© 2022 The Authors. Orthopaedic Surgery published by Tianjin Hospital and John Wiley & Sons Australia, Ltd.

CLINICAL ARTICLE

Comparison of Three-Dimensional Navigation-Guided Percutaneous Iliosacral Screw and Minimally Invasive Percutaneous Plate for the Treatment of Zone II Unstable Sacral Fractures

Xuan Pei, MM[1,2†], Wei Zhou, MM[1,2†], Guo-dong Wang, MD[1], Xian-hua Cai, MD[1], Yi fan Zheng, MM[1,3], Xi-ming Liu, MD[1]

[1]*Department of Orthopaedics Surgery, General Hospital of Central Theater Command, Wuhan Clinical Medicine College of Southern Medical University and* [2]*School of Medicine, Wuhan University of Science and Technology, Wuhan and* [3]*The First School of Clinical Medicine, Southern Medical University, Guangzhou, China*

Objective: The percutaneous IS screws and the minimally invasive percutaneous plate are the most popular internal methods for Zone II unstable sacral fractures. However, the choice of fixation remains controversial for orthopaedic surgeons. The purpose of study was to evaluate and compare the clinical results of percutaneous iliosacral (IS) screw fixation under three-dimensional (3D) navigation and minimally invasive percutaneous plate fixation in the treatment of Zone II unstable sacral fractures.

Methods: A retrospective study was performed, including 64 patients with Zone II unstable sacral fractures who underwent percutaneous IS screw fixation under 3D navigation (navigation group) and minimally invasive percutaneous plate fixation (plate group) from January 2011 and March 2021 in our department. The age, gender, fracture type, mechanism of injury, injury severity score (ISS), time from admission to operation, operative time, intraoperative blood loss, hospital stay, incision length, follow-up time, time to clinical healing, and complications were recorded and analyzed. Matta standard was used to assess fracture reduction outcomes. The Majeed function system assessed functional outcomes at the last follow-up.

Results: The average follow-up time was (14.42 ± 1.57) months in the navigation group and (14.79 ± 1.37) months in the plate group. No statistical difference between the two groups in age, gender, fracture type, mechanism of injury, ISS, time from admission to operation, and time to clinical healing. However, significant differences were detected in operative time, intraoperative blood loss, hospital stay, and incision length ($p < 0.001$). According to Matta standard at 2 days postoperatively, the excellent and good rate was 91.42% in the navigation group, and it was 93.10% in the plate group. There was no significant difference between the two groups ($p = 0.961$). According to Majeed function system at the follow-up, the excellent and good rate was 97.14% in the navigation group, and 93.10% in the plate group. The difference between the two groups was not statistically significant ($p = 0.748$). There were no neurovascular injuries associated with this procedure. The incidence of complications was 44.82% (13/29) in the plate group, while 14.28% (5/35) in the navigation group ($p = 0.007$).

Conclusion: This study found that compared with minimally invasive percutaneous plate fixation, percutaneous IS screw fixation under 3D navigation is a suitable option for the treatment of Zone II unstable sacral fractures. This

Address for correspondence Xi-ming Liu, MD, Department of Orthopaedic Surgery, General Hospital of Central Theater Command, Wuhan Clinical Medicine College of Southern Medical University, Wuhan, China 430070 Tel: +8602750772525; Fax: +00862750771320; Email: gklxm@163.com and Yi fan Zheng, The First School of Clinical Medicine, Southern Medical University, Guangzhou, China 510515 Tel: +86 15157761993; Fax: +00862750771320; Email: gkzyf@qq.com
†These authors are the co-first authors.
Received 15 June 2022; accepted 17 September 2022

This is an open access article under the terms of the Creative Commons Attribution-NonCommercial-NoDerivs License, which permits use and distribution in any medium, provided the original work is properly cited, the use is non-commercial and no modifications or adaptations are made.

approach is characterized by its shorter operation time, less surgical trauma, less bleeding, less hospital time, and fewer complications.

Key words: 3D navigation; Minimally invasive percutaneous plate; Sacroiliac screw; Zone II sacral fractures

Introduction

Sacral fractures are usually caused by high-energy trauma such as falling from a height or vehicle accidents, accounting for 30% of injuries to the pelvic ring and are connected to fractures of the pelvic ring.[1–3] The management of unstable sacral fractures, usually associated with multisystem injuries and multiple fractures, is a challenge even to an experienced surgeon.[4–6] Sacral fractures are classified according to Denis: involving the sacrum lateral to the foraminal line (Zone I), involving the foramina (Zone II), or involving the sacral canal (Zone III).[2] According to reports, Zone II unstable sacral fractures account for 34%–47.5% of sacral fractures.[2,7] Zone II sacral fractures always accompany nerve stretch or compression because the sacral nerve passes through the sacral foramina.[8] Because the sacrum is an essential component of weight-bearing, patients who receive improper treatment may experience permanent deformities and poor quality of life.[9] Surgical management to reduce and fix Zone II unstable sacral fractures is the current gold standard.[4,10,11]

The purpose of surgical Intervention is to provide adequate stability for early activity and to avoid malunion.[1,3,5,12] At present, IS screw fixation,[1] posterior tension band plating fixation,[5,12] the minimally invasive adjustable plate fixation (MIAP),[4] posterior pelvic ring screw-rod internal fixation,[10] and lumbopelvic fixation[11] can be used to treat Zone II unstable sacral fractures. As minimally invasive techniques, the percutaneous IS screws and the minimally invasive percutaneous plate are the most popular internal methods for Zone II unstable sacral fractures.[1,5,7,12] However, the choice of fixation remains controversial for orthopaedic surgeons.

Some scholars believe that the minimally invasive percutaneous plate has a lower risk of damaging nerves and blood vessels than the percutaneous IS screws and sufficient stability for posterior pelvic ring disruptions, which is also an optimal treatment alternative.[5,12] However, this technique has some disadvantages, a higher rate of symptomatic hardware, including skin discomfort, skin necrosis, and wound infection.[13] In addition, we need to pre-contour the plate to accommodate the irregular structure of the posterior pelvic ring, which is challenging to finish. In some cases, repeated bending of the plate may be unavoidable, and this can weaken the plate strength.[5]

Percutaneous IS screw fixation has been widely used in clinical practice due to its advantages of biomechanical stability, minimally invasive procedure, and low infection rate.[1] But, it is difficult to achieve clear and optimal fluoroscopic sacral visualization under fluoroscopic, especially those with associated intestinal gases, obesity, and variations in the anatomy of the posterior pelvis, which can lead to misplacement of screw.[14,15] Several studies showed that the placement rates of IS screws under the traditional fluoroscopic was 58%–60%, and the incidence of neurologic injury has been reported to be as high as 7.9%.[16–18] Furthermore, upper sacral dysmorphism can occur in 30%–50% of all sacrum and may influence S_1 IS screw fixation.[19] The placement of IS screws through the inlet, outlet, and lateral fluoroscopic radiographs requires detailed knowledge and extensive clinical experience. A surgeon's knowledge of relevant anatomy and experience are critical to surgery, but intraoperative imaging and navigation technology currently supplement this knowledge to improve the surgeon's orientation. At present, 3D navigation technology has been widely used in surgery. I's more accurate, has less screw placement time, and less intraoperative radiation than traditional fluoroscopic.[20] However, to our knowledge, there are few reports comparing the percutaneous IS screw under 3D navigation and the minimally invasive percutaneous plate in the treatment of Zone II unstable sacral fractures. In this study, we evaluate and compare the outcome of two methods in the treatment of Zone II unstable sacral fractures.

The objectives of this study were: (i) to demonstrate the clinical efficacy and safety of the use of percutaneous IS screw fixation under 3D navigation in the treatment of Zone II unstable sacral fractures, and (ii) to evaluate and compare the outcome of these two internal methods in the treatment of Zone II unstable sacral fractures.

Materials and Methods

Inclusion and Exclusion Criteria

The inclusion criteria were: (i) age ≥18 and ≤70 years; (ii) unilateral Zone II unstable sacral fractures; (iii) patients with satisfactory closed reduction; (iv) treatment of unilateral Zone II unstable sacral fractures with percutaneous IS screw under 3D navigation and the minimally invasive percutaneous plate; (v) at least 12 months of follow-up; (vi) no preoperative symptoms of nerve damage.

The exclusion criteria were: (i) preoperative vital signs were unstable and the time from injury to operation was more than 3 weeks; (ii) presence of severe open injuries or rupture of the abdominopelvic cavity; (iii) severe osteoporosis (bone density $T \leq -2.5$ SD); (iv) combination of severe bleeding disorders, severe heart disease, and severe respiratory disease, unable to tolerate anesthesia or surgery.

General Data of the Patients

This single-center retrospective study included 64 patients who received surgical treatment with percutaneous IS screw fixation under 3D navigation (navigation group) and the minimally invasive percutaneous plate (plate group) from January 2011 and March 2021. There were 16 males and 19 females in the navigation group, admitted between January 2011 and June 2015. According to AO classification, there were 10 type B and 25 type C fractures. The mechanisms of injury were traffic accident in 21 cases, fall from height in 11 cases, and weight crushing in three cases. There were 19 patients with combined limbs injury and five cases of shock at admission. There were 15 men and 14 women in the plate group, admitted between July 2011 and March 2021. According to AO classification, there were seven type B and 22 type C fractures. The mechanisms of injury were traffic accident in 16 cases, fall from height in seven cases and weight crushing in six cases. There were 16 patients with combined injury and four cases of shock at admission. The same team of surgeons performed the procedures. This trial was approved by the ethics committee of General Hospital of Central Theater Command (ref. no. 2020–027). All the study participants provided written informed consent for the study.

Surgery

Preoperative Preparation

The surgery was performed on a radiolucent operating table. For patients with the significant longitudinal displacement of the posterior ring of the pelvis, closed reduction was achieved by traction. After traction, anteroposterior pelvis radiographs were taken to check the quality of the closed reduction, and the following operations were performed only if the closed reduction was satisfactory.

Navigation Group

The patient was placed in the supine position. The tracer was fixed at the contralateral anterior superior iliac spine, and the navigation device was registered and activated. The pelvis of each patient was scanned by CT and data was transferred to a 3D navigation system (Stryker) to provide a 3D image on the screen. The guide-wire sleeve was calibrated, and then the guidewire was placed in the S_1 and S_2 vertebrae according to the preoperative plan, while viewing the navigation monitor. When the virtual guide needle was observed to avoid the sacral foramina and the sacral canal, the guide needle was slowly drilled through the iliac bone and sacroiliac joint to the appropriate depth. Next, 6.5-mm cannulated screws with washers were inserted and tightened sequentially through the inserted guide pins, and final X-rays were checked.

Plate Group

The patient was placed in the prone position. Two short vertical skin incisions were made above the posterior superior iliac spine. The skin and subcutaneous tissue were incised to the periosteum and the soft tissue near the periosteum is dissected to expose the fracture site. A deep subfascial tunnel leading to the contralateral side was prepared with a chisel. After shaping, the plate was slid into the prepared groove, crossing the bilateral sacroiliac joints under the deep fascia with the plate located below the S_1 spine. Three to four screws were needed for the fixation of each iliac crest.

Surgery of Anterior Pelvic Ring Fracture

Most unstable sacral fractures are associated with anterior ring fractures.[1] In general, anterior pelvic ring injuries include pubic rami fracture, ruptures of the symphysis pubic, and various combinations. Anterior ring fractures with no significant displacement, minimal displacement, or satisfactory closed reduction can be treated with intramedullary fixation or anterior ring external fixator.[21] The plate managed the symphysis pubis disruption.

Postoperative Management and Follow-Up

The 24-hour antibiotic treatment was given to prevent wound infection. Fluoroscopy (anteroposterior, inlet, and outlet radiographs) and CT were examined on the 2 days after surgery. Patients are encouraged to perform the active and passive exercise for 3–4 days after surgery, as long as the pain can be tolerated. Follow-ups were done and pelvic radiographs were taken to evaluate the reduction, the fracture union, and clinical function at 1, 2, 3 months, and every 3 months postoperatively.

Testing Indices

The age, gender, fracture type, mechanism of injury, ISS, time from admission to operation, operative time, intraoperative blood loss, hospital stay, incision length, follow-up time, time to clinical healing, and complications, quality of fracture reduction based on Matta standard, and Majeed pelvic score were recorded.

Blood Loss

Blood loss is the sum of the amount of blood through the suction apparatus and the bleeding volume at the gauzes.

Similar to the length of incision, it can reflect the extent of the operation trauma.

Fracture Reduction Standard

Fracture reduction was evaluated according to the maximum displacement degree at the inlet and outlet view for X-ray or CT. Matta standard[22] was adopted: displacement less than 4 mm was excellent, displacement 4–10 mm was good, displacement 10–20 mm was general, and displacement more significant than 20 mm was poor.

Functional Recovery Standard

At the last follow-up, the Majeed function system[23] was used to evaluate the function from five aspects: pain, work, standing, sitting, and sexual life. The outcome was graded by total points: excellent, 85–100 points; good, 70–84 points; fair, 55–69 points; and poor, less than 55 points.

Statistical Analysis

The statistical analysis of the data was performed using the SPSS 20.0 software (IBM Corporation). The age of the patients, ISS, time from admission to operation, operative time, intraoperative blood loss, length of hospital stay, incision length, follow-up time, and time to clinical healing were compared using the independent Student's *t*-test. The gender of patients, fracture type, mechanism of injury, complications, quality of fracture reduction, and postoperative Majeed score were compared by the chi-square test. $p < 0.05$ was considered statistically significant.

Results

Demographic Results

All patients were followed up for 12–24 months. In the navigation group, the age was an average of (44.28 ± 14.94) years (range, 20–68 years), and the time from admission to operation was an average of (8.05 ± 2.55) days (range, 5–14 days). In the plate group, the age was an average of (39.89 ± 12.78) years (range, 23–67 years), and the time from admission to operation was an average of (8.44 ± 2.18) days (range, 5–13 days). Follow-up time was not significantly different between the two groups with (14.42 ± 1.57) months in the navigation group and (14.79 ± 1.37) months in the plate group (P = 0.333). In the navigation group, nine vertically unstable sacral fractures were fixed with IS screws under 3D navigation (Fig. 1). We also found no significant differences in age, gender, fracture type, ISS, follow-up time, mechanism of injury, and time from admission to operation between the two groups (Table 1).

Quality of Fracture Reduction

Matta standard: There were 22 excellent cases, 10 good cases, three general cases, and zero poor cases in the navigation group; the overall excellent and good rate was 91.42%. There were 19 excellent cases, eight good cases, two general cases,

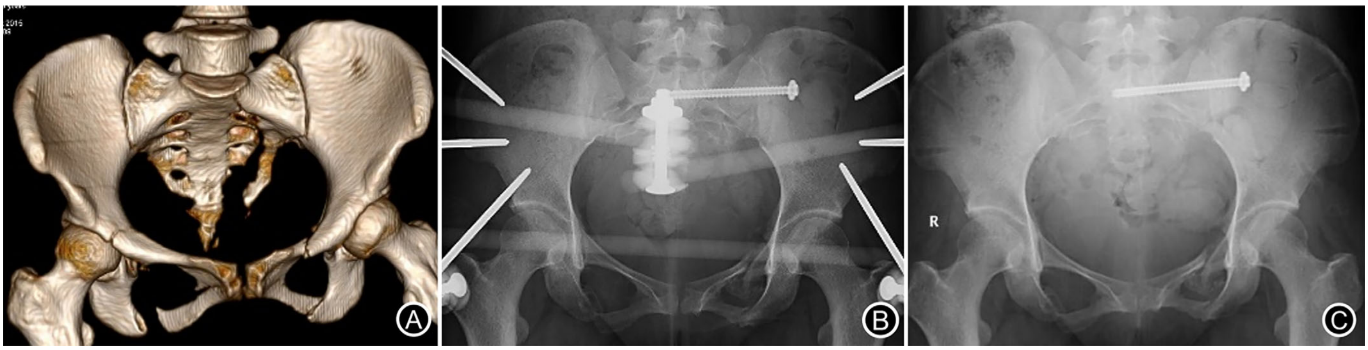

Fig. 1 (A) Female, 25 years old, injured by traffic accident. The patient accepted operation 5 days after injury. Three-dimensional CT showed the lift Zone II vertical unstable sacral fractures and significant fracture displacement. (B) Postoperative X-ray of AP showed the screw through the midline of the sacrum and the pubic rami fracture was treated with external fixator. (C) Radiographs 6 months postoperatively showed the sacral fracture normal union

TABLE 1 Comparison of the general data between two groups (mean ± SD)

Variable	Navigation group (n = 35)	Plate group (n = 29)	*t or* test	*p* value
Age (years)	44.28 ± 14.94	39.89 ± 12.78	t = 1.248	0.217
Gender (men/women)	16/19	15/14	χ2 = 0.229	0.632
Fracture type according to Tile				
Tile B B2	6	3	χ2 = 5.390	0.250
B3	4	4		
Tile C C1	11	14		
C2	5	6		
C3	9	2		
Mechanism of injury			χ2 = 3.212	0.201
Traffic accidents	21	16		
Fall from height	11	7		
Weight crushing	3	6		
ISS	24.54 ± 7.12	21.68 ± 6.88	t = 1.619	0.110
Time from admission to operation (days)	8.05 ± 2.55	8.44 ± 2.18	t = −0.651	0.518

TABLE 2 Comparison clinical outcomes between two groups (mean ± SD)

Variable	Navigation group (n = 35)	Plate group (n = 29)	*t or* test	*p* value
Operative time (min)	57.60 ± 10.38	132.31 ± 19.61	t = −19.492	P < 0.001
Intraoperative blood loss (mL)	51.28 ± 17.25	174.93 ± 44.60	t = −15.113	P < 0.001
Hospital stay (days)	13.62 ± 2.46	19.00 ± 3.56	t = −7.104	P < 0.001
Incision length (cm)	2.47 ± 0.25	8.81 ± 0.41	t = −74.91	P < 0.001
Follow-up time (months)	14.42 ± 1.57	14.79 ± 1.37	t = −0.975	0.333
Time to clinical healing (months)	3.54 ± 0.28	3.46 ± 0.30	t = 1.013	0.315
Complications(n)				
Loosening	2	0	χ2 = 7.318	0.007
Infection	0	3		
Deep vein thrombosis	2	5		
Delayed union	1	2		
Skin discomfort	0	3		
Matta standard			χ2 = 0.080	0.961
Excellent	22	19		
Good	10	8		
General	3	2		
Poor	0	0		
Majeed function system			χ2 = 0.581	0.748
Excellent	25	20		
Good	9	7		
General	1	2		
Poor	0	0		

and zero poor cases in the plate group; the overall excellent and good rate was 93.10%. There was no significant difference between the two groups (p = 0.961, Table 2).

Majeed Function Score Results

At the last follow-up, there were 25 excellent cases, nine good cases, one general case, and zero poor cases in the navigation group; the overall excellent and good rate was 97.14%. There were 20 excellent cases, seven good cases, two general cases, and zero poor cases in the plate group; the overall excellent and good rate was 93.10%. There was no statistical difference between the two groups (p = 0.748, Table 2).

Surgery and Hospitalization Indices

In the navigation group, the operative time was (57.60 ± 10.38) min (range, 44–80 minutes), intraoperative blood loss was (51.28 ± 17.25) ml (range, 20–90 mL), hospital stay was (13.62 ± 2.46) days (range, 10–18 days), and incision length was (2.47 ± 0.25) cm (range, 2.1–3.0 cm). In the plate group, the operative time was (132.31 ± 19.61) min (range, 100–160 min), intraoperative blood loss was (174.93 ± 44.60) mL (range, 100–310 mL), hospital stay was (19.00 ± 3.56) days (range, 13–25 days), incision length was (8.81 ± 0.41) cm (range, 8.1–9.6 cm). Compared to the plate group, the patients in the navigation group had shorter operation time (t = −19.492, p < 0.001), less intraoperative blood loss (t = −15.113, p < 0.001), shorter hospital stay (t = −7.104, p < 0.001), and shorter incision length (t = −74.91, p < 0.001, Table 2). Clinical healing time was (3.54 ± 0.28) months (range, 3.0–4.1 months) and (3.46 ± 0.30) months (range, 3–4 months) in the navigation and plate groups (p = 0.315), respectively (Table 2). All fractures in both groups healed well. Imaging data of the navigation group on typical cases are shown in (Fig. 2). Imaging data of the plate group in typical cases are shown in (Fig. 3).

Complications

There were no neurovascular injuries associated with this procedure. In the navigation group, there were two patients with screws loosening (Fig. 4), one screw did perforate cortical without symptoms of neurovascular injury, two patients with deep vein thrombosis, and one patient with delayed union, with the incidence of complications for 14.28% (5/35). In the plate group, there were two patients with an incision infection and finally healed after dressing changes, three patients with the plate removed as soon as the sacral fracture healed because they felt discomfort due to a prominent fixation, five patients with deep vein thrombosis, and two patients with delayed union, with the incidence of complications for 44.82% (13/29). There was a statistically significant difference between the two groups ($\chi^2 = 7.318$, p = 0.007). The deep vein thrombosis was not life-threatening in any cases and was cured by anti-coagulation treatment. After regular follow-up, the fracture has healed completely at the last follow-up.

Discussion

Clinical Efficacy and Safety of Percutaneous IS Screw Fixation Under 3D Navigation in the Treatment of Zone II Unstable Sacral Fractures

In this study, the operative time was (57.60 ± 10.38) min (range, 44–80 minutes), intraoperative blood loss was (51.28 ± 17.25) mL (range, 20–90 mL), hospital stay was

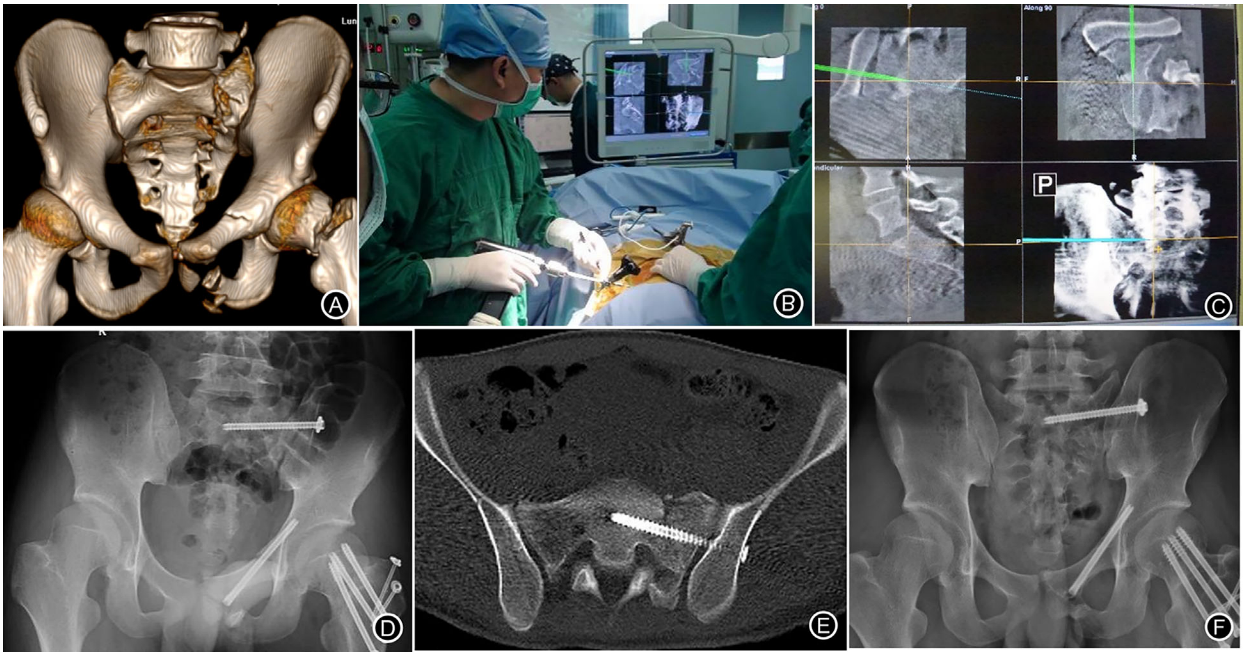

Fig. 2 (A) Male, 30 years old, was injured by a traffic accident. The patient accepted operation 5 days after injury. Preoperative three-dimensional computed tomography (CT) showed the left Zone II unstable sacral fractures. (B-C) Intraoperative 3D picture showed the track of IS screw placement. (D) Closed reduction and percutaneous IS screw fixation under 3D navigation was applied to treat Zone II unstable sacral fractures, and the pubic rami fracture was treated with intramedullary fixation. (E) Postoperative axial plane view of CT showed the sacral fracture had anatomic reduction and position of IS screw was excellent. (F) Radiographs of 6 months postoperatively showed the sacral fracture complete union

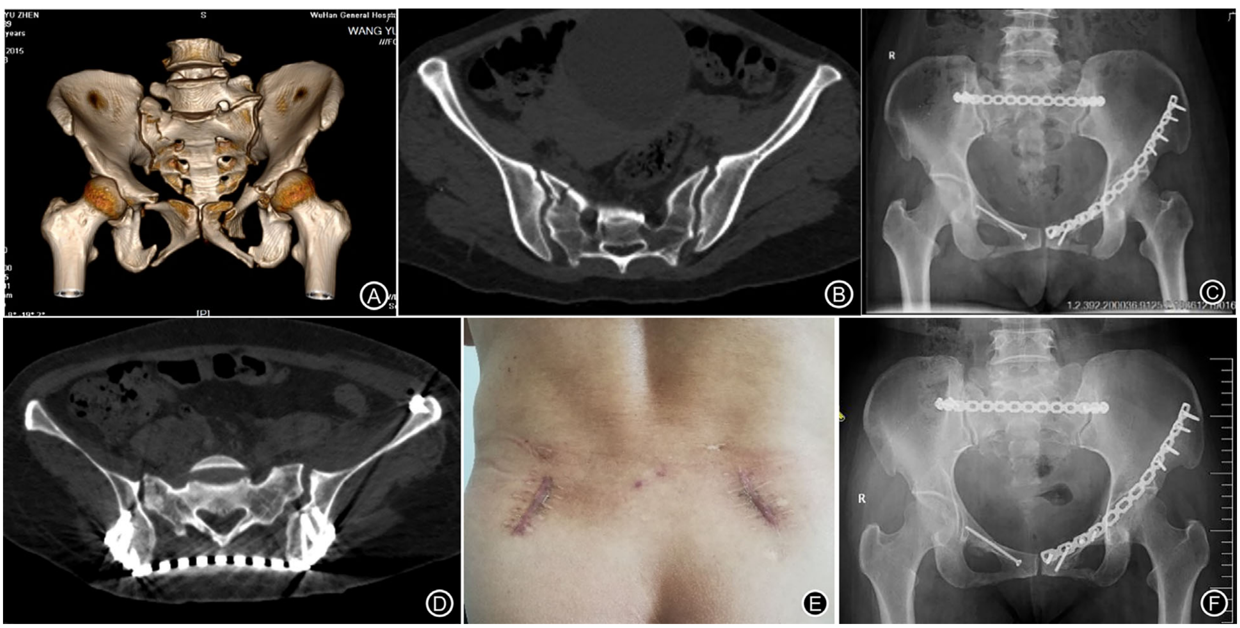

Fig. 3 (A-B) Female, 46 years old, was injured by fall from a height. The patient accepted operation 6 days after injury. Preoperative three-dimensional and axial plane view of CT showed the right Zone II unstable sacral fracture. (C) Postoperative X-ray of AP showed closed reduction and minimally invasive percutaneous plate was applied to treat Zone II unstable sacral fractures, the pubic rami fracture was treated with intramedullary fixation and reconstruction plate. (D) Axial plane view of CT showed the shape of the plate and the IS screw position is excellent. (E) Incision photos showed incision scar healing. (F) Radiographs of 6 months postoperatively showed the sacral fracture complete union

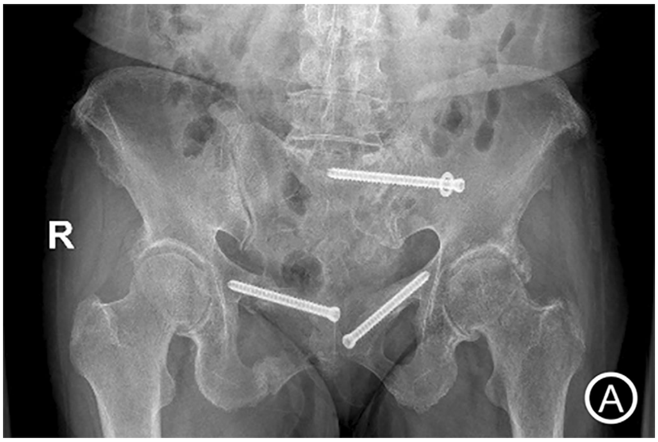

Fig. 4 Female, 52 years old, was injured by a traffic accident. The patient accepted operation 5 days after injury. Radiographs of 6 months postoperatively showed one screw loosening

(13.62 ± 2.46) days (range, 10–18 days), and incision length was (2.47 ± 0.25) cm (range, 2.1–3.0 cm) in the navigation group. There were no neurovascular injuries associated with this procedure. Clinical healing time was (3.54 ± 0.28) months in the navigation groups. According to Matta standard, the overall excellent and good rate was 91.42% in the navigation group. At the last follow-up, the overall excellent and good rate of Majeed Function Score was 97.14%.

Loosening and misplacement of the screw are common complications of IS screw fixation.[1,17] In the navigation group, two screws loosening occurred in two patients, without any further loosening occurring at the follow-up. No patients had a failure of the screws that required revision surgery. One screw did perforate cortical without symptoms of neurovascular injury. The reasons for screw loosening were analyzed. The patient was an older woman. Severe osteoporosis (T > –2.5 SD, preoperatively) and vertical instability of the posterior pelvic ring were the main reasons for internal fixation loosening. Oberkircher's biomechanical study concluded that the stability of IS screw with cement reinforcement technique was significantly higher than that of screw fixation without cement reinforcement.[24] The vertically unstable pelvic ring fracture or fracture with osteoporotic, the purchasing power of a conventional IS screw fixation is thought not to be sufficient. The IS screw can be appropriately lengthened, or the cement-augmented screw fixation can be a good option.

Vertical fracture of the sacral, often involving the sacral foramina, resulting in a Zone II unstable sacral fracture.[25] IS screws are popular in treating sacral fractures, but internal fixation failure can occur in vertically unstable sacral fractures, resulting in pain and malunion.[26] Fernández-Fernández *et al.*[27] reported four isolated vertical Dennis II sacral fractures managed by open reduction and IS screws with navigation that achieved satisfactory results. In 2002, Peter *et al.* compared the length of the IS screws placed under 3D navigation with those under X-ray fluoroscopy. The navigation group achieved the more extended screw placement because of a precise original entry point and correct drilling direction.[28] It is also possible to place the lengthened screw on the S_1 vertebral body according to the cross-section, especially for Zone II unstable sacral fractures. The longer the screw is placed on the S_1 vertebral body, the greater the fixation force and the stronger the fixation can be obtained. At the same time, we can increase the stability of the IS joint by placing S_2 IS screws. In the navigation group, nine vertically unstable sacral fractures were fixed with IS screws under 3D navigation. A total of 23 IS screws were passed through the sacral canal with a mean length of (97.60 ± 6.00) mm. None of these failures occurred in the patients with displacement at the initial reduction or in patients who were noted to be noncompliant with postoperative instructions. Suzuki[29] and Boudissa[30] believed the strength of posterior plate fixation provides enough stability to mobilize patients early with Zone II vertical unstable sacral fracture to avoid complications associated with prolonged bed rest.

The high incidence of dysmorphic sacral and the altered anatomy of the sacrum complicate the placement of IS screws, which are high-risk factors for screw placement.[1,31] In addition, misplaced SI screws can cause serious complications, possibly damaging nerve roots or vessels surrounding the sacrum and the sympathetic chain.[32] In 2017, Boudissa *et al.*[1] studied 165 posterior pelvic ring injury cases with closed reduction and percutaneous IS screw fixation. The results showed screw misplacement was recorded for 30 patients (16%) with sacral dysmorphia. Matityahu *et al.*[33] evaluate the accuracy of computer-assisted sacral screw fixation compared with conventional techniques in the dysmorphic. There were no misplaced screws with 3D navigation and there were good functional outcomes in the 54 patients. In the navigation group, five dysmorphic sacral patients were fixed with IS screws under 3D navigation, without misplacement screws. Nonetheless, closed placement of the IS screws under navigation fixes dysmorphic sacral fracture and still requires careful and adequate preoperative evaluation.

Percutaneous IS Screw Fixation Under 3D Navigation Versus Minimally Invasive Percutaneous Plate Fixation

There is a high incidence of sacral fractures in Zone II because the sacral foramen represents a weak area of the sacrum.[7] Zone II sacral fractures are a common unstable sacral fracture which requires internal fixation to rebuild the stability of the pelvis.[34] Chen *et al.*[5] believed that IS screw fixation and percutaneous plate fixation are suitable for treating Zone II unstable sacral fractures with reliable stability. Many scholars reported that the minimally invasive percutaneous plate and IS screw were effective treatment modalities for Zone II unstable sacral fractures.[5,12] Both types of internal fixation have advantages and disadvantages and should be individualized depending on the patient's situation. Percutaneous IS screw fixation under fluoroscopic guidance is the current standard of intraoperative visualization in most hospitals[1,25] and requires repeated fluoroscopy during the placement of IS screws to find a secure screw corridor, the process of which may carry a risk of neurovascular injuries.[14,15] The minimally invasive percutaneous plate has not inserted the screws into the sacrum, avoiding the risk of neurovascular injury.[29] Therefore, it is suitable for patients with sacral dysmorphia. However, patients may experience skin irritation, skin necrosis, or wound infection.[6] Kobbe *et al.*[6] reported three patients whose plates were removed for postoperative discomfort and three patients who developed wound infection. In addition, this technique should be used with extreme caution in cases of skin injury or Morel-Lavalleée lesions.[29] With the development of medical science and technology, 3D navigation technology has been widely used in surgery, which is more accurate, has shorter surgical time, and has less radiation exposure than conventional fluoroscopy in sacral fractures fixation.[20,33] Which of the two approaches is better still remains controversial.

In this study, the longer operation time was taken in the plate group compared to the navigation group ($p < 0.001$). We thought the reason was that the pre-contouring must be performed to match the anatomy of the bilateral posterior superior iliac spine (PSIS), which increased the operative time.[5] At the same time, intraoperative fluoroscopy was required to determine the appropriate positions of screws and plates. Percutaneous IS screw fixation is less invasive and reduces the risk of wound infection. The small incision avoids the "secondary trauma" to the patient and reduces the patient's postoperative pain. Patients can perform functional exercises early to speed up their recovery. In our study, intraoperative blood loss, hospital stay, and incision length were better in the navigation group than in the plate group ($P < 0.001$). Moreover, the rate of complication was 44.82% in the plate group, while it was only 14.28% in the navigation group. In addition, the rate of wound infection was 10.34% in the plate group, while it was 0% in the navigation group. Fortunately, the patients in the plate group who developed wound infections only required dressing changes. In the plate group, three patients were thin, and the plate was removed 6 months after surgery because they felt uncomfortable due to a prominent fixation. Therefore, the plate is optimally placed in areas with thick subcutaneous fat. Our study founded Majeed function system at the last follow-up, the excellent and good rates was 97.14% in the navigation group, and 93.10% in the plate group. The difference between the two groups were not statistically significant ($p = 0.748$). According to Matta standard, the overall excellent and good rate was 91.42%, while it was 93.10% in the plate group. This demonstrates that both kinds of internal fixation could result in similar clinical curative effect, but there are the advantages of operation time, surgical trauma, bleeding, hospital time, and complications in the navigation group.

Strengths and Limitations

All patients were unilateral Zone II unstable sacral fractures, which avoided the influence of Zone II bilateral unstable sacral fractures on the evaluation of clinical efficacy. Our study has some limitations, including that the clinical evidence generated by this study is not high-quality given that it is a retrospective study. The sample size was relatively small, and our study lacked long-term functional outcomes and long-term follow-up, which needs to be a feature of future studies. Although a single team performed all procedures, the surgeons' surgical experience may have increased over time. Therefore, a performance bias may potentially have been present. In addition, this study excluded bilateral sacral fractures. Therefore, the results may not apply to all Zone II unstable sacral fractures. However, this is the first comparison of the efficacy of these two surgical approaches in the treatment of Zone II unstable sacral fractures. Our findings provide a cornerstone and reference for future randomized clinical trials on this topic.

Conclusions

In summary, percutaneous IS screw fixation under 3D navigation has similar clinical outcomes compared to minimally invasive percutaneous plate fixation in the treatment of Zone II unstable sacral fractures. In addition, it has the advantages of shorter operation time, less surgical trauma, less bleeding, less hospital time, and fewer complications and can be recommended for clinical application.

Grant Sources

This work was funded by the special project of Innovation and Generation of Medical Service Support Capability (20WQ034) and the 2021 Translational Medicine Project of the Hubei Provincial Health Commission (WJ2021ZH0010).

Disclosure

The authors declare that they have no competing interests.

Ethical Approval

All procedures performed in the studies involving human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1975 Helsinki Declaration as revised in 2000. Informed consent was obtained from all individual participants included in the study.

Author Contributions

Conceptualization, supervision, validation*: X.P. and X.L.;* funding acquisition, project administration*: X.L. and Y.Z.;* methodology, investigation*: W.Z. and G.W.;* formal analyses and data curation*: W.Z.*

Conflict of Interest

The authors declare that they have no conflict of interest.

Acknowledgments

Not applicable.

References

1. Boudissa M, Roudet A, Fumat V, Ruatti S, Kerschbaumer G, Milaire M, et al. Part 1:outcome of posterior pelvic ring injuries and associated prognostic factors - a five-year retrospective study of one hundred and sixty five operated cases with closed reduction and percutaneous fixation. Int Orthop. 2020;44(6):1209–15.
2. Denis F, Davis S, Comfort T. Sacral fractures: an important problem: retrospective analysis of 236 cases. Clin Orthop Relat Res. 1988;227(227): 67–81.
3. Emohare O, Slinkard N, Lafferty P. The effect of early operative stabilization on late displacement of zone I and II sacral fractures. Injury. 2013;44(2):199–202.
4. Zhang R, Yin Y, Li S, Guo J, Hou Z, Zhang Y. Sacroiliac screw versus a minimally invasive adjustable plate for zone II sacral fractures: a retrospective study. Injury. 2019 Mar;50(3):690–6.
5. Chen HW, Liu GD, Fei J, Yi XH, Pan J, Ou S, et al. Treatment of unstable posterior pelvic ring fracture with percutaneous reconstruction plate and percutaneous sacroiliac screws: a comparative study. J Orthop Sci. 2012;17(5): 580–7.
6. Kobbe P, Hockertz I, Sellei RM, Reilmann H, Hockertz T. Minimally invasive stabilisation of posterior pelvic-ring instabilities with a transiliac locked compression plate. Int Orthop. 2012;36(1):159–64.
7. Herman A, Keener E, Dubose C, Lowe JA. Zone 2 sacral fractures managed with partially-threaded screws result in low risk of neurologic injury. Injury. 2016; 47(7):1569–73.
8. Tripathy SK, Goyal T, Sen RK. Nonunions and malunions of the pelvis. Eur J Trauma Emerg Surg. 2015;41(4):335–42.
9. Yang J, Zheng G, Zhou Z, Guo W. Application of MPR in sacral nerve injury during sacral fracture. J Trauma. 2011;70(6):1489–94.
10. Qi H, Geng X, Yu X, Chen W, Jia J, Tian W. Posterior INFIX for treating unilateral unstable sacral fractures. Orthop Surg. 2022;14(4):750–7.
11. Shetty AP, Renjith KR, Perumal R, Anand SV, Kanna RM, Rajasekaran S. Posterior stabilization of unstable sacral fractures: a single-center experience of percutaneous sacroiliac screw and lumbopelvic fixation in 67 cases. Asian Spine J. 2021;15(5):575–83.
12. Hao T, Changwei Y, Qiulin Z. Treatment of posterior pelvic ring injuries with minimally invasive percutaneous plate osteosynthesis. Int Orthop. 2009;33(5): 1435–9.
13. Krappinger D, Larndorfer R, Struve P, Rosenberger R, Arora R, Blauth M. Minimally invasive transiliac plate osteosynthesis for type C injuries of the pelvic ring: a clinical and radiological follow-up. J Orthop Trauma. 2007;21(9):595–602.
14. Sagi HC, Lindvall EM. Inadvertent intraforaminal sacroiliac screw placement despite apparent appropriate positioning on intraoperative fluoroscopy. J Orthop Trauma. 2005;19(2):130–3.
15. Ziran BH, Wasan AD, Marks DM, Olson SA, Chapman MW. Fluoroscopic imaging guides of the posterior pelvis pertaining to sacroiliac screw placement. J Trauma. 2007;62(2):347–56.
16. van den Bosch EW, van Zwienen CM, van Vugt AB. Fluoroscopic positioning of sacroiliac screws in 88 patients. J Trauma. 2002;53(1):44–8.
17. Zwingmann J, Konrad G, Mehlhorn AT, Südkamp NP, Oberst M. Percutaneous iliosacral screw insertion: malpositioning and revision rate of screws with regards to application technique (navigated vs. conventional). J Trauma. 2010;69(6): 1501–6.
18. Zwingmann J, Konrad G, Kotter E, Südkamp NP, Oberst M. Computer-navigated sacroiliac screw insertion reduces malposition rate and radiation exposure. Clin Orthop Relat Res. 2009;467(7):1833–8.
19. Kaiser SP, Gardner MJ, Liu J, Routt ML Jr, Morshed S. Anatomic determinants of sacral dysmorphism and implications for safe Iliosacral screw placement. J Bone Joint Surg Am. 2014;96(14):e120.
20. Lu S, Yang K, Lu C, Wei P, Gan Z, Zhu Z, et al. O-arm navigation for sacroiliac screw placement in the treatment for posterior pelvic ring injury. Int Orthop. 2021; 45(7):1803–10.
21. Caviglia H, Mejail A, Landro ME, Vatani N. Percutaneous fixation of acetabular fractures. EFORT Open Rev. 2018;3(5):326–34.
22. Matta JM. Fractures of the acetabulum: accuracy of reduction and clinical results in patients managed operatively within three weeks after the injury. J Bone Joint Surg Am. 1996;78(11):1632–45.
23. Majeed SA. Grading the outcome of pelvic fractures. J Bone Joint Surg Br. 1989;71(2):304–6.
24. Oberkircher L, Masaeli A, Bliemel C, Debus F, Ruchholtz S, Krüger A. Primary stability of three different sacroiliac screw fixation techniques in osteoporotic cadaver specimens-a biomechanical investigation. Spine J. 2016; 16(2):226–32.
25. Griffin DR, Starr AJ, Reinert CM, Jones AL, Whitlock S. Vertically unstable pelvic fractures fixed with percutaneous sacroiliac screws: does posterior injury pattern predict fixation failure. J Orthop Trauma. 2003;17(6):399–405.
26. Tabaie SA, Bledsoe JG, Moed BR. Biomechanical comparison of standard sacroiliac screw fixation to transsacral locked screw fixation in a type C zone II pelvic fracture model. J Orthop Trauma. 2013;27(9):521–6.
27. Fernández-Fernández R, Diaz-Freire P, Rubio-Suárez JC. Open reduction and navigated sacroiliac screws for vertically unstable pelvic fractures. Injury. 2021; 52:S22–6.
28. Peters P, Langlotz F, Nolte L-P. Computer assisted screw insertion into real 3D rapid prototyping pelvis models. Clin Biomech. 2002;17(5):376–82.
29. Suzuki T, Hak DJ, Ziran BH, Adams SA, Stahel PF, Morgan SJ, et al. Outcome and complications of posterior transiliac plating for vertically unstable sacral fractures. Injury. 2009;40(4):405–9.
30. Boudissa M, Saad M, Kerschbaumer G, Ruatti S, Tonetti J. Posterior transiliac plating in vertically unstable sacral fracture. Orthop Traumatol Surg Res. 2020;106(1):85–8.
31. Hasenboehler EA, Stahel PF, Williams A, Smith WR, Newman JT, Symonds DL, et al. Prevalence of sacral dysmorphia in a prospective trauma population: implications for a《safe》surgical corridor for sacroiliac screw placement. Patient Saf Surg. 2011;5(1):8.
32. Miller AN, Routt MLC. Variations in sacral morphology and implications for sacroiliac screw fixation. J Am Acad Orthop Surg. 2012;20(1):8–16.
33. Matityahu A, Kahler D, Krettek C, Stöckle U, Grutzner PA, Messmer P, et al. Three-dimensional navigation is more accurate than two-dimensional navigation or conventional fluoroscopy for percutaneous sacroiliac screw fixation in the dysmorphic sacrum: a randomized multicenter study. J Orthop Trauma. 2014; 28(12):707–10.
34. Bydon M, Fredrickson V, De la Garza-Ramos R, Li Y, Lehman RA Jr, Trost GR, et al. Sacral fractures. Neurosurg Focus. 2014;37(1):E12.