods have achieved satisfactory mechanical and clinical outcomes. However, the requirements of additional plate implanting and intraoperative plate contouring are time-consuming, laborious, and complicated, thereby potentially prolonging surgical duration and the risk of poor prognosis [12]. Furthermore, non-anatomical designs are not conducive to anatomic reduction and may lead to the risk of screw penetration [12]. Although 3D-printed pelvic models can be employed to pre-contour plates and simulate placement, the time and expense for the preoperative preparation limit their application. Lastly, combined fixation methods require multiple plates for stabilization, which are susceptible to loosening over time and potentially result in the loss of fracture reduction [9].

Here, we designed a novel posterior anatomical integrated locking compression plate (PAILCP) to resolve the previously mentioned shortcomings. The PAILCP is composed of a main posterior wall compression plate, two posterior column compression wing plates, and two marginal locking subplates, which allow the integrated fixation of the posterior wall (including marginal comminution) and column fractures. The plate, screw hole, and path are all designed in the safe placement area based on big data analysis of posterior wall morphology. Previous finite element mechanics analysis [11] has demonstrated that such a structure could provide a comparable mechanical stability compared to traditional fashion, even better in terms of stress distribution. This study aims to evaluate the feasibility and effectiveness of the PAILCP in the clinical setting by conducting a retrospective comparison of the outcomes of patients with PWAFs who were treated with PAILCP and traditional fixation methods.

Materials and methods

This retrospective cohort study was conducted on patients with PWAFs who were surgically treated at the Department of Orthopedics in the Union Hospital of Tongji Medical College of Huazhong University of Science & Technology between January 2018 and December 2022. The study was approved by the relevant Institutional Research Ethics Committee, and written informed consent was obtained from all included patients.

The patient inclusion criteria were as follows: (i) surgical management for isolated posterior wall acetabular fracture, posterior column and posterior wall acetabular fracture, and transverse and posterior wall acetabular fracture and (ii) age ≥ 18 years. The patient exclusion criteria were as follows: (i) old acetabular fractures (> 3 weeks); (ii) pathological or open PWAFs; (iii) combined femoral head or neck fractures; or (iv) follow-up of < 1 year or incomplete radiographic data.

A total of 48 patients with PWAFs were selected for the study analysis. According to the administered fixation method, the 48 patients were classified into groups A (PAILCP method, $n=25$) and B (traditional method, $n=23$). All patients underwent radiographic evaluation that included the CT scans, Judet and anteroposterior (AP) pelvis views. For patients with posterior hip dislocation, closed reduction followed by bone traction of supracondylar femoral was performed under general anesthesia in the emergency room within 12 h of injury.

Structure of the PAILCP

As shown in Fig. 1, the PAILCP (Double Medical Technology, Inc., Xiamen, China) is made by pure titanium (TA3) and comprises one main posterior wall compression plate, two posterior column compression wing plates, and two marginal locking subplates. The main plate, with its seven-hole long strip, extends from the anterior inferior iliac spine to the ischial tuberosity, covering the fracture sites of the classical, posterosuperior, and posteroinferior posterior wall of the acetabulum. The two-hole upper and one-hole lower wing plates directly connect to the main plate to provide adequate fixation for

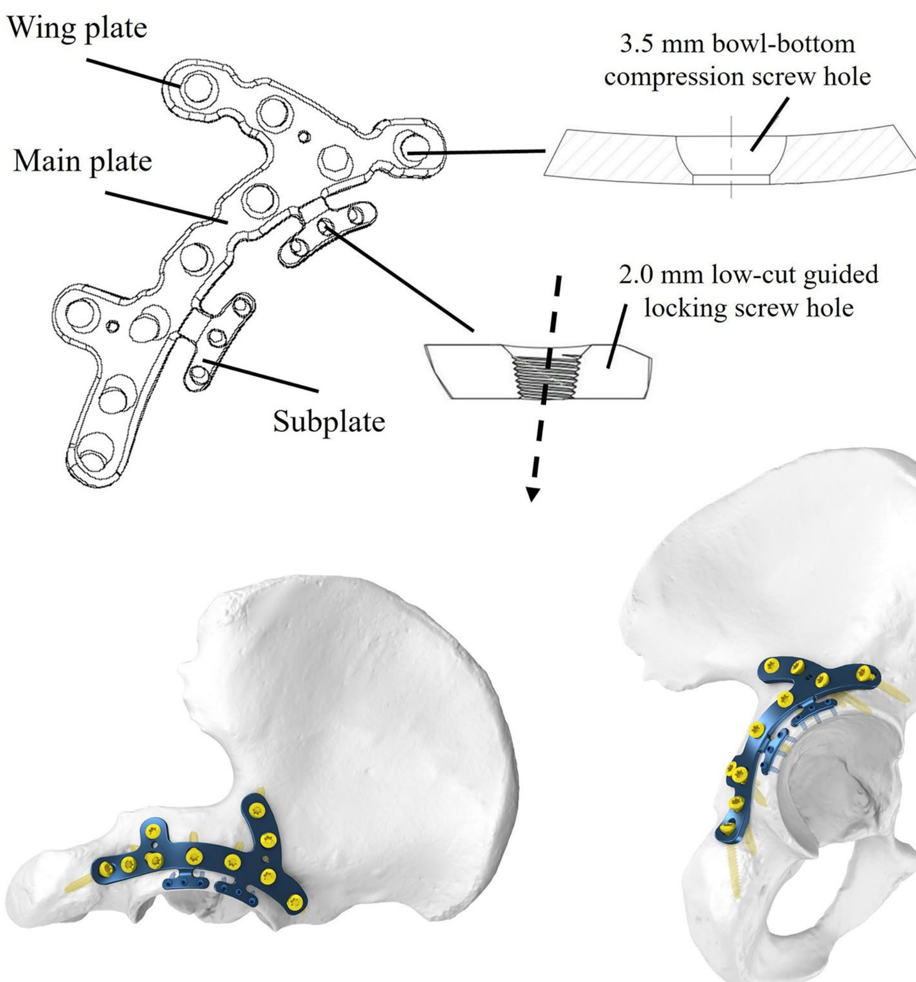

Fig. 1 Structure of the PAILCP. The PAILCP consists of a main plate, two wing plates, and two marginal subplates, which facilitate the integrated fixation of the posterior wall and column fractures. The bowl-bottom design of the compression screw holes (non-locking) on the main and wing plates allows for the complete tighten of the 3.5-mm diameter screws in the pre-designed direction. The marginal subplates have 2.0-mm low-cut guided locking screw holes to prevent screws from entering the joint cavity

the posterior column, including high-level posterior column and partial iliac fractures. The compression screw holes (non-locking) on the main and wing plates have a bowl-bottom design, which enables the complete tighten of the 3.5-mm diameter screws in the pre-designed direction to avoid screw loosening. Additionally, the two three-hole T-shaped subplates connect to the main plate via connecting rods, providing better resistance to rotational displacement of the rim fragments during early postoperative rehabilitation exercise. The marginal subplates are designed with 2.0-mm low-cut guided locking screw holes to avoid screw penetration into the joint cavity.

Surgical procedure

The same experienced trauma surgeon team performed all operations under general anesthesia on patients lying laterally on a radiolucent table. In both groups, the Kocher–Langenbeck approach was employed to expose the posterior wall and column of the acetabulum. Temporary fixation was performed using multiple Kirschner wires after fracture reduction. For large osteochondral free fragments, cancellous screws were used for preliminary fixation (Fig. 3e). In cases of marginal impaction, the compressed articular surface was required to be lifted, and autologous cancellous bone grafting was performed to enhance subchondral support using bone harvested from the greater trochanter (Fig. 4f). Bone defects were filled with demineralized bone matrix (DBM) (Fig. 4g).

In group A, PAILCP fixation was conducted with minimal need for intraoperative contouring due to the anatomical design. As illustrated in Fig. 4, the PAILCP was an anatomical match with a randomly 3D-printed acetabular model. The fixation strategy encompassed the following steps. Initially, screws 1, 2, and 3 were placed sequentially in the sciatic tuberosity, anterior inferior

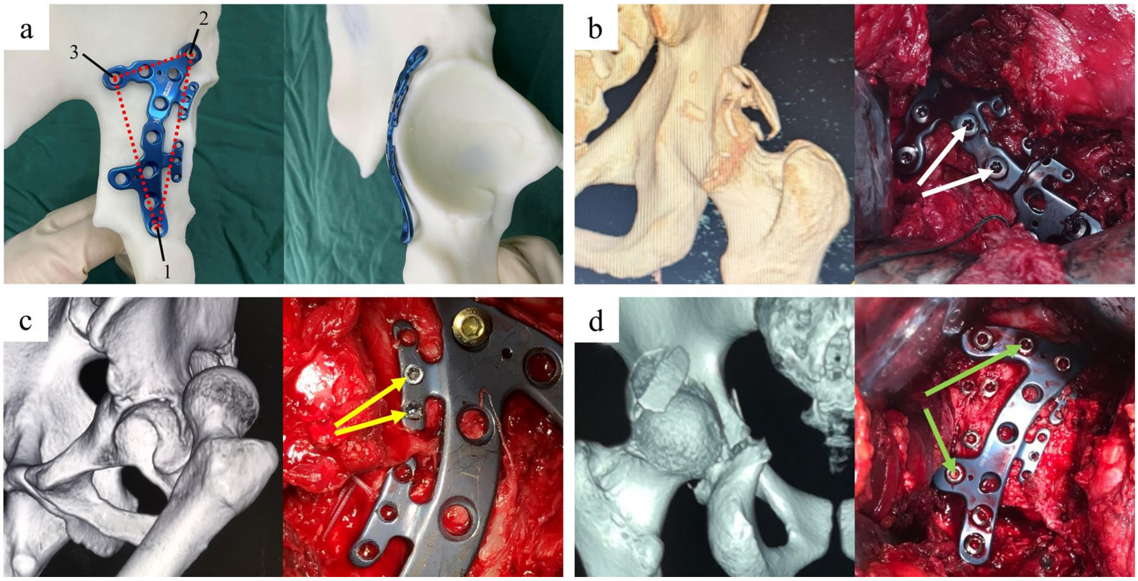

Fig. 2 Fixation strategy using the PAILCP. (**a**) PAILCP fixation requires limited intraoperative contouring due to the anatomical design. Screws 1, 2, and 3 are placed sequentially in the sciatic tuberosity, anterior inferior iliac spine, and sciatic support to form a stable triangular structure for initial fixation. (**b**) For a single large posterior wall fragment, compression screw fixation via the main plate (white arrow) is conducted. (**c**) The mini-locking screw holes (yellow arrow) in the subplates can be used to secure small fragments with mini-screws. (**d**) In patients with combined posterior column fractures, the structural stability can be enhanced by utilizing screws in the upper and lower wing plates (green arrow)

iliac spine, and sciatic support to form a stable triangular structure for the initial fixation of the plate. Subsequently, the remaining screws were placed according to the fracture characteristics. In cases of comminuted fractures, the 2.0-mm low-cut guided locking screw holes in the subplates allowed the insertion of mini-screws to secure the small marginal fragments. In combined posterior column fractures, additional strengthening was achieved by utilizing screws in the upper and lower wing plates. Two representative patients who underwent the PAILCP fixation method are presented in Figs. 2 and 3.

In group B, reconstruction and mini-T plates were contoured intraoperatively, followed by combined sequential fixation based on the distribution of the fracture lines. In particular, the mini-T plates refer to the metacarpophalangeal plates used for comminuted PWAFs in our trauma center. Given that the screw holes were orientated perpendicular to the mini-T plate, extremely short screws of 4–8 mm were typically used to avoid penetration of the joint.

In both groups, the severed short external rotator muscle and ruptured joint capsule were routinely sutured. In situations where suturing was limited due to the significant rupture of the joint capsule, the repair was facilitated using the micro screw holes on the subplates or mini-T plates as attachment points. Furthermore, 2−0 absorbable sutures were placed on the broken labrum, and 2.8-mm anchors were employed to repair the labrum (Fig. 2f). All these soft tissue repairs were performed to prevent postoperative posterior dislocation. Additionally, fracture reduction, plates and screws positioning were confirmed intraoperatively by fluoroscopy in the two groups. Finally, the incision was irrigated with diluted povidone iodine and closed with a layer-by-layer suture and a drainage tube.

Postoperative management

The identical management protocol was implemented for both groups A and B. All patients received anticoagulation with apixaban and infection prevention with cephalosporin. Postoperative X-ray images (Judet and AP views) and CT scans of the pelvis were obtained within a week. Postoperative rehabilitation training was supervised by specialized rehabilitation physicians. Follow-up examinations were conducted at 1, 2, 3, 6, and 12 months post-surgery and annually thereafter.

Outcome evaluation

The parameters evaluated in all patients included blood loss, instrumentation time, surgical time, fracture reduction quality, complications, and number of plates. The term 'instrumentation time' is defined as the duration required for plate fixation, which encompasses the processes of plate contouring, configuration adjustment, drilling of screw holes, measurement of screw lengths, plate locking, and fluoroscopy to confirm screw position. The quality of fracture reduction was categorized based on Matta's criteria [2] into poor (>3 mm), imperfect (2–3 mm), and anatomic (0–1 mm) grades. The modified Merle d'Aubigné score [13] was used at the final

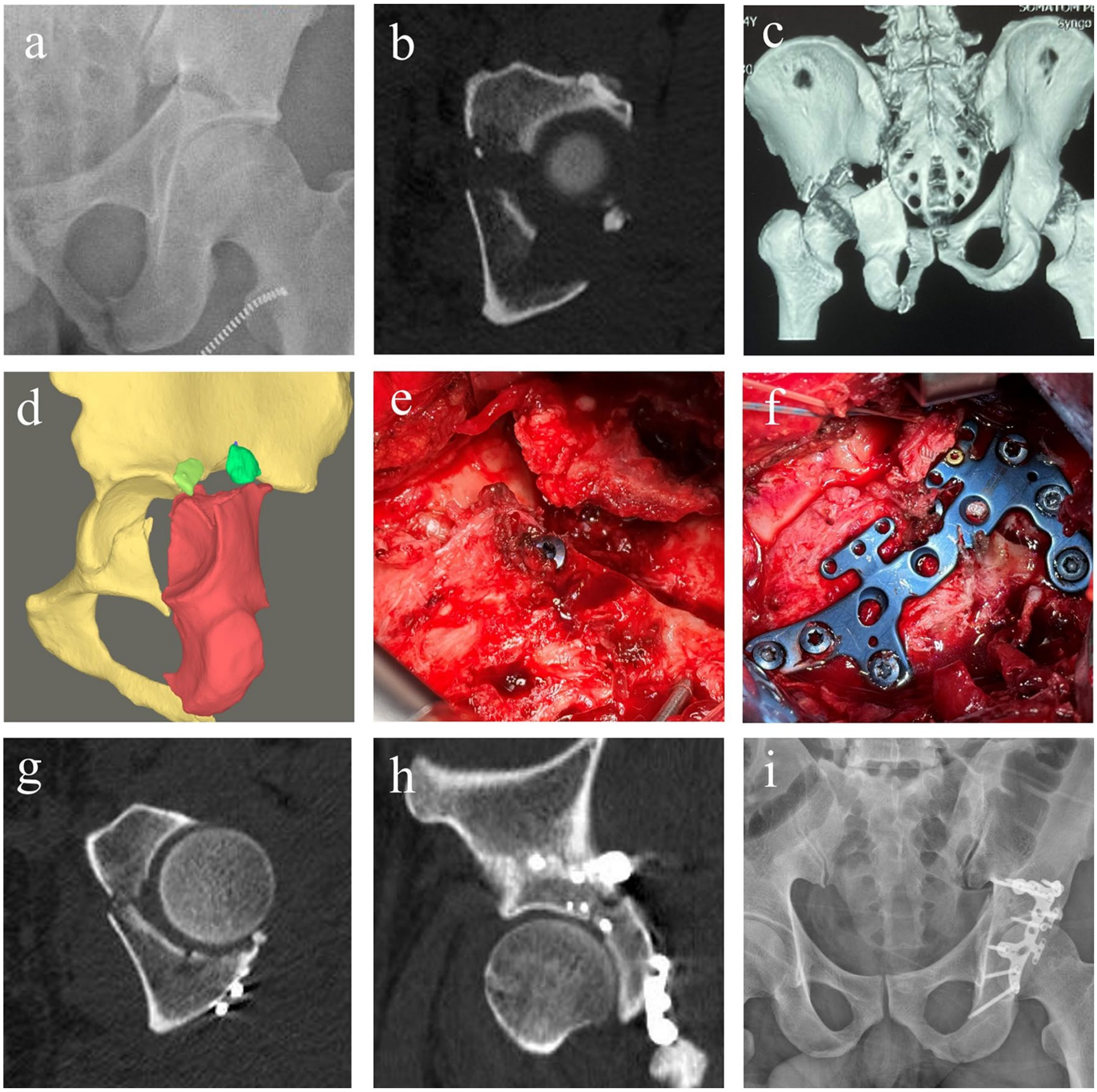

Fig. 3 A 44 years old man with a posterior column and posterior wall acetabular fracture underwent PAILCP fixation and labrum repair. The preoperative (**a**) AP view and (**b**, **c**) axial and 3D-CT images showed a posterior column and wall fracture of the left acetabulum with pronounced displacement. (**d**–**f**) The osteochondral free fragment (dark green) was initially fixed utilizing a cancellous screw, followed by the integrated fixation of the posterior column (red) and posterior wall (light green) fragments with the PAILCP. The torn labrum was repaired using an anchor. (**g**–**1**) Postoperative axial, sagittal CT images and AP view demonstrated anatomical reduction, along with good positioning of the mini-locking screws

follow-up to assess clinical outcomes, rating them as poor (<13), fair (13–14), good (15–17), or excellent (18).

Statistical analysis

The statistical analysis was conducted utilizing the SPSS software (version 21; IBM). Continuous variables with a normal distribution were articulated as the mean ± standard deviation and scrutinized via the t-test. Categorical and graded variables were depicted as relative (%) and absolute (n) frequencies and evaluated using the Chi-square and Mann–Whitney U tests, correspondingly. A p-value of less than 0.05 was deemed to hold statistical significance.

Results

General patient data

Table 1 presented the demographic data, time to surgery, preoperative sciatic nerve damage, hip dislocation, concurrent injuries, and fracture side and type for all patients. A comparative analysis of the preoperative variables between groups A and B revealed no statistically significant differences (all $p > 0.05$). The average follow-up periods for groups A and B were 24.52 ± 7.78 months and 27.74 ± 6.36 months, respectively, with no significant difference ($p = 0.125$). Furthermore, there was no significant disparity in fracture healing time between the two groups

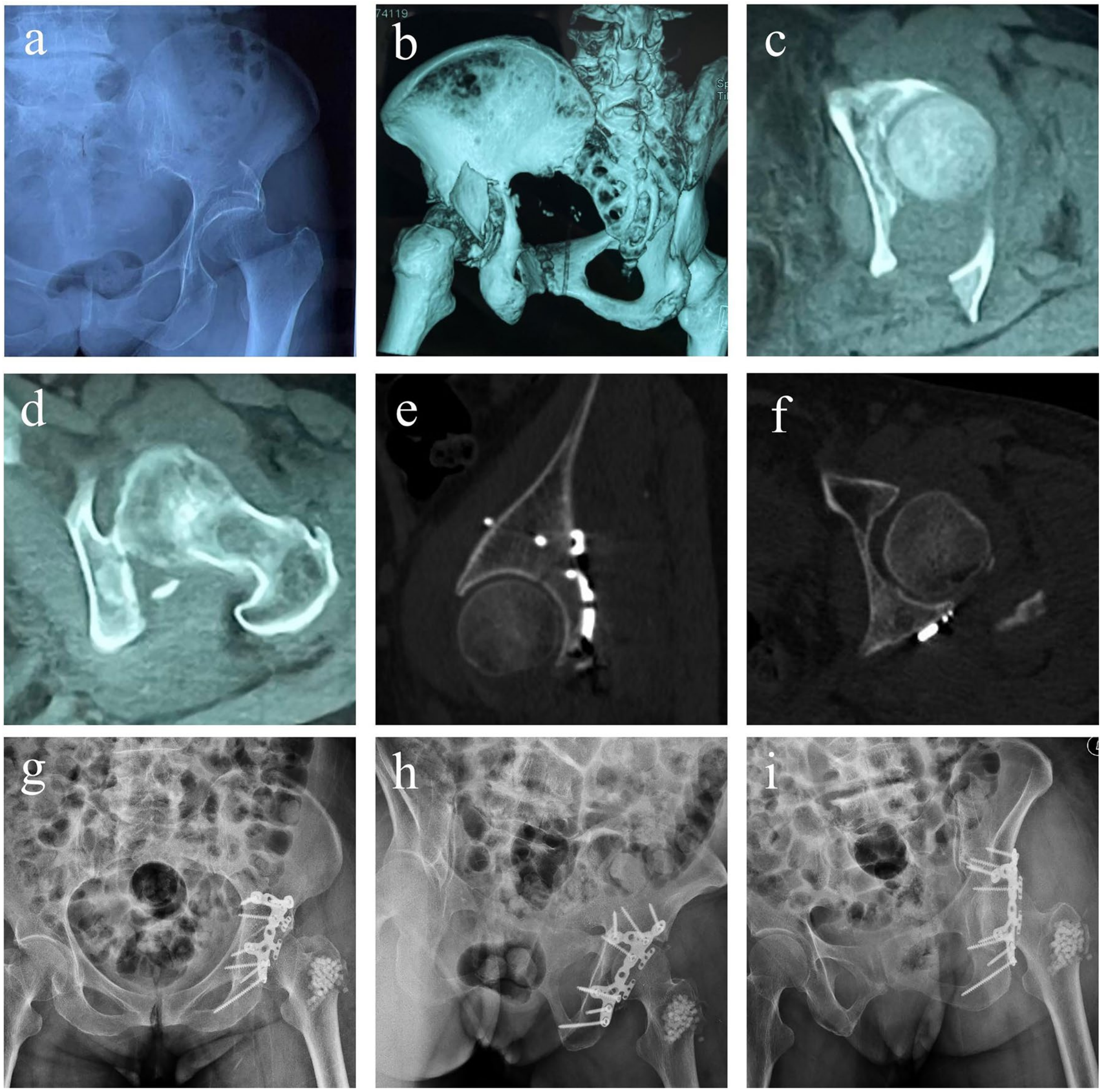

Fig. 4 A 69 years old woman with an isolated posterior wall acetabular fracture underwent PAILCP fixation and autologous bone grafting. The preoperative (**a**) AP view and (**b**) 3D-CT image indicated a posterior wall fracture of the left acetabulum with prominent displacement. (**c**, **d**) The preoperative axial CT images exhibited a single large fragment combined with marginal impaction. (**e**, **f**) Postoperative axial and sagittal CT images showed that the compressed articular surface was fully lifted, leading to the anatomical restoration of the articular congruence. (**g**–**i**) Postoperative AP and Judet views revealed a favorable positioning of the PAILCP

(15.56±2.47 weeks for group A and 16.91±2.19 weeks for group B, $p=0.051$).

Surgical outcomes

In the study, group A utilized a total of 25 PAILCPs, while group B employed 34 mini-T plates and 29 reconstruction plates. It was observed that the mean blood loss and surgical duration in group A were significantly less than those in group B, with values of 415.60±124.60 ml versus 539.13±149.21 ml ($p=0.003$), and 148.40±48.38 min versus 171.30±31.38 min ($p=0.060$), respectively. Additionally, the average instrumentation time in group A was notably shorter than in group B, with a mean of 20.52±5.21 min versus 36.30±9.72 min ($p<0.001$). Utilizing the Matta scoring system, it was observed that anatomic, imperfect, and poor grades were present in 21 (84.0%), three (12.0%), and one (4.0%) patient, respectively, in Group A. In contrast, Group B exhibited anatomic, imperfect, and poor grades in 19 (82.6%), two (8.7%), and two (8.7%) patients, respectively. Despite these differences, the quality of fracture reduction was statistically similar between the two groups ($p=0.848$) as shown in Table 2.

Table 1 Baseline characteristics of the patients

Variables	Group A (*n* = 25)	Group B (*n* = 23)	Test value	*P* value
Age (years)	45.68 ± 12.81	43.30 ± 12.61	t = 0.647	0.521
Gender				
Male	17	16	χ2 = 0.014	0.907
Female	8	7		
Mechanism of injury				
Fall from height	5	6	χ2 = 0.298	0.861
Traffic accident	17	14		
Other injuries	3	3		
Fracture side				
Left	14	10	χ2 = 0.751	0.386
Right	11	13		
Fracture type				
I-PWAF	15	17	χ2 = 1.187	0.553
PC-PWAF	6	3		
T-PWAF	4	3		
Concomitant injuries				
extremity fractures	6	5	χ2 = 0.570	0.903
spine fractures	3	4		
rib fractures	4	3		
craniocerebral trauma	2	1		
Hip dislocation	19	15	χ2 = 0.674	0.412
Pre sciatic nerve damage	6	4	χ2 = 0.317	0.573
Time to surgery (days)	8.52 ± 2.95	9.65 ± 3.68	t = − 1.182	0.243

I-PWAF: isolated posterior wall acetabular fracture; PC-PWAF: posterior column and posterior wall acetabular fracture; T-PWAF: transverse and posterior wall acetabular fracture

Table 2 Surgical outcomes of the patients treated with posterior anatomical integrated locking compression plate fixation (group A) and traditional fixation (group B)

Variables	Group A (*n* = 25)	Group B (*n* = 23)	Test value	*P* value
Number of plates				
PAILCP	25	-	NA	NA
Mini-T plate	-	34		
Reconstruction plate	-	29		
Blood loss (ml)	415.60 ± 124.60	539.13 ± 149.21	t = − 3.123	0.003
Instrumentation time (min)	20.52 ± 5.21	36.30 ± 9.72	t = − 7.090	0.000
Surgical time (min)	148.40 ± 48.38	171.30 ± 31.38	t = − 1.927	0.060
Reduction quality				
Anatomic	21 (84.0%)	19 (82.6%)	z = − 0.191	0.848
Imperfect	3 (12.0%)	2 (8.7%)		
Poor	1 (4.0%)	2 (8.7%)		

Table 3 Clinical outcomes of the patients treated with posterior anatomical integrated locking compression plate fixation (group A) and traditional fixation (group B)

Variables	Group A (*n* = 25)	Group B (*n* = 23)	Test value	*P* value
Hip function				
Excellent	18 (72.0%)	16 (69.6%)	z = − 0.285	0.775
Good	6 (24.0%)	5 (21.7%)		
Fair	1 (4.0%)	1 (4.3%)		
Poor	0 (0.0%)	1 (4.3%)		
Complications				
Yes	3 (12.0%)	6 (26.1%)	χ2 = 1.560	0.212
No	22 (88.0%)	17 (73.9%)		
Heterotopic ossification	2 (8.0%)	3 (13.0%)		
Posttraumatic arthritis	1 (4.0%)	2 (8.7%)		
Avascular necrosis of femoral head	0 (0.0%)	1 (4.3%)		

Clinical outcomes

Utilizing the modified Merle d'Aubigné score as a metric, the final follow-up of hip functional results were categorized as fair for one patient (4.0%), good for six patients (24.0%), and excellent for 18 patients (72.0%) in group A. In group B, the results were poor for one patient (4.3%), fair for one patient (4.3%), good for five patients (21.7%), and excellent for 16 patients (69.6%). A statistical analysis revealed no significant disparity in the hip function outcomes between the two groups ($p = 0.775$) as shown in Table 3.

Three patients were observed to develop posttraumatic arthritis, with one patient (4.0%) belonging to group A and two patients (8.7%) from group B. In group A, no instances of avascular necrosis of the femoral head were observed postoperatively. However, in group B, one patient (4.3%) developed avascular necrosis of the femoral head and subsequently required total hip arthroplasty two years after the initial operation. According to the Brooker classification, five patients exhibited class I heterotopic ossification (HO), which was asymptomatic. Of these five patients, two were from group A and three were from group B. Furthermore, no patients experienced any perioperative complications such as incision infection, iatrogenic sciatic nerve injury, or deep vein thrombosis, and no patients demonstrated main plate breakage, miniplate displacement, screw loosening, or intra-articular screw penetration on follow-up in the two groups (Table 3).

Discussion

Although numerous determinants may influence the clinical outcomes of patients who undergo surgical treatment for PWAFs, achieving anatomical reduction remains the most significant prognostic factor in this population [14–17]. Moreover, maintaining reduction with adequate fixation is particularly critical for performing early postoperative functional exercises until fracture healing [3]. The standard fixation method for PWAFs involves using 3.5-mm longitudinal reconstruction plates, often combined with lag screws for larger fragments or supplementary spring plating application for smaller comminuted fragments [4, 8, 18]. Such combined fixation methods require the utilization of multiple plates and intraoperative plate contouring, which can be technically demanding and carry the risk of screw penetration into the joint space due to the complex retro-acetabular surface [5, 10, 18]. Therefore, we improved the combined fixation of spring-locking plates and longitudinal reconstruction plates into an anatomical integrated fixation method, aiming to develop an easier and safer surgical management procedure for PWAFs. To our knowledge, this study is the first to conduct a retrospective cohort analysis comparing the surgical and clinical outcomes of anatomical single-plate fixation with those of traditional combined fixation in patients with various types of PWAFs.

In this study, satisfactory radiographic and clinical outcomes were obtained in both groups, with no significant differences between the two groups. The rates of anatomic reduction and excellent-to-good hip function were 84.0% and 96.0% in group A and 91.3% and 82.6% in group B, respectively. In line with the present results, findings from our previous studies [6, 7, 9, 11] have also demonstrated that mini-T plates combined with reconstruction plates are feasible and effective in treating posterior wall fractures, especially concentric comminuted type and rim avulsion fractures. Compared to the classical spring plates such as the 1/3 tubular plate, the mini-T plate was found to be more resistant to rotation and could be fixed with locking screws, thus preventing fracture displacement during postoperative hip movement. Furthermore, “total repair” was achieved in all patients through not only the compression and strong fixation of the fragments but also via the repair of the joint capsule, labrum, and other soft tissues. One of the crucial components in the soft tissue repair was the mini-T plates, where its micro holes were used as suture attachment points to assist in repairing the joint capsule and labrum. All these findings suggest that the total repair of the posterior wall contributes to preventing further postoperative dislocation.

Our study revealed that the patients who underwent PAILCP fixation had better surgical outcomes than those treated using the traditional method, as evidenced by lower blood loss and shorter instrumentation and surgical time (all $p<0.05$). These results can be explained by several possible factors. First, the PAILCP was anatomically designed to match the complex retro-acetabular surface, thereby having minimal requirement for intraoperative plate contouring. The average time for the intraoperative contouring of plates has been reported to be 20 min/plate in a study by Shen et al. [19] and 9 min/plate by Maini et al. [20] Correspondingly, our study showed that the patients in group A who were treated with anatomically designed plates had a significantly shorter instrumentation time (−16 min) than those in group B who received intraoperatively contoured plates. Second, the PAILCP featured an integrated, single-plate design that drew on features of mini-T and longitudinal reconstruction plates, thus allowing the simultaneous fixation of the posterior wall and column of the acetabulum. In this study, 34 mini-T plates and 29 reconstruction plates were utilized in group A ($n=23$) through the combined fixation method, while only 25 PAILCPs were employed in group A ($n=25$) with the integrated fixation method. Compared to combined fixation, integrated fixation was demonstrated to reduce surgical time (−23 min) and blood loss (−123 ml). Finally, the screw holes and paths of the PAILCP were designed with specific directions to ensure screw placement in safe areas. Although intra-articular screw penetration was not observed among the patients in both groups, additional screw angle adjustment and fluoroscopic confirmation were necessary in the traditional method [8, 18]. Prior researchers have also indicated that safe screw placement can be accomplished using computer-aided preoperative planning or pre-surgery with 3D-printed models [6, 7, 9, 12, 21]. However, the technical requirements, time, and expenses involved cannot be ignored, particularly in emergencies.

The current study has a few limitations that should be considered. This study was a single-center retrospective investigation with a relatively small sample size. Therefore, further multi-center prospective randomized controlled trials with large sample sizes are essential to ascertain the role of the novel PAILCP method in PWAFs management. Although finite element analysis and clinical analysis have confirmed the mechanical stability of the PAILCP, comprehensive mechanical evidence is still required via standard biomechanical tests of sawbones or cadaver specimens.

Conclusion

The PAILCP method is an effective and feasible procedure that facilitates the adequate fixation of various types of PWAFs. Compared to traditional fixation, the PAILCP fixation leads to shorter instrumentation and surgical time and lower blood loss during the surgical treatment of PWAFs. Consequently, the PAILCP fixation method is a potentially suitable alternative for managing PWAFs that augments surgical ease and safety.

Abbreviations

PWAFs Posterior wall acetabular fractures
3D Three-dimensional
PAILCP Posterior anatomical integrated locking compression plate
AP Anteroposterior
CT Computerized tomography
DBM Demineralized bone matrix
LMWH low molecular weight heparin
HO Heterotopic ossification

Author contributions
JC, GH, KC and YX designed the study. PX followed up with the patients and collected the relevant data. XG analyzed and interpreted the data. JC, GH, XG and KC performed the surgery. JC and YX wrote the manuscript. The authors read and approved the final manuscript.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
This study was approved by the ethics committee of Union Hospital, Tongji Medical College, Huazhong University of Science & Technology; All patients signed the informed consent to participate in the study.

Consent for publication
The authors affirm that patients provided informed consent regarding publishing their data and images.

Competing interests
The authors declare no competing interests.

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