

CLINICAL ARTICLE

Single Ilioinguinal Approach to Treat Complex Acetabular Fractures with Quadrilateral Plate Involvement: Outcomes Using a Novel Dynamic Anterior Plate–Screw System

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Objectives: To evaluate the efficacy and safety of a novel fixation technique referred to as the dynamic anterior plate–screw system for quadrilateral plate (DAPSQ) for complex acetabular fractures with quadrilateral plate involvement through the single ilioinguinal approach.

Methods: A total of 32 patients with acetabular fractures, selected between January 2009 and March 2016, were managed by DAPSQ with “quadrilateral screws” through single ilioinguinal approach. The primary outcomes measure was the reduction quality evaluated according to the Matta radiological criteria, and the functional outcomes were evaluated by the modified Merle d’Aubigné score at the last follow-up. Secondary outcomes were postoperative complications and intraoperative conditions included, for instance, operation time and blood loss.

Results: Of these 32 consecutive patients, 19, 9, and 4 were classified as both columns, anterior column posterior hemi-transverse, and T-shaped fractures, respectively, and with an average of 47 months’ follow-up. Anatomic reduction was obtained in 19 cases (59%), imperfect reduction in 9 cases (28%), and poor reduction in 4 cases (13%). The modified Merle d’Aubigné scores were excellent in 15 cases (47%), good in 13 cases (41%), fair in 2 cases (6%), and poor in 2 cases (6%). Three cases sustained temporary lateral femoral cutaneous nerve injuries. One patient had a superficial wound infection that resolved after debridement. Five patients had posttraumatic arthritis; one of them underwent total hip arthroplasty at 46 months. No cases had quadrilateral screws entering the hip joint.

Conclusion: The use of DAPSQ with quadrilateral screws is an effective and safe choice for complex acetabular fractures with quadrilateral plate involvement through the single ilioinguinal approach.

Key words: Acetabular fracture; Acetabulum reconstruction; Ilioinguinal approach; Quadrilateral

Introduction

In the past 10 years, with the rapid development of the construction and transportation industry in China, the incidence of acetabular fractures due to high-energy trauma has been increasing. To allow early rehabilitation, to improve

functional outcomes, and to decrease the risk of post-traumatic arthritis, operative reduction and stabilization have become the “gold standard” for displaced and unstable acetabular fractures^{1,2}. Through long-term clinical practice, we have found that apart from the simple anterior and posterior

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Disclosure: The authors have no commercial or any other associations that might pose a conflict of interest in connection with the submitted article. Received 14 January 2020; accepted 6 February 2020



wall fractures, there are other types of acetabular fractures, such as those involving both columns, anterior column posterior hemi-transverse (ACPHT) fractures and T-shaped fractures, that may involve medial wall fractures of the acetabulum (quadrilateral plate)³⁻⁵. Although quadrilateral plate fractures are not formally considered as a separate parameter for the classification of acetabular fractures, due to the deep location and many important surrounding blood vessels and nerves, they have been considered as an important factor affecting surgical complexity^{6,7}.

With the latest advances in surgical methods, both direct and indirect reduction techniques have been implemented in surgical reconstruction. Implants are currently being used to address the reduction and fixation challenges of this particular anatomical area. However, it is extremely difficult to fix the quadrilateral plate directly using screws, and slightly improper manipulation can cause screws to penetrate into the hip. To overcome these problems, several authors have proposed new fixing strategies, including an infrapectineal plate and several novel quadrilateral surface buttress or spring plates to support quadrilateral plate⁸⁻¹⁰. However, the abovementioned fixation methods cannot directly fix the fracture fragments of quadrilateral plate, which may reduce the reliability of fixation.

In view of these concerns, we have developed a new technique using a specially shaped reconstruction plate with several dynamic pressurized buttress screws for quadrilateral plate (named quadrilateral screws) according to the anatomical and biomechanical features of the acetabulum, and material and mechanical properties of the reconstruction plate. This internal fixation system has been used in our hospital for more than 10 years. It is called the dynamic anterior plate-screw system for quadrilateral plates (DAPSQ) and has been patented in China (No. ZL 2013 2 0106378.0)¹¹. The primary objective of this article is to report on the technical aspects, radiological and functional outcomes, and complications of our team's experience with DAPSQ, and to determine the feasibility of only using a single ilioinguinal approach in the treatment of complex acetabular fractures involving the quadrilateral plate.

Materials and Methods

All procedures were approved by the medical ethical committee of the hospital. Written informed consent was obtained from all patients. Between January 2009 and March 2016, 32 patients treated with "quadrilateral screws" were enrolled in our study group. These 32 patients were part of a cohort of 125 patients treated by DAPSQ at our Level I trauma center during this time.

Inclusion and Exclusion Criteria

Inclusion criteria were: (i) fresh fractures (<3 weeks); (ii) men or women aged 18 to 75 years old; (iii) fixation with DAPSQ through a single ilioinguinal approach; and (iv) complex acetabular fractures involving the quadrilateral plate. Exclusion criteria were: (i) open or pathologic

acetabular fractures: (ii) patients with pre-existing avascular necrosis of the femoral head; (iii) combination with severe lung and heart diseases, or preoperative American Society of Anesthesiologists (ASA) grade \geq IV; and (iv) complicated with posterior wall fracture of acetabulum which needs the combination of Kocher-Langenbeck approach.

Retrospective Case Series Study

Patient data was collected in a dedicated acetabular fracture database by investigators who were not involved in the initial intervention. All patients were evaluated preoperatively and postoperatively with roentgenograms including anterior-posterior (AP) views and Judet views (iliac and obturator oblique views), along with 2-D CT and 3-D CT reconstruction to assess the fracture pattern according to the Judet and Letournel classification system¹². Preoperative demographics and characteristics of patients, including gender, age, mechanism and side of injury, fracture type, and concomitant injuries, are summarized in Table 1.

Surgical Technique

All operations were performed with the cooperation of two senior surgeons using general anesthesia. Surgery was performed with the patient positioned supine on a radiolucent table. The ipsilateral buttock was slightly elevated, and the ipsilateral lower extremity was extended naturally for the flexion and external rotation of the hip during the operation.

A standard ilioinguinal approach, as described by Letournel¹³, was performed to gain access to the acetabular anterior column, the pelvic boundary, and the upper part of the quadrilateral plate. Flexion of the hip and knee could help to relieve the tension of the psoas muscle and the iliac vessels and increase the exposure. The soft tissue was separated using a curved periosteal elevator to expose the fractures of the quadrilateral plate, preserving the integrity of the sacrotuberous and sacrospinous ligaments. From the middle or the inner window, the fracture fragments of the anterior acetabular wall could be pulled forward, or the fracture fragments of the quadrilateral plate extracted into the pelvis so that the broken fragments and hematomas in the hip joint cavity could be cleaned.

After the exposure and cleaning work were completed, the first step was to reduce the medial displacement of the femoral head by manual traction on the leg or with the assistance of mechanical lateral traction via a Schanz pin in the proximal femur. The continuity of the pelvic ring from proximal to distal was then restored, which can be done by means of instruments or manipulation, and temporarily fixed with the Kirschner wire or plate. Next, (two-claw or three-claw) reduction forceps were used to reduce the fractures of the quadrilateral plate.

Then a straight reconstruction plate was pre-contoured into an S-shape or a C-shape; the detailed shaping steps are described in Fig. 1. The molding plate was placed along the pelvic rim, through the pubic region, the upper edge of quadrilateral plate, and the iliac region. After being well

TABLE 1 Patients' clinical details

Patient	Gender	Age (years)	Mechanism of injury	side	Fracture type	Time to surgery (days)	Concomitant injuries	
1	Male	47	Fall from height	L	ACPHT	3	—	
2	Male	59	Fall from height	R	ACPHT	8	Ipsilateral ulnar olecranon fracture	
3	Female	36	Traffic accident	L	Both columns	6	Ipsilateral rib fracture, head injury	
4	Male	51	Fall	L	ACPHT	6	Ipsilateral ulnar and radius fracture	
5	Male	52	Fall from height	L	Both columns	8	—	
6	Male	45	Traffic accident	L	ACPHT	10	Ipsilateral rib and femoral shaft fracture	
7	Female	59	Traffic accident	R	Both columns	12	—	
8	Female	66	Traffic accident	L	ACPHT	5	—	
9	Male	42	Fall from height	L	Both columns	8	—	
10	Female	63	Traffic accident	L	Both columns	11	Ipsilateral hip dislocation	
11	Male	36	Fall from height	R	ACPHT	5	—	
12	Male	54	Traffic accident	R	Both columns	9	—	
13	Female	43	Traffic accident	L	T-shaped	9	Ipsilateral hip dislocation	
14	Male	47	Traffic accident	R	T-shaped	7	—	
15	Male	41	Fall from height	L	T-shaped	4	Ipsilateral distal radial fracture	
16	Male	61	Fall	R	Both columns	12	Ipsilateral tibial plateau fracture, head injury	
17	Male	50	Traffic accident	R	Both columns	11	Ipsilateral rib and ankle fracture	
18	Female	55	Traffic accident	L	Both columns	7	Lumbar fracture	
19	Male	49	Fall from height	L	Both columns	9	—	
20	Female	61	Traffic accident	L	T-shaped	11	—	
21	Female	47	Fall from height	R	ACPHT	7	Ipsilateral rib fracture	
22	Female	52	Traffic accident	L	Both columns	5	—	
23	Male	42	Fall from height	R	ACPHT	7	Ipsilateral ulnar olecranon and intertrochanteric fracture	
24	Male	47	Fall from height	R	Both columns	6	—	
25	Female	31	Traffic accident	R	Both columns	8	Bladder injury and lumbar fracture	
26	Male	45	Fall from height	R	Both columns	13	Lumbar fracture	
27	Male	34	Traffic accident	L	ACPHT	17	—	
28	Male	27	Fall from height	R	Both columns	15	—	
29	Male	56	Traffic accident	L	Both columns	9	Head injury	
30	Male	19	Fall from height	L	Both columns	13	—	
31	Female	37	Traffic accident	R	Both columns	8	Ipsilateral ankle fracture	
32	Female	40	Traffic accident	L	Both columns	6	Ipsilateral rib fracture and hip dislocation	
Average		47				9		
Range		19–66				3–17		

Patient	Operation time (min)	Blood loss (mL)	Recon and quadrilateral screws used	Follow-up (months)	Grades	MAP score	Complications
1	185	400	16 holes recon, 3 quadrilateral screws	24	2–3 mm	16 (5/5/6)	—
2	342	900	16 holes recon, 3 quadrilateral screws	37	2–3 mm	18 (6/6/6)	—
3	210	500	16 holes recon, 3 quadrilateral screws	49	<1 mm	18 (6/6/6)	LFCNI
4	397	600	12 holes recon, 3 quadrilateral screws	48	<1 mm	17 (5/6/6)	—
5	191	800	12 holes recon, 3 quadrilateral screws	38	<1 mm	18 (6/6/6)	—
6	280	1000	14 holes recon, 2 quadrilateral screws	38	<1 mm	16 (5/6/5)	—
7	237	600	14 holes recon, 3 quadrilateral screws	37	2–3 mm	15 (5/5/5)	LFCNI
8	355	800	14 holes recon, 3 quadrilateral screws	58	<1 mm	16 (5/5/6)	—
9	217	600	16 holes recon, 4 quadrilateral screws	67	<1 mm	18 (6/6/6)	—
10	206	700	16 holes recon, 4 quadrilateral screws	45	>3 mm	14 (5/4/5)	Posttraumatic arthritis
11	255	800	14 holes recon, 4 quadrilateral screws	37	<1 mm	16 (5/6/5)	—
12	242	500	16 holes recon, 4 quadrilateral screws	35	2–3 mm	15 (5/5/5)	—
13	320	800	16 holes recon, 3 quadrilateral screws	55	>3 mm	10 (3/4/3)	Posttraumatic arthritis (THA)

TABLE 1 Continued

Patient	Operation time (min)	Blood loss (mL)	Recon and quadrilateral screws used	Follow-up (months)	Grades	MAP score	Complications
14	188	400	12 holes recon, 3 quadrilateral screws	34	<1 mm	18 (6/6/6)	—
15	342	1000	12 holes recon, 3 quadrilateral screws	36	>3 mm	15 (5/5/5)	—
16	309	700	14 holes recon, 3 quadrilateral screws	39	2-3 mm	12 (3/4/5)	Posttraumatic arthritis
17	295	1200	14 holes recon, 3 quadrilateral screws	44	<1 mm	18 (6/6/6)	—
18	246	600	14 holes recon, 2 quadrilateral screws	35	<1 mm	16 (5/5/6)	—
19	255	500	15 holes recon, 4 quadrilateral screws	53	<1 mm	18 (6/6/6)	—
20	267	1000	12 holes recon, 2 quadrilateral screws	48	2-3 mm	18 (6/6/6)	—
21	225	800	11 holes recon, 3 quadrilateral screws	57	<1 mm	17 (6/5/6)	LFCNI
22	185	500	13 holes recon, 4 quadrilateral screws	64	2-3 mm	18 (6/6/6)	—
23	198	600	14 holes recon, 4 quadrilateral screws	55	<1 mm	18 (6/6/6)	Superficial wound infection
24	190	600	13 holes recon, 3 quadrilateral screws	35	<1 mm	18 (6/6/6)	—
25	362	1200	14 holes recon, 4 quadrilateral screws	60	<1 mm	15 (5/5/5)	Posttraumatic arthritis
26	240	600	14 holes recon, 3 quadrilateral screws	51	2-3 mm	16 (5/6/5)	—
27	182	500	13 holes recon, 4 quadrilateral screws	68	<1 mm	18 (6/6/6)	—
28	227	700	14 holes recon, 2 quadrilateral screws	84	>3 mm	13 (4/4/5)	Posttraumatic arthritis (THA)
29	210	600	18 holes recon, 3 quadrilateral screws	32	<1 mm	18 (6/6/6)	—
30	256	800	13 holes recon, 4 quadrilateral screws	44	2-3 mm	17 (6/5/6)	—
31	189	400	12 holes recon, 3 quadrilateral screws	38	<1 mm	18 (6/6/6)	—
32	192	600	12 holes recon, 3 quadrilateral screws	58	<1 mm	18 (6/6/6)	—
Average	250	697		47			
Range	182–397	400–1200	11–18 holes recon, 2–4 quadrilateral screws	24–84	—	—	—

ACPHT, anterior column posterior hemitransverse type; LFCNI, lateral femoral cutaneous nerve injury; THA; total hip arthroplasty.

placed, both ends of the plate were upturned; there were not positioned firmly against the bone surface but could be pressed onto the bone surface during nailing using special instruments. The placement sequence of screws followed certain rules (Fig. 2). Screws on the iliac and pubic region were first fixed to stabilize the acetabular anterior column. Then the quadrilateral screws, in turn, were placed on the medial surface of the quadrilateral plate using special nailing methods (Fig. 3). The quadrilateral screws were inserted along the pelvic brim and parallel to the surface of the quadrilateral plate, with only 1/3 to 1/2 the transverse diameter of the quadrilateral screw penetrating into the bone to avoid entering the joint cavity. In the process of nailing, the torsion and elastic recoil of the plate could provide a strong holding

force for the quadrilateral screws. It is also important to check by hand that the quadrilateral screw is located on the quadrilateral surface and the length the screw is at least 10 mm beyond the fracture line of the quadrilateral plate, which could be achieved through the second window using the ilioinguinal approach (Fig. 4).

In addition, for patients with iliac wing fractures, achieving anatomic reduction of the fracture is the first priority. An arcuate pre-bent reconstruction plate was fixed along the iliac crest to reconstruct the normal curve of the iliac fossa, which was the foundation for a good reduction of anterior and posterior column fractures. Finally, the reduction of fractures, the length, and the position of the plate and screws were carefully checked by C-arm. After acquiring

fluoroscopy, the operation area was flushed completely prior to wound closure to decrease the incidence of heterotopic ossification.

Postoperative Management

Postoperative prophylactic antibiotics were used regularly for 3 to 5 days. A drainage tube was used for 1 to 3 days and removed when the drainage flow within 24 h remained <20 mL. All patients underwent pelvic X-rays, including standard AP, Judet views, and 3D CT reconstruction on the third postoperative day. Rehabilitation was initiated after the patient awoke from anesthesia, including isometric contraction training of the lower limbs, and passive and active ipsilateral hip flexion or extension motion. The abovementioned non-weight-bearing exercises were performed for 4 weeks. Patients were encouraged to carry out protected weight-bearing exercises with a pair of crutches or a walker 4–8 weeks after the operation. Thereafter, full weight-bearing was allowed. All patients obtained rehabilitation instructions from doctors and physiatrists during hospitalization and follow-up.

Outcome Measures

Operation time, blood loss, and reduction quality were evaluated before discharge. Operation time was defined as the duration from incision to the closure of skin. Blood loss was assessed by used gauze and the amount of blood in the suction bottle. The reduction quality of the acetabulum was evaluated by three senior orthopaedic surgeons according to the Matta radiological criteria¹⁴. After discharge, all patients were required to undergo regular outpatient review and follow-up at 1 month, 2 months, 3 months, 6 months, 1 year, and yearly thereafter. During the follow-up, clinical function, radiographic progress, fracture healing, and complications were assessed and recorded. Clinical functions were evaluated using the modified Merle d'Aubigné score¹⁵ at the last follow-up. Complications that were analyzed included lateral femoral cutaneous nerve injury (LFCNI), surgical site infections, posttraumatic arthritis, avascular necrosis of the femoral head, screws penetrating into the hip joint cavity, and implant failure.

Matta Grading Score

Matta grading scores were classified as anatomic (0–1 mm displacement), satisfactory (2–3 mm displacement), or unsatisfactory (>3 mm displacement) based on millimeters of residual displacement evaluated from standard AP and Judet views.

Modified Merle d'Aubigné Score

This hip scoring system was mainly evaluated from three aspects, including pain, walking, and range of activity. The scores were categorized as excellent (18 points), good (15–17 points), fair (13 or 14 points), or poor (<13 points).

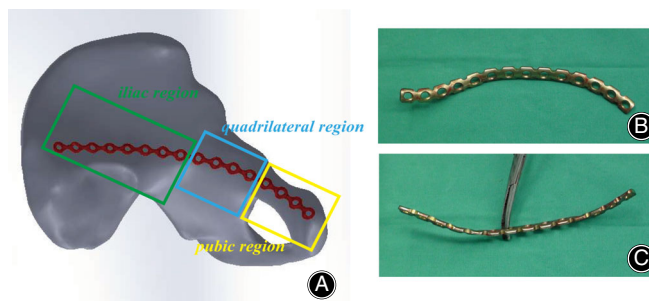


Fig. 1 The components and shaping method of dynamic anterior plate-screw system for quadrilateral plates (DAPSQ). According to the placement position on the pelvis, DAPSQ was divided into three parts: the iliac region, the quadrilateral region, and the pubic region (A), and the screws placed in the quadrilateral region were called “quadrilateral screws.” First, we chose a straight reconstruction plate of the appropriate length and pre-contoured it into an S-shape or C-shape. Then the plate was shaped according to the partition of the three regions. Both ends of the plate were reverse twisted and upturned, and the slope of the plate in the quadrilateral region was slightly incline to the plevis (B, C).

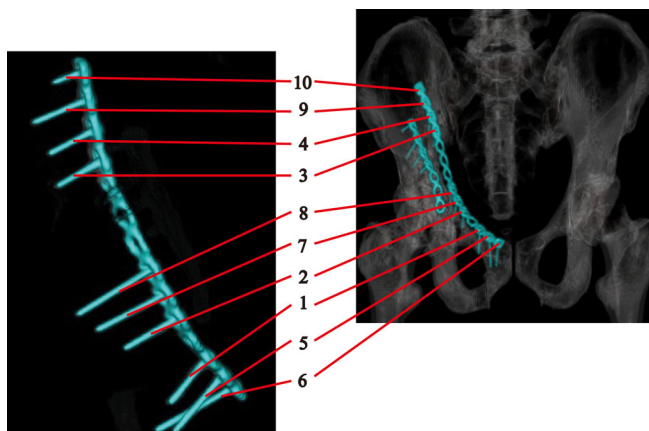


Fig. 2 The placement sequence of screws. After being placed in a proper position on the pelvic brim, the reconstruction plate was pressed onto the bone surface using special instruments. The 1[#] screw is fixed on the superior ramus of the pubis, and then the 2[#] quadrilateral buttress screw was placed parallel to the surface of quadrilateral plate. We pushed the plate of the iliac region away from the pelvic rim so that the 2[#] buttress screw could fit snugly against the medial surface of the quadrilateral plate. Next, the 3[#] and 4[#] screws were fixed on the iliac wing, and the 5[#] and 6[#] screws were fixed on pubic bone to stabilize the acetabular anterior column. At this time, the plate of the quadrilateral region was attached tightly against the upper edge of the quadrilateral plate. Then the 7[#] and 8[#] quadrilateral screws, in turn, were placed on the medial surface of the quadrilateral plate using special nailing methods (Fig. 3), and, finally, the 9[#] and 10[#] screws were placed.

Statistical Analysis

Statistical analysis was performed using the Statistical Package for the Social Sciences software (version 19.0, USA). Descriptive statistics were used to describe clinical characteristics.

Results

Patients' Information

Of these 32 consecutive patients, 20 were male and 12 female, with an average age of 47 years (range, 19 to 66 years). Fractures were classified as both columns in 19, ACPHT in 9, and T-shaped in 4. All cases involved fractures of the quadrilateral plate and some cases had anteromedial displacement of the femoral head. All patients underwent surgery through a single ilioinguinal approach and the average duration of preoperative management was 9 days (range, 3 to 17 days).

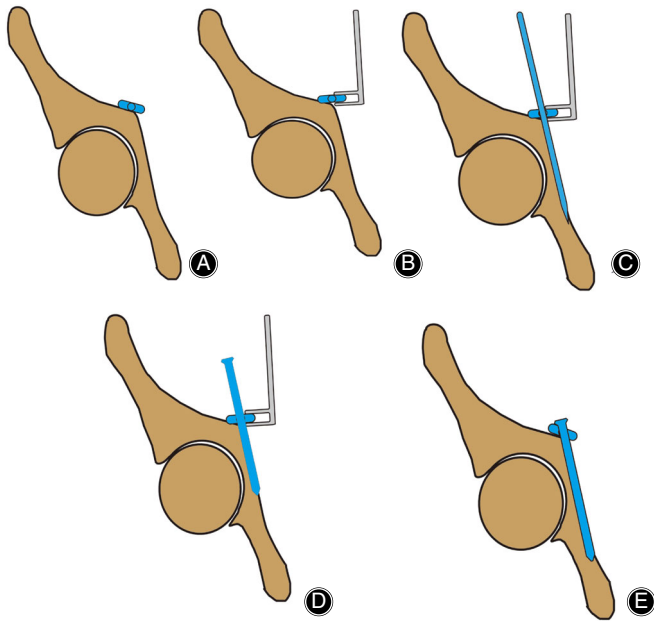


Fig. 3 Structure and working principle of the quadrilateral screws. (A) Step one: After the screw placement of the iliac and pubic region is completed, the plate of the quadrilateral region is attached tightly against the upper edge of quadrilateral plate. (B) Step two: Using a special instrument to lift the internal edge of the plate, the curvature should be slightly smaller than the arcuate line so that the 1/3 to 1/2 of the screws hole are exposed to the inner edge of the pelvic brim. (C) Step three: Drilling holes along the surface of the quadrilateral plate. In this process, the drill bit should be prevented from entering the bone completely. (D) Step four: Insert the quadrilateral screw along the pelvic brim and parallel to the surface of the quadrilateral plate, and only insert the 1/3 to 1/2 transverse diameter of the quadrilateral screw into the bone to avoid entering the hip. (E) Step five: After the screw placement is completed, the torsion tool for the plate is removed, and the plate can naturally bounce back to sit tightly against the upper edge of the quadrilateral plate again.

Operative Details

The average operation time was 250 min (range, 182 to 397 min), and the average blood loss was 697 mL (range, 400 to 1200 mL). Between 2 and 4 quadrilateral screws were used to control the medial displacement of the quadrilateral plate, and an 11 to 18-hole reconstruction plate was used to provide the holding force. For 17 patients (53%) with iliac wing fractures, a 5–12-hole arcuate pre-bent reconstruction plate was fixed along the iliac crest.

Matta Grading Score

Follow-up was greater than 12 months in all patients, with an average of 47 months (range, 24 to 84 months). Postoperative Matta grading scores showed that 19 cases (59%) were graded as excellent, 9 cases (28%) as good, and 4 cases (13%) as poor. Radiological evidence of fracture union was obtained in all patients at 3-month follow-up. There were no cases of quadrilateral screws entering the hip joint cavity and no cases among the 32 patients of early fracture displacement or implant failure.

Modified Merle d'Aubigné score

According to the modified Merle d'Aubigné scores, the functional outcomes were excellent in 15 cases (47%), good in 13 cases (41%), fair in 2 cases (6%), and poor in 2 cases (6%). Detailed data are shown in Table 1, and 2 typical cases are shown in Figs 5 and 6.



Fig. 4 The medial aspect of the quadrilateral plate was visualized through the middle window of the ilioinguinal approach. The quadrilateral screws were elastically fixed at many points of the quadrilateral surface.

Complications

The early complications included surgical site infections, deep venous thrombosis, and pulmonary infection or embolism. There were 3 cases of LFCNI recovered within 2 months after the operation. It was often noticed hypoesthesia in the anterior thigh caused by intraoperative excessive stretching. Superficial wound infection was observed in 1 patient, who recovered with antibiotics and superficial debridement. Late complications included posttraumatic arthritis; 4 cases were mild and 1 was severe according to the Kellgren–Lawrence osteoarthritis classification system¹⁶. The severe cases ultimately required total hip arthroplasty at

46 months. For mild cases, nonsteroidal anti-inflammatory drugs were used as needed.

Discussion**Clinical Characteristics of Quadrilateral Plate Fracture**

Once subjected to the strong violence along the femoral neck, complex acetabular fractures often involve displacement of the quadrilateral plate. Quadrilateral plate fractures are often comminuted, with the femoral head moving into the pelvic cavity with the fragments². These fracture patterns are technically challenging because of the deep site and weak bones^{3–5}. During

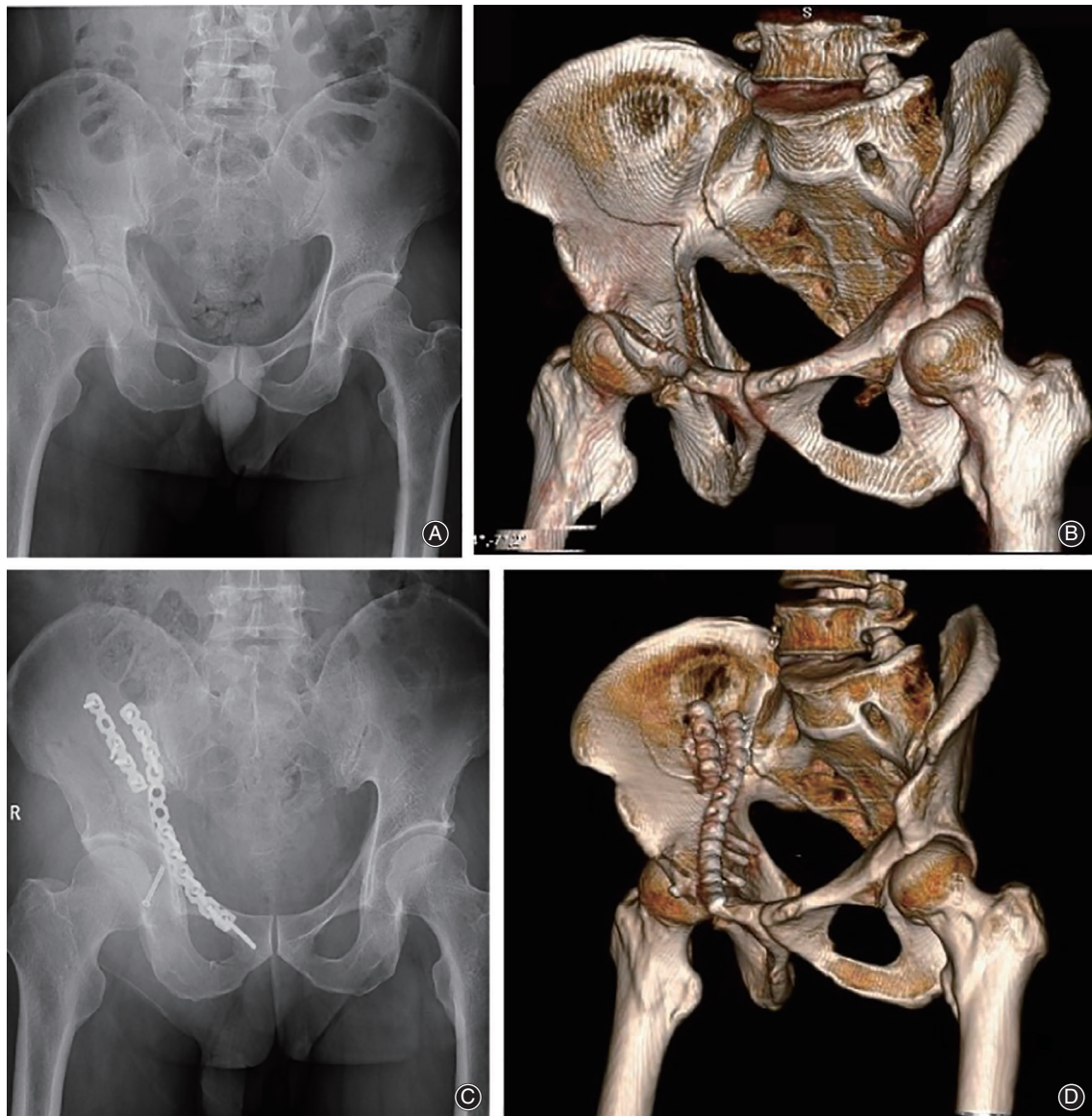


Fig. 5 Typical case one: A 47-year-old man presented with T-shaped fracture of the right acetabulum following a traffic accident. Fixation was performed at 7 days using the ilioinguinal approach and three quadrilateral screws to control the medial displacement of the quadrilateral plate (3-D view). Postoperative anteroposterior (AP) pelvis views showing that Matta's X-ray evaluation was scored as excellent. At his 2-year follow-up visit, the patient was symptom-free. Preoperative AP view (A) and 3D CT reconstruction (B). Postoperative AP view (C) and 3D CT reconstruction (D).

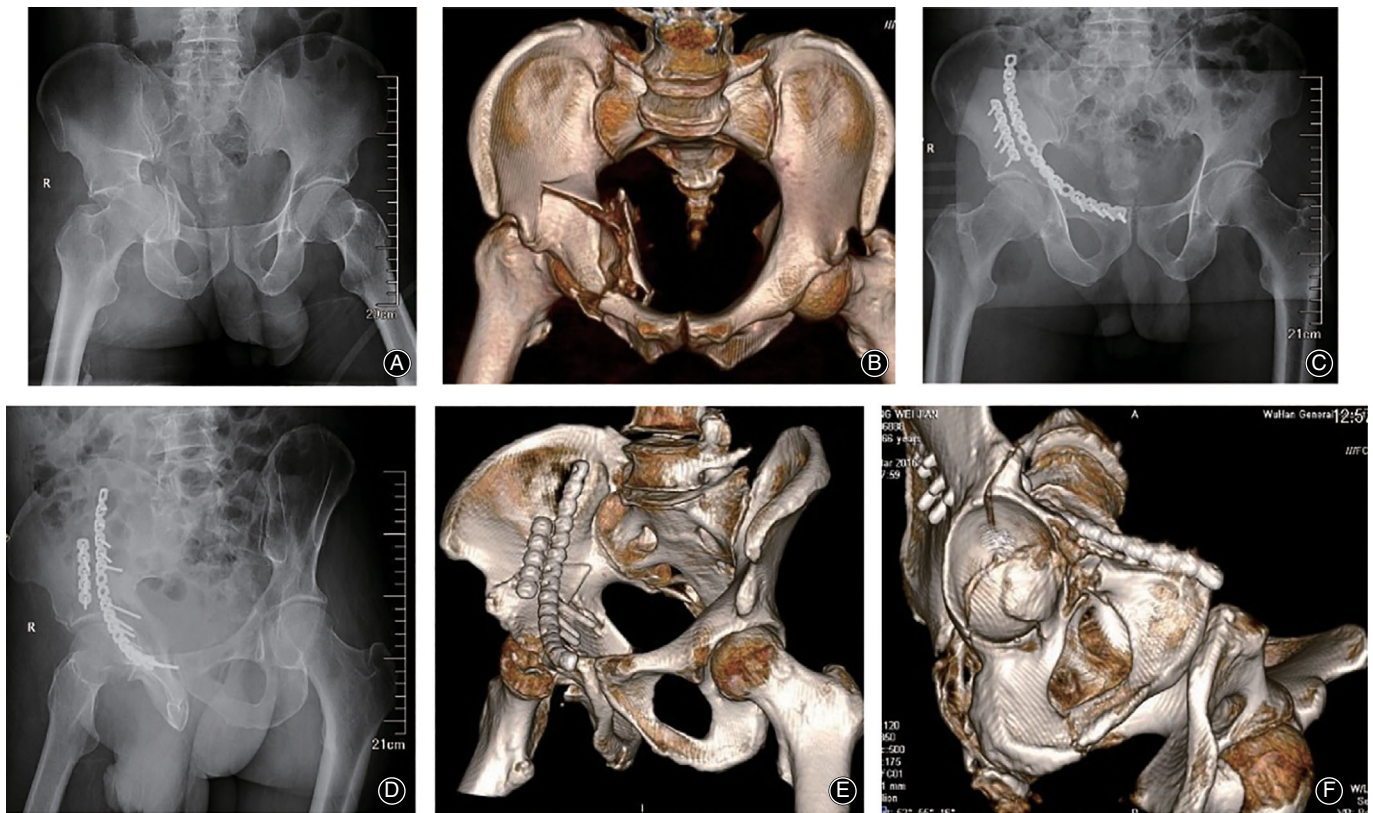


Fig. 6 Typical case two: A 59-year-old man presented with anterior column and posterior hemitransverse of the right acetabulum following a fall from height. Fixation was performed at 8 days after the injury. Postoperative 3D view showing that the quadrilateral screws that were placed on the surface of the quadrilateral plate have not entered the joint cavity. At his 1-year follow-up visit (X-ray), the patient was symptom-free. Preoperative anteroposterior (AP) view (A) and 3D CT reconstruction (B), postoperative AP view (C), Judet view (D), and 3D CT reconstruction (E, F).

the operations of this group, we found that fracture fragments of quadrilateral plates often had the tendency of posterior inferior displacement, apart from the inward displacement to the pelvic cavity. This means that in the process of reduction and fixation, the tendency of inward and posterior inferior displacement of the quadrilateral plate needs to be overcome; that is, internal fixation should not only prevent the fracture fragments from moving inward but pull the fragments forward and upward. However, the bone in the quadrilateral plate is extremely thin and weak, and some scholars have even identified the thinnest area as a “dangerous zone” for screws¹⁷. If insertion is necessary, the direction of the screw should deviate from the hip joint surface or parallel to the surface of the quadrilateral plate, or a short screw should be used (<12 mm); otherwise there is a risk of the screw entering the hip^{11,18}. However, if the screw is placed far away from the acetabulum, the reliability of internal fixation will be reduced by approximately 50%^{8,18}. Therefore, it is generally believed that an anterior reconstruction plate and screws alone cannot achieve reliable fixation of this part.

Surgical Difficulty of Quadrilateral Plate Fracture

To achieve direct fixation of quadrilateral plate fractures through an anterior approach, some scholars have conducted

studies based on anterior reconstruction plates, and a variety of methods have been described^{7–10}. Letoumel et al.¹³ achieved good effect combined with a lag screw fixation in the posterior column but also could not directly fix the fracture fragments of the quadrilateral plate; it is difficult to insert the screw, especially when the fracture is comminuted or there is severe osteoporosis. Other scholars have applied the technology of buttress plate, such as the T-shaped plate⁵, the L-shaped plate⁴, the butterfly plate¹⁹, the omega plate²⁰, or the one-third tubular plate²¹ to fix quadrilateral fracture. Subsequently, several scholars have reported a successful experience when using a buttress plate for osteopenic acetabular fractures involving the quadrilateral plate^{4,22}. However, taking the T-shaped, L-shaped, and one-third tubular plates as examples, these plates can be difficult to accurately contour to provide adequate medial buttress for all individuals, because of the single fulcrum, limited fixation range, and the weak effect in correcting fracture separation. Farid et al.²³ introduced a method of cerclage wire-plate composite for fixation of quadrilateral plate fractures. Although having the function of anti-segregation, it is easy to injure the sciatic nerve, superior gluteal vessels, and nerves because the wire needs to surround the small pelvis for one circle, and only certain fractures higher than the greater

sciatic notch can be treated. In recent fifteen years, some scholars have used an infrapectineal plate to fix the quadrilateral plate through the modified Stoppa approach⁸. Although it can solve some problems, such as comminuted fractures and osteoporosis, the fixation range is limited and an additional incision is often needed for complex fractures such as anterior column fractures^{24,25}.

Technical Characteristics and Surgical Efficacy of the Dynamic Anterior Plate-Screw System for Quadrilateral Plates

Placement of a reconstruction plate along the pelvic rim is a common treatment for acetabular fractures. Because of the special anatomical characteristics of the quadrilateral plate, the 3–5 holes of the reconstruction plate above the quadrilateral plate are often put aside without screws, which means the loss of direct fixation. To solve the problem, we used the reconstruction plate of DAPSQ in this study, which has a simple and ingenious design based on the traditional reconstruction plate for the pelvic rim¹³. The screws placed around the hip joint were transferred to the medial surface of quadrilateral plate, and the quadrilateral screws were not on the same plane as the screws fixed at both ends of the plate, which avoids the risk of screws penetrating into the joint. In the process of nailing, the torsion and elastic recoil of the plate could provide a strong holding force for the quadrilateral screws to control the tendency of inward displacement in the quadrilateral plate. The quadrilateral screws parallel to the surface of the quadrilateral plate formed a plane like a “bamboo raft” and can provide multi-point elastic support and fixation of this area. Meanwhile, the quadrilateral screws were tightly attached to the medial surface of the quadrilateral plate and 1/3 to 1/2 the transverse diameter of the screws have entered the bone plays a role of part-fixation and buttress. Therefore, the fixation can effectively maintain the reduction of the acetabulum. In this case series, we found that the superior rate of reduction was 88% (28/32), and there was no instance of the quadrilateral screw entering the hip and no occurrence of early fracture displacement or implant failure. In addition, we were surprised to find that the fixation method was effective in 4 elderly patients (above 60 years) with mild osteoporosis, but larger sample sizes are necessary for future research. The functional outcomes were poor in 1 case, which was combined with comminuted fracture of the quadrilateral plate, and the reduction was not satisfactory.

Biomechanical Characteristics of Dynamic Anterior Plate-Screw System for Quadrilateral Plates

We have done some research on the biomechanical characteristics of this fixation method and the results have shown that the stability of DAPSQ is no weaker than the fixation of two columns. For example, Yongde Wu *et al.*²⁶, members of our team, had analyzed the stress distribution of both column fractures fixed by DAPSQ, under 500 N load of standing on one foot, through finite element analysis. The results showed that the stress conduction of the acetabulum was

basically consistent with the normal biomechanical conduction of pelvis²⁷. In the further biomechanical test with the cadaver, the results showed that compared with an anterior construct plate plus 1/3 tube buttress plate, the stability of the pelvis following our fixation method was stronger in both sitting and standing positions, which was more in line with the biomechanical principles of internal fixation such as neutrality, tension band, pressure band, and load sharing²¹.

Key Technologies

Although the fixation technique is simple and easy to use, there are issues that need further attention. According to the technical characteristics and the related literature review, the main points for attention are as follows. First, DAPSQ is more suitable for displaced acetabular fractures characterized by anterior column injuries, and fractures involving the quadrilateral plate, such as both columns mainly with anterior column injury, transverse fractures with anterior displacement, partial ACPHT, and T-shaped fractures. For old acetabular fractures, acetabular posterior wall fractures, or in cases of both columns mainly with posterior column injury, an anterior–posterior surgical approach is often needed. Moreover, due to the limited compression and deformation of the reconstruction plate after screw placement, DAPSQ cannot be applied to patients with severe osteoporosis. Second, correct plate shaping and placement sequence are the key elements for quadrilateral screws to work. For example, if the plate is shaped in full accordance with the radius and curvature of the pelvis, the quadrilateral screws will become loose and have no holding force after nailing. Mahmoud *et al.*²⁸ used a similar method of buttress screws being parallel to the surface of the quadrilateral plate, but the process of plate shaping and nailing was obviously different from ours, which deserves further discussion. Third, the integrity of the sacrotuberous and sacrospinous ligaments is critical; they cooperate with the quadrilateral screws to stabilize the fragments of the quadrilateral plate. The whole operation process should be switched back and forth between the three “anatomical windows” of the ilioinguinal approach to minimize the iatrogenic injury of iliac vascular bundles and nerves. During the reduction and fixation of fractures, special attention should be paid to avoid excessive traction, compression, or cutting of the external iliac vascular bundle to reduce injury of the vascular intima²⁴. In addition, although this technique can help surgeons insert quadrilateral screws under direct vision and greatly reduce the risk of screws penetrating into the joint, repeated fluoroscopy should be performed during the operation to ensure good reduction of the fracture and safe screw placement. Finally, because of the complicated shaping process of the plate, it is necessary to select the appropriate length of the plate according to some pelvic anatomical parameters. Powerful software tools such as the Mimics, can select the valuable information of the bone data from the serial two-dimensional images of spiral CT, process the cross-section images and finish 3D reconstruction of the bone, which we believe are essential for

preoperative planning. Besides, 3D printing technology can also be used to print the fracture model of the pelvis before an operation, and the plate shaping can be carried out in advance to reduce the time-consuming during the operation, which is also the work that our research team is studying^{29,30}.

Limitations

This study has several limitations, including that it is a retrospective analysis, the sample size is small, and there is no comparative cohort. Therefore, further studies of randomized controlled trials with larger numbers of cases are needed. All the operations in this study were performed with the cooperation of two senior surgeons, using consistent indications, implants, and techniques. We believe that the application of DAPSQ combined with quadrilateral screws can achieve good results in complex acetabular fractures, as long as its indications, the shaping method, and the nailing technique of the plate are fully understood.

Conclusion

Managing acetabular fractures involving quadrilateral plates has always been challenging for orthopaedic surgeons. The reconstruction plate of DAPSQ combined with quadrilateral buttress screws through the classic ilioinguinal approach provides a new fixation concept for the treatment of complex acetabular fractures. Using this fixation mode can overcome the shortcomings of screws entering the joint and injuring the important nerves and vessels, and the placement trajectory of the plate is more in line with the characteristics of pelvic mechanical conduction. Nevertheless, there are some factors that require attention during the surgical procedure.

Acknowledgments

This work was supported by the Technological Innovation Projects of Hubei Province (Grant No. 2017ACA099). Thanks to Kunming Cheng, for her love and support all through this work.

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