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The "safe zone" for infrapectineal plate-screw fixation of quadrilateral plate fractures
An anatomical study and retrospective clinical evaluation

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Abstract

Extra-articular screw placement in the true pelvis for fixing quadrilateral plate fractures remains challenging. We aimed to define the "safe zone" on the quadrilateral surface to facilitate safe plate-screw placement.

Twenty cadaveric hemipelves were sectioned and assembled to define the projection of the acetabular boundary on the quadrilateral surface. Three lines (X, Y, and Z) were drawn tangent to the projection, with X parallel to the iliopectineal line, Y perpendicular to the iliopectineal line, and Z parallel to the posterior border of the ischial body. Then, the distances between X and the iliopectineal line (D1), Y and the sacroiliac joint (D2), and Z and the posterior border of the ischium (D3) could be used to determine a "safe zone" on the quadrilateral surface for screw insertion. We included 15 patients whose conditions satisfied the definition of a comminuted quadrilateral plate fracture and applied two-ended buttress plates for treatment in accordance with this "safe zone."

The average D1 was 50.0 mm, the average D2 was 30.6 mm, and the average D3 was 12.4 mm. For all 15 patients with comminuted quadrilateral fracture who were treated, no intraoperative or postoperative screw penetration of the acetabulum was identified, and no loss of reduction was observed during an average follow up of 17.7 months.

The "safe zone" established in this study simplifies extraarticular screw placement for managing quadrilateral plate fractures in the true pelvis. As a result, two-ended buttress plate fixation in the true pelvis becomes safe, therefore, treatment with two-ended buttress plates may represent a viable alternative to single-ended elastic fixation in the management of comminuted quadrilateral fractures.

Abbreviations: AC = anterior column, AW = anterior wall, CT = computed tomography, E = iliopectineal eminence, IL = iliopectineal line, IP = infrapectineal, MVA = motor-vehicle accident, PC = posterior column, PW = posterior wall, QL = quadrilateral plate, SD = standard deviation, SI = sacroiliac joint, SP = suprapectineal.

Keywords: infrapectineal, plate-screw fixation, quadrilateral plate fracture, safe zone, two-ended fixation

1. Introduction

Acetabular fractures involving a displaced quadrilateral plate can be technically challenging to treat.[1] In addition to respective column fixation, a displaced quadrilateral plate in such cases requires infrapectineal buttressing to prevent femoral head subluxation.[2] As newly developed anterior intrapelvic approaches gain popularity, including the modified Stoppa[3] and pararectus approaches,[4] screw insertion at the deep end of the quadrilateral plate has become easier to achieve. Recently, Kistler reported a quadrilateral surface buttress plate that was shown to be biomechanically comparable or superior to traditional fixations in a synthetic model.[2] However, infrapectineal two-ended buttress plate placement carries safety concerns related to intraarticular screw placement, and there have been no previous anatomical studies regarding safe screw insertion below the projection of the acetabular boundary on the quadrilateral surface.

We assume the presence of a "safe zone" on the quadrilateral surface that indicates the region within which a surgeon can conveniently apply two-ended buttress plates (Fig. 1A–D) in the true pelvis for fixing quadrilateral plate fractures. The purpose of this study was to define the "safe zone" through an anatomical study and to evaluate the use of two-ended buttress plates placed according to this zone for managing comminuted quadrilateral plate fractures.

2. Methods

2.1. Anatomical study

Twenty (14 male, 6 female; mean age, 65 years; age range, 32–83 years) Chinese adult cadaveric hemipelves were obtained from
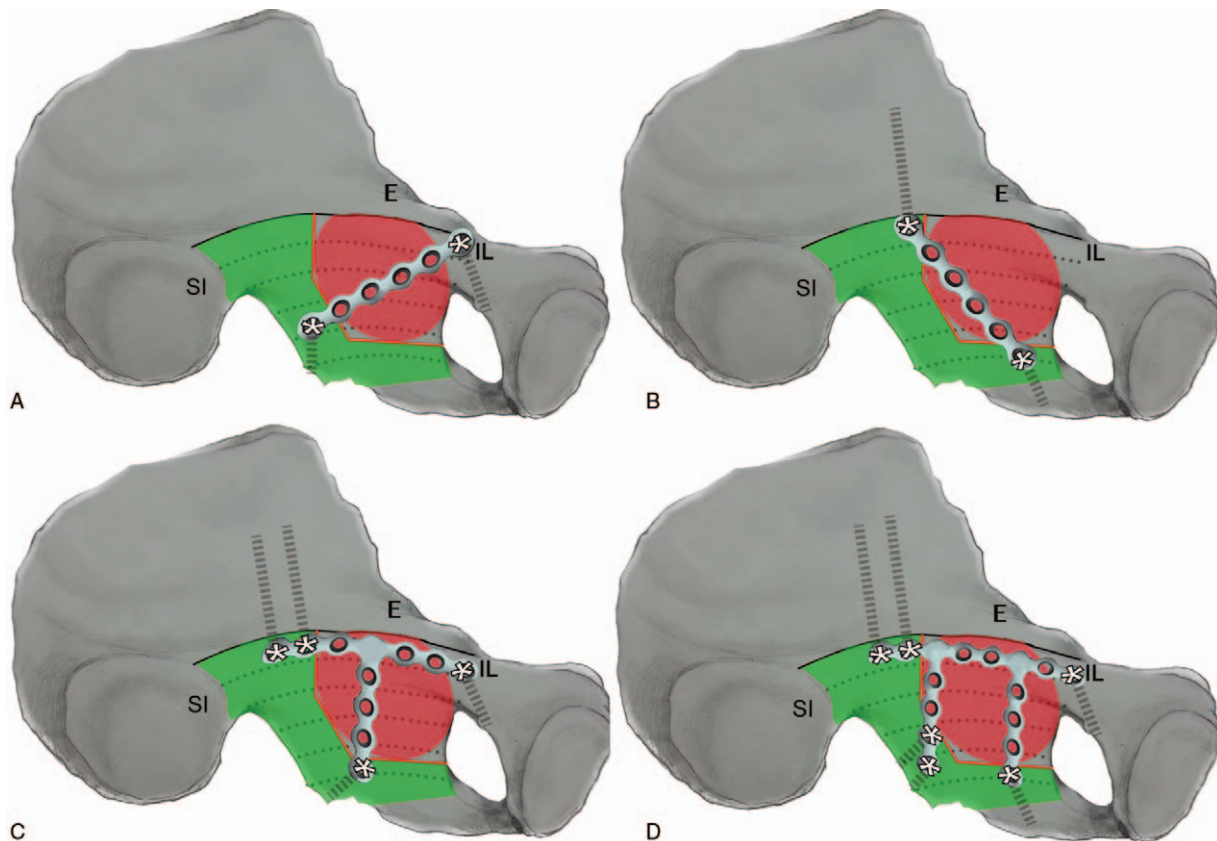
Figure 1. A reconstruction plate in one of several different configurations (A and B), a T-shaped plate (C) or a π-shaped plate (D) was used to fix quadrilateral plate fractures. The symbol * indicates the potential locations for safe screw insertion in the "safe zones" (green areas), which are located outside the projection of the acetabulum on the quadrilateral surface (red area). E = iliopectineal eminence, IL = iliopectineal line, SI = sacroiliac joint.

the Department of Anatomy, Tongji Medical College, Huazhong University of Science and Technology. The need to acquire consent for obtaining these cadaveric hemipelves was waived by the Institutional Review Board of Tongji Hospital, Tongji Medical College, Huazhong University of Science and Technology. Only healthy pelves in good condition were included, and all soft tissues were stripped from the specimens.

In accordance with the method described by Ebraheim,[5] all specimens were sectioned at 1 cm intervals perpendicular to the quadrilateral surface and parallel to the iliopectineal line (Fig. 2A). The initial cut was made at the superior border of the quadrilateral plate, and sectioning proceeded to the inferior border of the quadrilateral plate. Two lines tangential to the boundary of the acetabulum and perpendicular to the quadrilateral surface were drawn and projected to two points on the surface (Fig. 2B). The sections were then assembled to form the original acetabulum, and these points were connected to indicate the exact projection of the acetabular boundary on the quadrilateral surface (Fig. 2C). Next, three lines (X, Y, Z) were drawn tangent to the projection, with X parallel to the iliopectineal line, Y perpendicular to the iliopectineal line, and Z parallel to the posterior border of the ischial body. Then, the distance between X and the iliopectineal line (D1), Y and the sacroiliac joint (D2), and Z and the posterior border of the ischium (D3) were measured with a caliper and a flexible ruler (Fig. 2D). To minimize risks of error and avoid intraobserver variability, all measurements

throughout the study were repeated three times and then averaged by a single author.

2.2. Clinical evaluation

Written informed consent was obtained from all participants and this study was approved by the Institutional Review Board of Tongji Hospital, Tongji Medical College, Huazhong University of Science and Technology. According to ElNahal,[6] quadrilateral plate fractures can be classified as type I fractures, which involve a simple quadrilateral plate fracture with incomplete separation; type II fractures, which involve a comminuted quadrilateral plate that remains partially attached to the posterior column; type III fractures, which involve a comminuted quadrilateral plate separated from the columns of the acetabulum; and type IV fractures, a theoretical group of fractures in which a quadrilateral plate exhibits a simple fracture but is completely separated from both columns of the acetabulum. Based on the above definition, 15 patients (7 patients with type II fractures and 8 patients with type III fractures) were recruited at Tongji Hospital between May 2013 and May 2016. All fractures were confirmed via pelvic radiography and computed tomography (CT) with three-dimensional reconstruction. Patients were excluded if they had a severe medical condition or other situations that contraindicated operative treatment. Demographic and injury characteristics of the included patients are listed in Table 1.
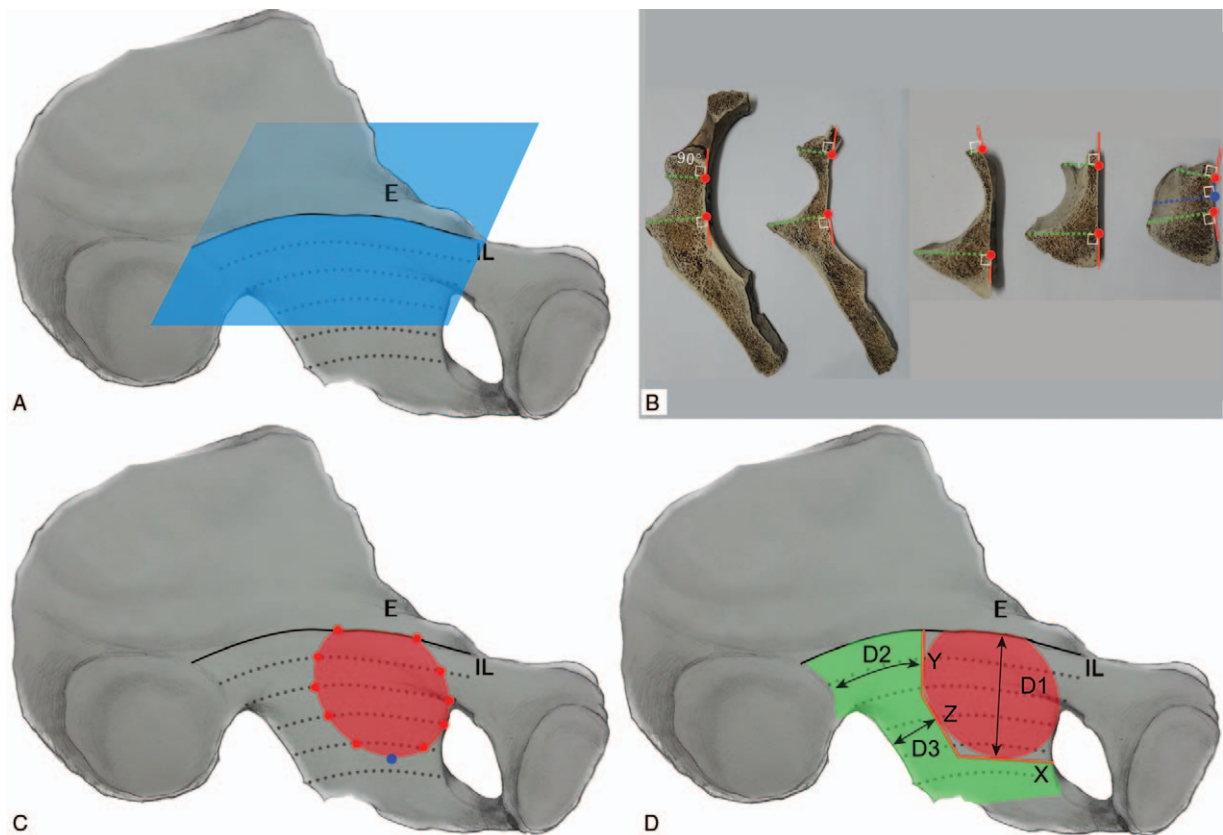
Figure 2. The initial cut was made at the superior border of the quadrilateral plate in line with IL and perpendicular to the quadrilateral surface. The first cut plane is indicated by the blue plane (A). Two green dotted lines tangential to the boundary of the acetabulum and perpendicular to the quadrilateral surface (as indicated by the red lines) were drawn and projected two points (red dots) on the quadrilateral surface. One blue dotted line tangential to the lowest boundary of the acetabulum and perpendicular to the quadrilateral surface (as indicated by the blue line) was drawn and projected one point (blue dot) on the quadrilateral surface (B). The sections were then assembled to form the original acetabulum and all red dots were connected to depict the exact projection of the acetabular boundary on the quadrilateral surface, as indicated by the red area (C). Next, three red lines (X, Y, Z) were drawn tangent to the projection, with X parallel to IL, Y perpendicular to IL, and Z parallel to the posterior border of the ischial body. The distance between X and IL (D1), Y and the sacroiliac joint (D2), Z and the posterior border of the ischium (D3) can be used to determine the "safe zone," as indicated by the green area (D). E = iliopectineal eminence, IL = iliopectineal line.

Table 1

Patient demographics and injury characteristics.

Patient number	Age (years)	Gender	Mechanism of injury	Fracture type[*]	Concomitant injuries	Time to surgery (days)
1	57	Male	Fall	AC + QL	Ipsilateral rib fracture	14
2	49	Male	MVA	PC + QL	–	3
3	54	Male	MVA	Transverse + QL	Ipsilateral tibial fracture	15
4	52	Female	Fall	AW + QL	Ipsilateral distal radial fracture	4
5	44	Male	MVA	AC + QL	–	7
6	57	Female	MVA	Transverse + QL	–	3
7	29	Male	Fall	AC + QL	–	15
8	68	Female	MVA	AC + QL	–	2
9	67	Male	Fall	PC + PW + QL	Ipsilateral ankle fracture	6
10	57	Male	MVA	AW + QL	Bilateral rib fracture	3
11	52	Male	Fall	AC + QL	Ipsilateral distal radial fracture	5
12	56	Female	MVA	AC + PW + QL	Ipsilateral intertrochanteric fracture	7
13	53	Female	MVA	AC + QL	–	10
14	47	Male	MVA	AC + QL	Ipsilateral elbow dislocation	4
15	53	Male	MVA	AC + QL	–	3

[*] Fractures were classified according to but not limited to the system devised by Judet and Letournel.
AC = anterior column, AW = anterior wall, MVA = motor-vehicle accident, PC = posterior column, PW = posterior wall, QL = quadrilateral plate.

Table 2

Variables D1, D2, and D3 (mm).

Variable (n = 20)	Maximum	Minimum	Mean	SD	Median
D1	52.1	47.0	50.0	1.7	50.6
D2	35.0	26.9	30.6	3.1	29.9
D3	14.5	10.3	12.4	1.2	12.6

SD = standard deviation.

Based on anatomical evaluation, we applied reconstruction plates in different configurations (Fig. 1A and B) or used buttress plates, including T-shaped plates (Fig. 1C) and π-shaped plates (Fig. 1D) to fix the patients' quadrilateral plate fractures. The screws were placed according to the "safe zone" and were inserted perpendicular to or pointing away from the projection of the acetabular boundary on the quadrilateral surface (Fig. 2A and B).

The modified Stoppa (12 cases) or pararectus (3 cases) approach were selected for open reduction and internal fixation because these approaches permit adequate exposure of the quadrilateral surface and subsequent placement of screws and plates in the deep true pelvis. For the modified Stoppa approach, special attention should be given to the urinary bladder and the obturator nerve and vessels. A retractor can be used to improve exposure at the pelvic brim. Of particular concern are the ureter and the L5 nerve root during posterior exposure. It is important to maintain a strict subperiosteal plane throughout the dissection. Then, the obturator internus should be adequately elevated to expose the entire quadrilateral surface for the deep application of plates. Corkscrew traction along the femoral neck and a ball spike pushing against the fracture fragments contribute to fracture reduction. To provide a rigid buttressing effect on the quadrilateral plate, we recommend that the plate should be undercontoured. In the present study, the screws were placed directly into the "safe zone." Then, the stability was checked by axial compression of the femoral head against the medial wall after implants were seated. Additional injuries to the pelvis, if unstable, were treated with either plates or screws. All surgeries were performed by the senior author (CY). Clinical outcomes were assessed during follow up via chart review by authors who were not involved in the treatment of any of the patients.

All patients received postoperative pelvic radiograph (anterior/posterior (A/P) view, obturator oblique view, and iliac oblique view) for the operated hip. The accuracy of the reduction was assessed using the radiological grading criteria of Matta.[7] The functional outcomes were assessed using the modified Merle d'Aubigne hip score.[8] Follow up occurred at 3, 6, and 12 months and annually thereafter. The postoperative rehabilitation protocol consisted of immediate toe-touch weight bearing, followed by protected partial weight bearing for 6 to 12 weeks, advancing to full weight bearing activity thereafter.

The measurements were analyzed using SPSS version 16.0 (SPSS Institute, Chicago, IL) for Windows (Microsoft, Redmond, WA). Data were reported as the mean ± standard deviation.

3. Results

3.1. Anatomical study

The distance between X and the iliopectineal line (D1) was 50.0 ± 1.7 mm, the distance between Y and the sacroiliac joint (D2) was 30.6 ± 3.1 mm, and the distance between Z and the posterior border of the ischium (D3) was 12.4 ± 1.2 mm (Table 2). An additional file shows the dataset of our measurements (Additional file 1, http://links.lww.com/MD/C969). Because the anatomical landmarks used in this study (iliopectineal line, sacroiliac joint, and posterior border of the ischium) can all be determined by direct visualization or finger palpation through an anterior intrapelvic approach, the "safe zone" determined in this study can be conveniently applied intraoperatively. Screws in the "safe zone" should be inserted within the plane perpendicular to the quadrilateral surface or should point away from the acetabular projection; otherwise, they will encroach upon the acetabulum (Fig. 3A and B).

3.2. Clinical evaluation

For all 15 comminuted quadrilateral fracture patients who were treated, no intraoperative or postoperative screw penetration of the acetabulum was identified (Fig. 4A–E), and no loss of reduction was observed during an average follow up of 17.7 months (range, 14–26 months). Patients' fractures were eventually healed in an average time of 4.2 months (range, 3–6 months). The surgery characteristics and outcomes of the treated patients are listed in Table 3. One patient developed a superficial wound infection on postoperative day 7 that was managed with
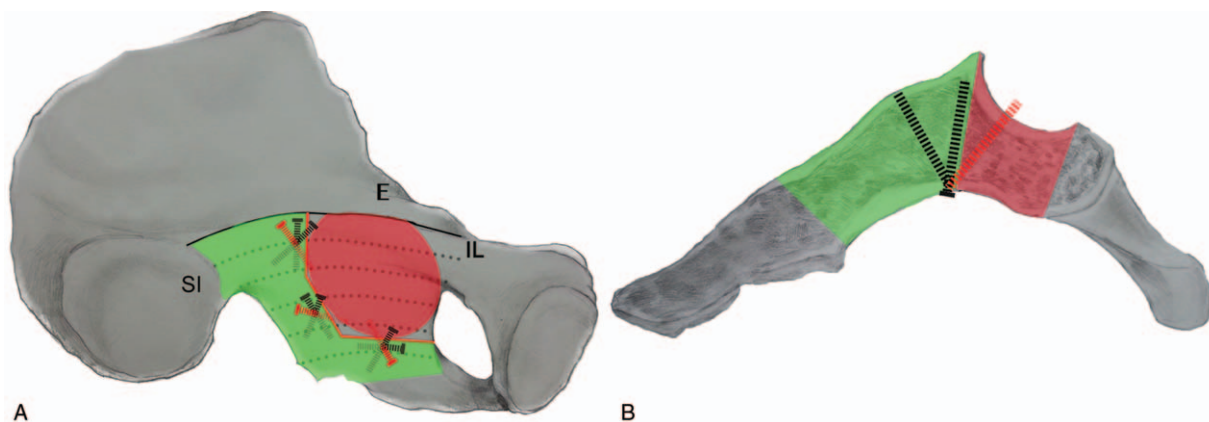

Figure 3. Screws in the green "safe zone" should be inserted perpendicular to the quadrilateral surface or should point away from the red acetabular projection, as indicated by the black screws; otherwise, they will encroach upon the acetabulum, as indicated by the red screws (A). The screw angulation is further demonstrated in a section perpendicular to the quadrilateral surface and parallel to the IL (B). E = iliopectineal eminence, IL = iliopectineal line, SI = sacroiliac joint.
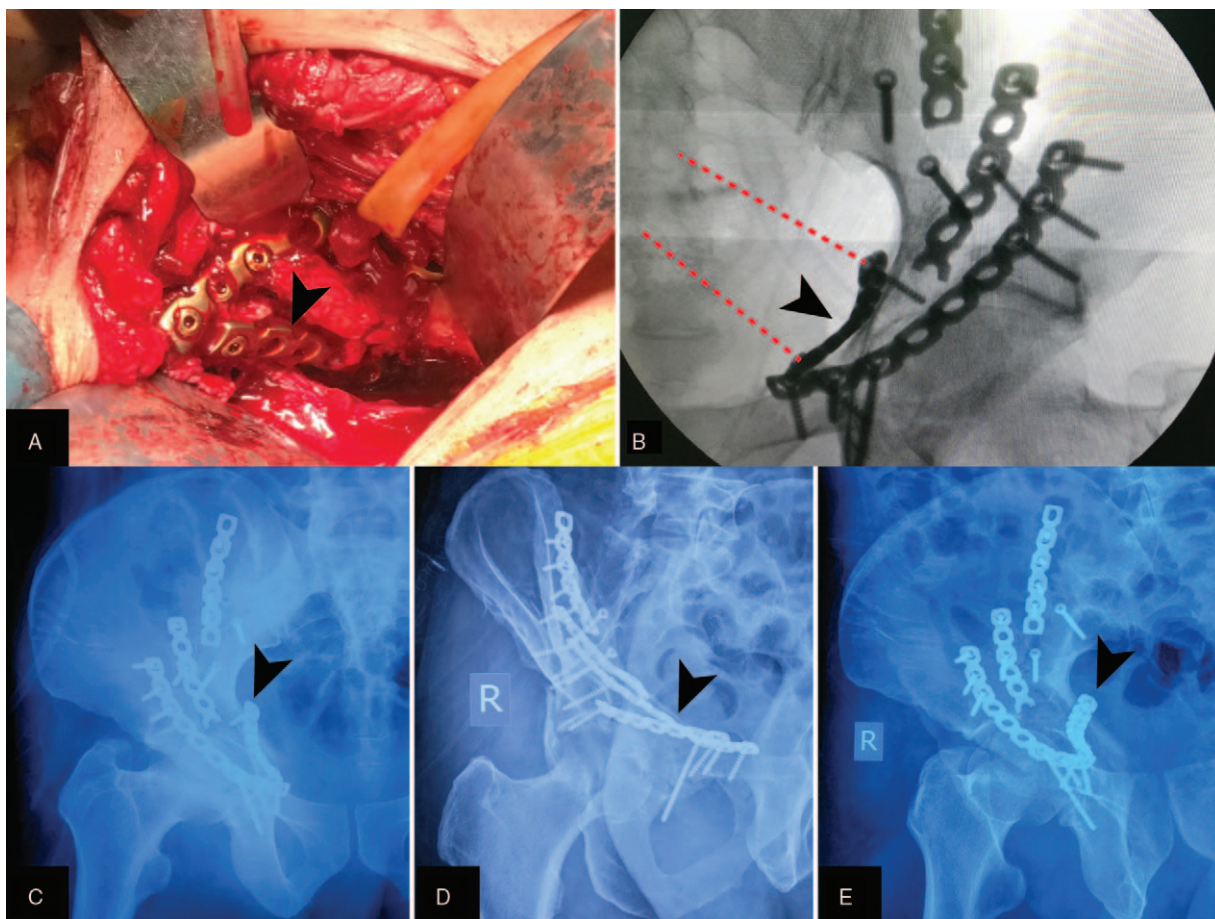
Figure 4. Intraoperative image showing the infrapectineal plate, which is indicated by the black arrowhead (A). Intraoperative image showing screw angulation, which is indicated by the red dotted lines (B). Postoperative pelvic radiographs in the AP view (C), the obturator oblique view (D), and the iliac oblique view (E) revealed no screw penetration of the acetabulum; the infrapectineal plate is indicated by the black arrowhead.

antibiotics; this patient had recovered at 4 weeks after surgery. One patient had transient extensor weakness prior to surgery due to peroneal nerve palsy and recovered 12 months after surgery. In one patient, the external iliac vein was injured during dissection

and required sutures. Qualities of reduction according to the Matta criteria were evaluated as anatomical in 12 cases, satisfactory in 2 and unsatisfactory in 1. The functional outcomes assessed by the modified Merle d'Aubigne hip score criteria were

Table 3

Surgery characteristics and outcomes.

Patient number	OR time (min)	Blood loss (mL)	Fixation devices	Matta grades	Union time (months)	Follow up (months)	Scores[*]
1	238	1000	SP (AC) plate + IP (QL) plate	Anatomic	3	15	13
2	166	1200	Ischial (PC) plate + IP (QL) plate	Anatomic	4	26	15
3	249	1600	SP (AC) plate + Ischial (PC) plate + IP (QL) plate	Unsatisfactory	5	17	8
4	84	600	AW plate + IP (QL) plate	Anatomic	5	16	18
5	95	700	SP (AC) plate + IP (QL) plate	Anatomic	4	18	18
6	187	1100	SP (AC) plate + Ischial (PC) plate + IP (QL) plate	Anatomic	5	25	14
7	163	900	SP (AC) plate + IP (QL) plate	Anatomic	4	20	17
8	118	500	SP (AC) plate + IP (QL) plate	Satisfactory	3	14	14
9	201	1200	Ischial (PC) plate + PW plate + IP (QL) plate	Anatomic	5	21	15
10	138	500	AW plate + IP (QL) plate	Anatomic	3	15	18
11	136	600	SP (AC) plate + IP (QL) plate	Anatomic	4	14	18
12	216	1100	SP (AC) plate + PW plate + IP (QL) plate	Anatomic	6	20	18
13	104	800	SP (AC) plate + IP (QL) plate	Satisfactory	5	15	18
14	94	600	SP (AC) plate + IP (QL) plate	Anatomic	4	15	18
15	85	500	SP (AC) plate + IP (QL) plate	Anatomic	3	15	18

[*] Modified Merle d'Aubigne hip score: excellent in 8 cases, good in 3 cases, fair in 3 cases, poor in 1 case. Radiographic grades: anatomic in 12 cases, satisfactory in 2 cases, unsatisfactory in 1 case. AC = anterior column, AW = anterior wall, IP = infrapectineal, PC = posterior column, PW = posterior wall, QL = quadrilateral plate, SP = suprapectineal.
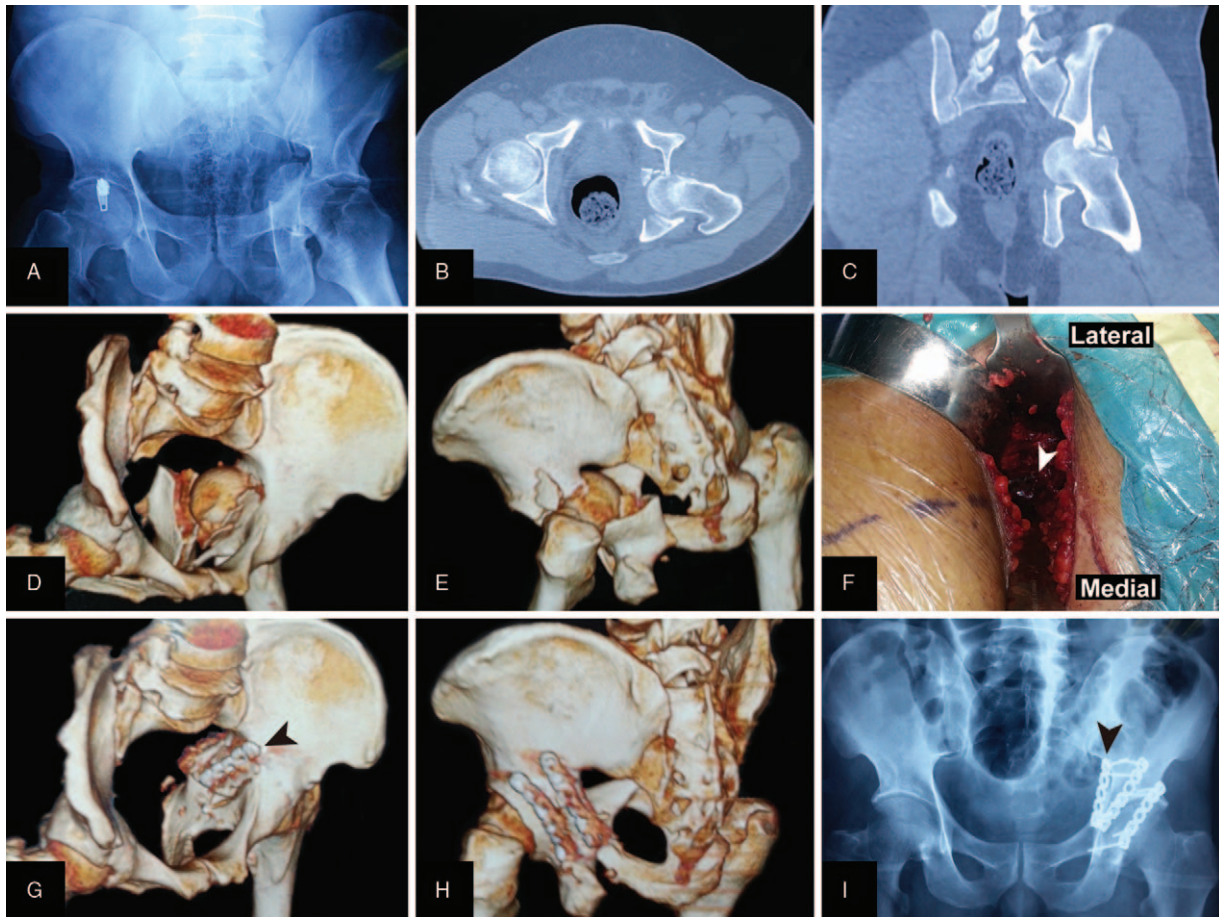
Figure 5. Patient number 2 was a 49-year-old male with posterior column and quadrilateral plate fractures. His fractures were reduced through the modified Stoppa approach combined with the Kocher-Langenbeck approach. Pre-operative anteroposterior pelvic radiograph (A) and CT scan (B and C) all showing a quadrilateral plate fracture on the left side, with obvious protrusion of the femoral head. Preoperative three-dimensional reconstruction CT scan providing a comprehensive image of the fracture and showing a disruption of the posterior column (D and E). The surgeon is positioned on opposite side of the fracture, and the quadrilateral plate is visualized through the Stoppa approach and fixed with a plate as indicated by the white arrowhead (F). Postoperative three-dimensional reconstruction CT scan (G and H) and anteroposterior pelvic radiograph (I) showing that the quadrilateral plate fracture has been reduced. The two-ended buttress plate for quadrilateral plate fracture fixation is indicated by the black arrowhead (G, I).

excellent in 8 cases, good in 3, fair in 3, and poor in 1 (Table 3). Details of the demonstration cases are shown in Figures 5 and 6.

4. Discussion

There have been many anatomical studies on avoiding intraarticular placement of implants[5,9–12], but few investigations have focused on the bottom of the quadrilateral plate, including the ischial body and ischial ramus.[13,14] The thick bone structure of the ischial body and ischial ramus may facilitate achieving a highly favorable bony purchase in specific cases, such as in comminuted quadrilateral plate fractures. All 15 patients included in this study had a comminuted quadrilateral plate pattern, which represents the worst scenario. The complex data provided by those pioneering anatomical studies are hard to comprehend and remember, making it difficult to use them for clinical application. In contrast, our study sought to provide simple guidance to surgeons for safe screw placement with the appropriate location (an area defined by the distance between the projection of the acetabulum and three anatomical landmarks) and angulation (perpendicular to the quadrilateral surface or

pointing away from the projection of the acetabulum), thereby simplifying safe screw placement. It is important to note that a distance of half the diameter of the screw should be taken into consideration to avoid cartilage damage.

It is important to ensure that anatomic landmarks used as references are easy to identify intra-operatively and reproducible among different cases. Focusing on the anterior column, Benedetti measured safe medial angulations perpendicular to the longitudinal axis of the anterior column.[9] However, the position of the screw entrance point relative to the longitudinal axis might change for acetabular fractures, rendering the angulation measurements from this study of limited clinical value.[9] In contrast, the anatomical landmarks we used can be determined conveniently by visualization or finger palpation via anterior intrapelvic approaches. The definition of the "safe zone" on the quadrilateral surface for safe plate-screw placement has clinical significance.

For acetabular fractures involving a comminuted quadrilateral plate, in addition to respective column fixation, the quadrilateral plate needs infrapectineal buttressing to prevent medial subluxation of the femoral head.[2] Unfortunately, previous widely used
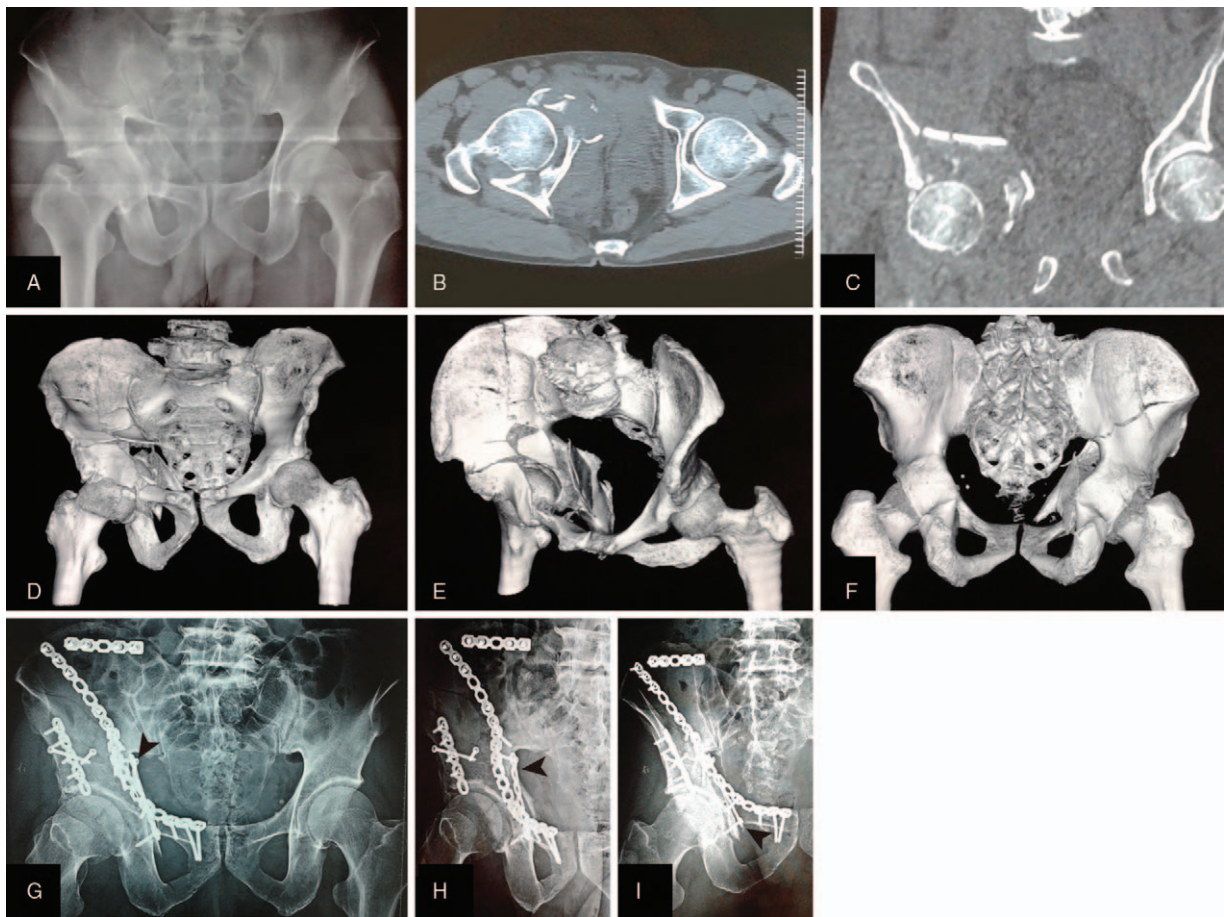
Figure 6. Patient number 1 was a 57-year-old male with anterior column and quadrilateral plate fractures, and his fractures were reduced through the modified Stoppa approach combined with the first window of the ilioinguinal approach. Pre-operative anteroposterior pelvic radiograph (A) and CT scan (B and C) all showing a comminuted quadrilateral plate fracture on the right side of the pelvis. Pre-operative three-dimensional reconstruction CT scan showing the quadrilateral plate fracture (D–F). Post-operative anteroposterior view (G) showing that the radiographic grade was anatomic. The correct position of the screws can be verified in the iliac oblique view (H) and obturator oblique view (I). The two-ended buttress plate for quadrilateral plate fracture fixation is indicated by the black arrowhead (G–I).

approaches that include the ilioinguinal approach are unable to obtain sufficient exposure of the quadrilateral plate, so reduction forces cannot be applied along the pelvic brim and orthogonal to the medial displacement of fractures. This inability is the main factor underlying the use of spring plates, buttress screws and plate-wire methods.[15–18] As the quadrilateral surface can be exposed sufficiently through newly developed anterior intrapelvic approaches, screw insertion at the deep end of the quadrilateral plate has become easier to achieve. Two-ended plates can provide a viable alternative to single-ended spring plates, buttress screws, and plate-wire methods. Meanwhile, over-bent plates can provide reducing and buttressing effects on the comminuted bone fragments. The fixation methods we describe in Fig. 1A–C were implemented for ten, three and two patients, respectively. No screw penetration of the acetabulum was observed during or after surgery, and all the fractures healed during follow up.

Anterior intrapelvic approaches provide improved access to not only the quadrilateral surface but also the medial aspect of the posterior column; thus, the quadrilateral surface buttress plates described by Kistler can simultaneously span both the anterior and posterior column and provide a quadrilateral surface buttress.[2] However, the safety of screw insertion into the bottom holes of the plate had not been verified via anatomical study. In addition, in specific cases, placed plates and screws are critical pivot points for reducing displaced fragments, and one-piece quadrilateral surface buttress plates can be placed only upon complete anatomical reduction. By contrast, our positioning of two-ended buttress plates can be conveniently used as a pivot point for reduction and can be contoured easily, which is a key factor in some scenarios.

4.1. Limitations

First, this study was limited by a small sample size, and differences related to sex, race, height, and body weight were not analyzed in this anatomical study. There are studies that have addressed sex- or race-based differences in implant methods of repairing acetabular fractures.[12,19–21] However, it is unlikely that these relatively small differences would have any clinical importance, which negates the need for sex-specific or race-specific implants.[21] Second, the "safe zone" was defined using a two-dimensional projection rather than a three-dimensional map on the quadrilateral surface, without precise measurements such as the "absolute safe zone" or "relative safe zone" for screw insertion. However, despite the fact that the acetabulum has a curved structure, the quadrilateral surface is relatively flat.

Therefore, we simplified the safe screw trajectory as being within the plane perpendicular to the quadrilateral surface or pointing away from the acetabular projection, thereby omitting complex angle control in the "relative safe zone." Finally, the number of treated patients was small, which is not surprising as patients with comminuted quadrilateral plate fractures are rare.

5. Conclusion

The "safe zone" established in this study simplifies extra-articular screw placement for managing quadrilateral plate fractures in the true pelvis. As a result, two-ended buttress plate fixation in the true pelvis becomes safe, therefore, treatment with two-ended buttress plates may represent a viable alternative to single-ended elastic fixation in the management of comminuted quadrilateral fractures.

Author contributions

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Software: Li He.
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