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Sacroiliac screw *versus* a minimally invasive adjustable plate for Zone II sacral fractures: a retrospective study

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ABSTRACT

Objective: Fracture line of the sacrum always involves the Zone II region because sacral foramina are anatomically and physiologically weak regions of the sacrum. The purpose of this study is to compare the therapeutic effects of a sacroiliac screw and a minimally invasive adjustable plate (MIAP) for Zone II sacral fractures.
Methods: Patients with unilateral Zone II sacral fractures fixed with a unilateral sacroiliac screw or MIAP from August 2009 to January 2016 were recruited into this study and were divided into two groups: group A (sacroiliac screw) and group B (MIAP). Surgical time, blood loss, frequency of intraoperative fluoroscopy, and relative complications were reviewed. Radiographs and CT scans were routinely acquired to evaluate the fracture displacement and reduction quality. Fracture healing was evaluated in the radiographs at each follow-up. Functional outcome was assessed based upon the Majeed scoring system at the final follow-up.
Results: Thirty-one patients in group A and thirty-nine patients in group B were included in this study. No significant differences in average surgical time ($P = 0.221$) or blood loss ($P = 0.234$) were noted between group A and group B. The mean frequency of intraoperative fluoroscopy was 15.74 ± 2.98 in group A and 6.08 ± 1.94 in group B ($P = 0.000$). All fractures healed well within four months in all patients, and the healing time exhibited no significant difference between the two groups ($P = 0.579$). Satisfactory rates of reduction quality and functional outcome were not statistically different between the two groups ($P > 0.05$). The complication rate was 16.13% (5/31) in group A and 5.13% (2/39) in group B ($P = 0.222$).
Conclusion: MIAP has a fixation effect and exhibits reduction potential for Zone II sacral fractures. Favourable radiographic and functional results could be obtained through the MIAP technique, which is easy to conduct without pre-contouring. Compared with the unilateral S1 sacroiliac screw technique, repeated projections and iatrogenic sacral injury can be avoided.

Introduction

Posterior pelvic ring disruptions, including sacral fractures, are consistently caused by high-energy trauma [1,2]. Pubic rami fracture or pubis symphysis disruption may be associated with sacral detachment. Denis classified sacral fractures into three zones according to the location of fracture line: extra foramina (Zone I), involving the sacral foramina (Zone II), and involving the sacral canal (Zone III) [2,3]. A high incidence of Zone II sacral fractures is observed because the neural foramina represent a weak region of the sacrum [3]. Neurological deficiency is always accompanied with Zone II sacral fractures because the sacral nerve passes through the sacral foramina [4,5]. Permanent deformity may be noted in patients who received improper conservative treatment given that the sacrum is an essential component of weight bearing [6]. Thus, surgery with internal fixation has become the gold-standard technique for Zone II sacral fractures [7]. Some fixation devices, including the percutaneous sacroiliac screw, the posterior tension band plate, and the minimally invasive adjustable plate (MIAP), along with the spinopelvic technique, have been reported to manage displaced Zone II sacral fractures in recent decades [8,9]. However, the choice of fixation remains controversial for orthopaedic surgeons. The

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purpose of this study is to compare the therapeutic effects of a sacroiliac screw and a minimally invasive adjustable plate (MIAP) for Zone II sacral fractures.

Materials and methods

Ethical statement

Informed consent was obtained from all the patients and the study was approved by the institutional internal review board of the participating institution. The study has been performed in accordance with the ethical standards of the Declaration of Helsinki in 1964.

Patients

Patients with unilateral Zone II sacral fractures admitted to our institution who received surgical treatment from August 2009 to January 2016 were reviewed in this study. The inclusion criteria for patients were as follows: 18–65 years old, unilateral Zone II sacral fractures without sacral nerve injury, normal activity ability before injury, and fixed with a unilateral S1 sacroiliac screw or a MIAP. The exclusion criteria of patients were as follows: pathologic fractures, open fractures, preoperative ROM (range of motion) deficiency of the hip, other associated severe injuries (traumatic brain injury), risk factors affecting bone healing (smoking, osteoporosis, metabolic diseases), and non-completion of one-year follow-up. Patients who met the inclusion criteria were divided into two groups based on different fixation methods: group A (sacroiliac screw) and group B (MIAP).

Surgical techniques

Surgical procedures were carried out by the same surgical team. Open reduction and plate fixation were recommended to manage anterior pelvic ring detachment. However, the INFIX technique was performed for extremely obese patients or with abdominal skin abrasions. Flexed hip joint should be maintained during surgical procedures to reduce the tension of the femoral neurovascular bundle. Then, displaced sacral fragments were managed with different methods as follows.

For group A patients, most Zone II sacral fractures were indirectly reduced after the management of anterior ring detachment. Open reduction in supine/prone position was conducted for the patients with closed reduction failure. Then, percutaneous sacroiliac screw placement was accomplished using the projection technique with a S1 pedicle axial view. First, a strict lateral projection of the sacrum was performed by the C-arm to obtain the outline of the S1 vertebral body. Second, a clear oval track of the S1 body could be gained after the projection angle was gradually changed cephalad (approximately 35°) and ventrally (approximately 30°), which was the S1 pedicle axial view (Fig. 1A). Third, the C-arm was fixed, and the entry point of the guiding wire was located in the centre of the oval track (Fig. 1B). Fourth, the insertion direction of the wire was adjusted to be parallel with the C-arm projection; then, the radiograph served as a reference point (Fig. 1C). Fifth, the guiding wire was hammered into the ilium to fix the sacral fragments (Fig. 1D-E). Sixth, a cannulated screw of the proper length was placed from the posterior ilium (Fig. 1F).

The components of MIAP are presented in Fig. 2A. The structure of the brackets conformed to the specific shape of the posterior superior iliac spines (PSISs), and pre-bending procedure could be avoided. For group B patients, the fixation of sacral fractures should be accomplished with prone decubitus. Two 4–6 cm longitudinal incisions were made medial to the bilateral PSISs (Fig. 2B). The insertion of gluteal muscles in the outer side of the iliac crest should not be released during the surgical procedure. The brackets were placed in the bilateral PSISs with screws. A subcutaneous tunnel

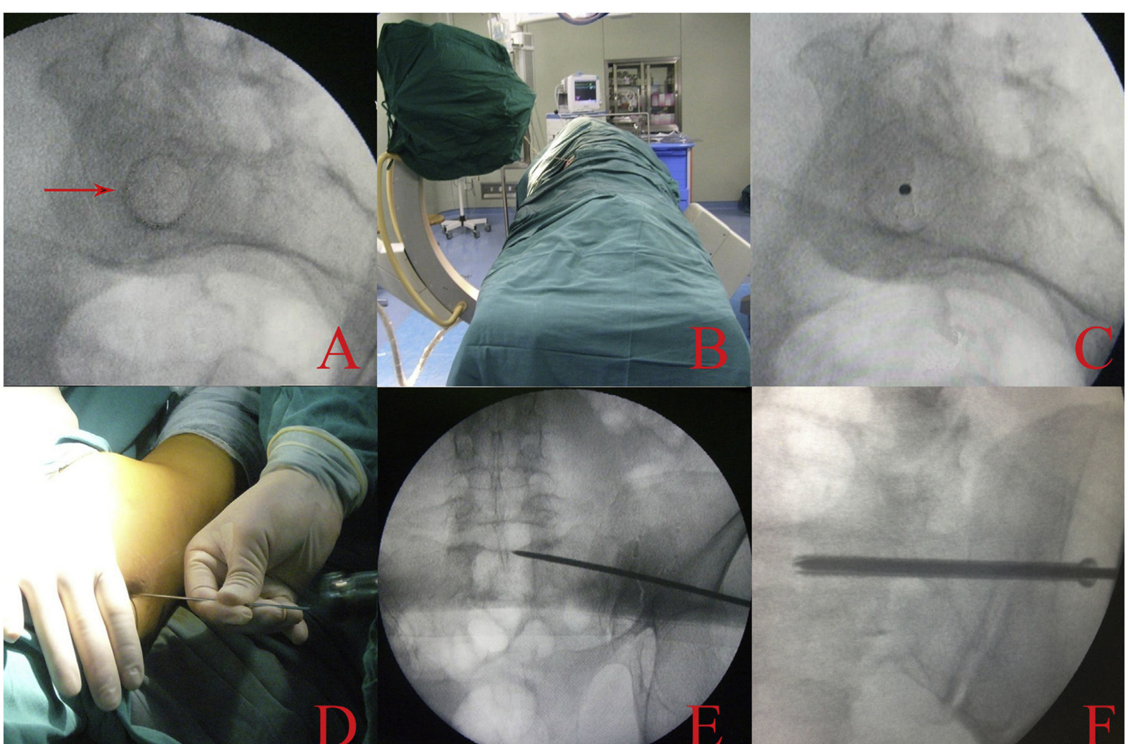

Fig. 1. The sacroiliac screw placement with the projection technique of S1 pedicle axial view was presented. A, a clear oval track of S1 body (red arrow); B, the projection direction was fixed; C, the guiding wire would become a point in the radiograph when it was parallel with the C-arm projection; D, the guiding wire was hammered into the ilium; E, intraoperative radiography of guiding wire; F, a cannulated screw was placed to fix the sacral fractures. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

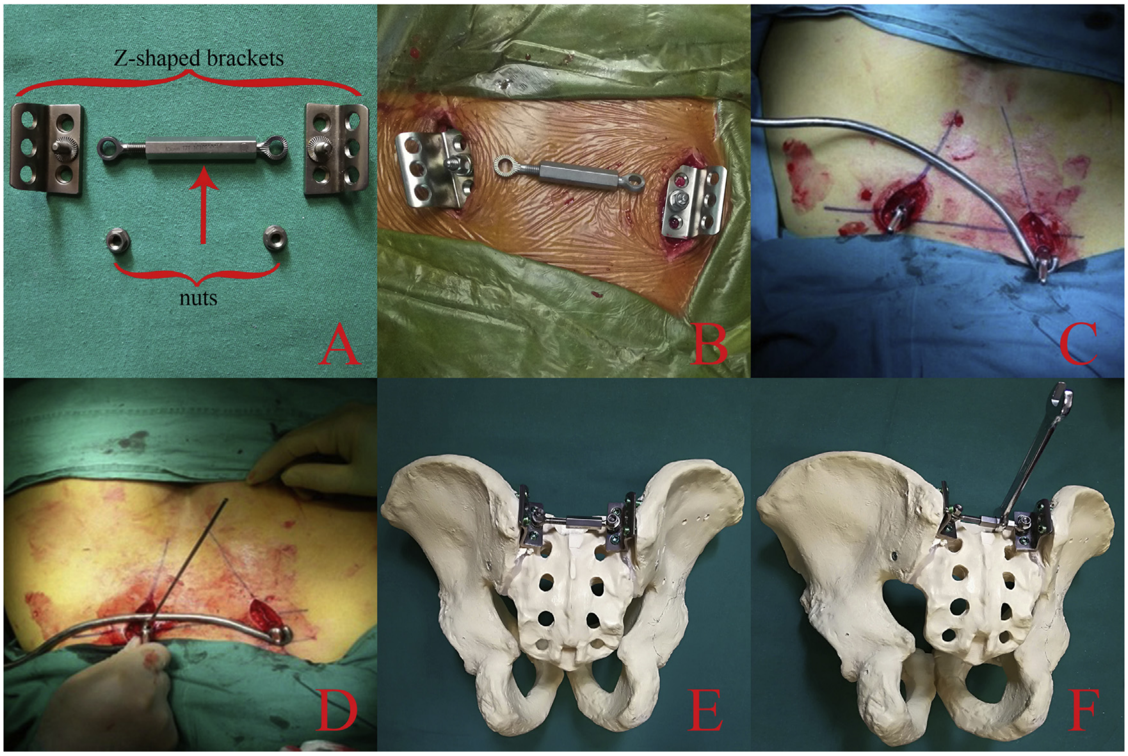

Fig. 2. The MIAP technique for sacral fractures was presented. A, MIAP components, including the Z-shaped brackets, nuts and hexagon-shaped adjustable connecting bar (red arrow); B, surgical incisions of MIAP technique; C–D, poking reduction procedure for vertical displacement; E, the brackets were fixed in the bilateral PSISs and connected; F, the compressed or separated dislocation could be reduced by elongating or shortening the connecting bar through rotating the hexagonal tube with a wrench. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

between the bilateral PSISs was created to place the adjustable connecting bar. The reduction procedures for vertical displacement are presented as follows. Two reduction screws were inserted in the PSISs, separately, which served as two fulcrums for prying the fragments (Fig. 2C). Thus, the cephalad-displaced fragments could be reduced with a crowbar (Fig. 2D). The force applied to the affected iliac wing reduced the residuary rotational detachment. After the vertical and rotational dislocation was reduced, the eye bolts of the adjustable connecting bar could be fixed to the two Z-shaped brackets (Fig. 2E). Then, the compressed or separated dislocation was reduced by elongating or shortening the connecting bar by rotating the hexagonal tube with a wrench (Fig. 2F) (reduction video). The incisions were sutured after normal saline irrigation.

Postoperative management and statistical analysis

Identical postoperative, therapeutic protocols were performed for patients in both groups in this study. Twenty-four-hour antibiotic treatment was routinely administered to prevent wound infection. Active joint exercise in bed was encouraged, and full weight-bearing training was conducted when the fractures appeared to be healed on the radiographs. Surgical time, blood loss, the frequency of intraoperative fluoroscopy, and relative complications were reviewed in this study. The retained displacement was measured on the radiographs and was classified as excellent (0–5 mm), good, (6–10 mm), fair (11–15 mm), and poor (> 15 mm) [10]. Follow-up was conducted at one, three, and six months postoperatively and every six months thereafter to assess fracture healing and functional recovery. Individualized therapy and rehabilitation exercise were performed based on the recovery situation (fracture healing and functional score) at each follow-up. The functional outcome was assessed based upon the Majeed scoring system, which was classified as excellent (> 85), good (70–84), fair (55–69) and poor (< 55) [11]. Excellent and good assessment for postoperative reduction quality and functional outcome were regarded as satisfactory results in this study. Relevant data were processed by SPSS software (version 23.0; SPSS, Chicago, IL), and a value of $P < 0.05$ was regarded as significantly different in this study.

Results

Thirty-one patients in group A and thirty-nine patients in group B were included in this study. The demographic data of the two groups revealed no significant differences in this study (Table 1). The mean surgical time was 109.35 ± 27.32 min in group A and 117.31 ± 26.30 min in group B ($P = 0.221$). The mean blood loss was 194.03±91.75 ml in group A and 219.49±85.25 ml in group B ($P = 0.234$). The mean frequency of intraoperative fluoroscopy was 15.74±2.98 in group A and 6.08±1.94 in group B, revealing an obviously significant difference in this study ($P = 0.000$). All fractures healed well within four months for all patients in this study, and no significant

Table 1
The demographic data of two groups.

Characteristics	Group A	Group B	*P* values
Age (year)	41.55 ± 11.17	43.64 ± 12.67	0.472
Gender (M/F)	21/10	27/12	0.894
Displacement (mm)	17.97 ± 3.07	18.05 ± 5.43	0.939
Time to surgery (day)	5.19 ± 1.94	5.51 ± 1.73	0.470
Plate/INFIX for anterior injury	28/3	33/6	0.727
Follow-up time (month)	24.03 ± 4.59	25.15 ± 5.26	0.353

The demographic data of two groups showed no statistical difference in this study.

difference in the healing time was noted between the two groups ($P = 0.579$). Satisfactory rates of reduction quality and functional outcome were not statistically different between the two groups ($P > 0.05$) (Table 2). The complication rates were 16.13% (5/31) in group A and 5.13% (2/39) in group B, respectively ($P = 0.222$). In group A, sacral nerve injury caused by screw malposition developed in one patient (Fig. 3A). Timely adjustment of the malposition was performed to prevent permanent neurological damage. Related symptoms, including dorsiflexed disability of the ipsilateral ankle, disappeared after three months of conservative treatment. Screw loosening developed in 3 patients postoperatively; however, secondary displacement of the sacrum did not occur (Fig. 3B). In group B, a hematoma developed in one patient, and the symptoms disappeared after treatment by puncture. One patient with soft tissue infection was noted in each group, and the symptoms disappeared after thorough debridement (Table 3).

Discussion

Zone II is a weak region of the sacrum, and fractures in this area are a common type of posterior pelvic ring injury. The management of Zone II sacral fractures remains a challenging problem for orthopaedic surgeons [12]. An increasing number of traumatologists accept the concept that anatomic reduction and internal fixation are the gold-standard treatment for sacral fractures. Most sacral fractures are associated with anterior ring instability. Anterior pelvic ring injury, including pubic rami fracture and pubis symphysis disruption, can be managed by INFIX and plate [13–,14,15,16]. Compared with the INFIX device, better reduction quality and stability can be obtained using the plating technique [17]. Moreover, a second surgery for internal fixator removal was indispensable for most patients [13]. Thus, INFIX was not routinely applied in our institution. Compared with ilioinguinal incision, the Stoppa approach was easier to perform with a lower complication rate, which was thus subsequently recommended to manage anterior ring disruption [18].

However, disruption exposure was difficult to obtain in extremely obese patients given obstruction by abdominal contents. Infection rate of incisions may increase for the patients with abdominal skin abrasions. Then, Stoppa incision was not recommend for those cases and INFIX technique was performed. Rahul Vaidya reported that satisfactory results were achieved in obese individuals using anterior disruption with the INFIX technique [13,16,17]. Iatrogenic injury of the lateral femoral cutaneous nerve may be accompanied by the INFIX technique, and relevant symptoms could disappear after months of conservative treatment in most patients. However, relative complications were noted in this study.

Posterior reconstruction plate could provide sufficient stability for posterior pelvic ring, however, the limited reduction potential may restrict its application for displaced sacral fractures [19]. Additionally, the pre-contouring procedure must be performed to match the anatomy of bilateral PSISs, which is time consuming [8]. Vertical displacement could be reduced through the spinopelvic technique. However, the unaffected lower lumbar vertebras supposed to have a certain degree motion are fixed in this procedure, which may lead to lumbar adjacent segment degeneration [20–,21,22,23]. Moreover, the surgical incision is much larger than that of other fixation techniques. Thus, reconstruction plates and the lumbopelvic technique are not recommended routinely in our institution.

The placement of a percutaneous sacroiliac screw through the sacroiliac joint, popularized by Routt, has been widely applied for posterior pelvic ring disruption [24]. Denis F reported that the biomechanical stability of the posterior ring could be regained by the central fixation [2]. As a minimally invasive technique, sacroiliac screw was used as a common fixation method for Zone II sacral fractures in our institution. However, it is challenging to achieve the reduction of displaced sacral fractures through traditional percutaneous technique, especially for the vertical and rotational detachment. A novel computer-aided pelvic reduction frame was invented to achieve percutaneous reduction for displaced sacral fractures [25,26]. However, the device is relatively expensive, and popularization of the technique has not been accomplished. Then, open reduction for sacral fractures may be not uncommon in the clinical practice.

Traditionally, the entry point of the S1 sacroiliac screw should be located in the area between the iliac cortical density (ICD) line and the posterior edge of the sacrum in the lateral projection [27]. Then, inlet and outlet projections are repeatedly conducted to assure the safety of the guiding wire [28,29]. Surgeons and patients are subject to considerable radiation exposure during screw insertion with this traditional technique [27]. Additionally, intraoperative changing the projection angle of the tube are time-consuming, which may prolong surgery time [30,31]. Intraoperative 3D navigation could reduce the malposition rate of sacroiliac screw insertion with less radiation exposure [32,33]. However, osseous landmarks for registration are essential to the surgical procedure, which means that several extra incisions are required. Additionally, the technique may not be popularized in primary hospitals given the financial burden of the device.

Zhiyong Hou et al proposed that S1 sacroiliac screws could be inserted with axial projection of the S1 pedicle [34]. They conducted a cadaver study and found that the mean safe angle for the axial projection of the S1 pedicle was $38.3 \pm 1.9°$ ventrally and $29.6 \pm 2.0°$ cephalad. Yingchao Yin et al reported that a unilateral S1 sacroiliac screw could be placed using the technique with less radiation exposure and complications than those of the conventional method [35]. The technique was widely applied to accomplish placement of the S1 sacroiliac screw in our institution (Fig. 4). However, the frequency of intraoperative fluoroscopy of sacroiliac screw was still more than that of MIAP in this study.

The percutaneous sacroiliac screw technique is unreliable in patients with dysmorphic upper sacral segments or osseous compression of neural elements [36,37]. No reduction potential was noted for the percutaneous technique. The symptoms of sacral nerve injury may be aggravated by the compression force on

Table 2
Clinical results of two groups.

Characteristics	Group A	Group B	*P*
Mean surgical time (min)	109.35 ± 27.32	117.31 ± 26.30	0.221
Mean blood loss (ml)	194.03 ± 91.75	219.49 ± 85.25	0.234
Mean frequency of intraoperative fluoroscopy	15.74 ± 2.98	6.08 ± 1.94	0.000
Satisfactory rate of reduction quality	23/31	35/39	0.086
Fracture healing time (month)	3.29 ± 0.64	3.38 ± 0.75	0.579
Satisfactory rate of functional outcome	24/31	32/39	0.630

The Mean frequency of intraoperative fluoroscopy in group B was superior to that in group A. However, there was no statistical difference in mean surgical time, blood loss, fracture healing, satisfactory rate of reduction quality and satisfactory rate of functional outcome between two groups.

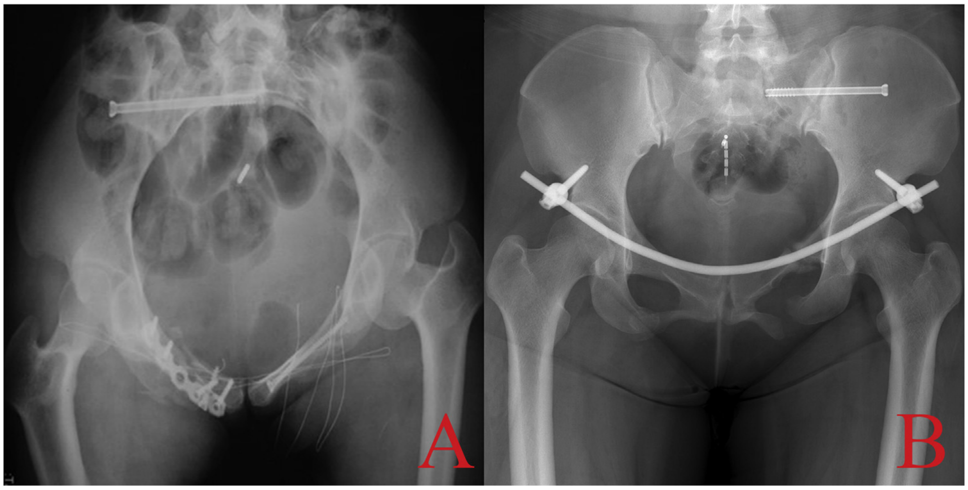

Fig. 3. Some relevant complications were presented. A, the sacroiliac screw was threaded through the anterior sacral cortex in the inlet view, which would lead to sacral nerve injury; B, screw loosening occurred during the rehabilitation process.

Table 3
Complications of two groups.

Characteristics	Group A	Group B
Sacral nerve damage	1	–
Screw loosening	3	–
Hematoma	–	1
Soft tissue infection	1	1

The complication rate was 16.13% (5/31) in group A and 5.13% (2/39) in group B (P = 0.222).

fracture sites generated from sacroiliac screws. Additionally, screw loosening may occur during rehabilitation exercise because there is a certain degree of micro-motion in the sacroiliac joint.

The Z-shaped plates of MIAP conformed well to the irregular contour of bilateral PSISs. Thus, the device can be easily implanted without pre-bending. The majority of rotational deformities in the hemipelvis can be managed through the anterior approach. Poking reduction of the vertically displaced sacral fractures could also be accomplished through minimally invasive incisions. Additionally, a rotational rod is included in the MIAP, which could reduce separated or compressed displacement through adjusting its length. Compared with the percutaneous sacroiliac screw

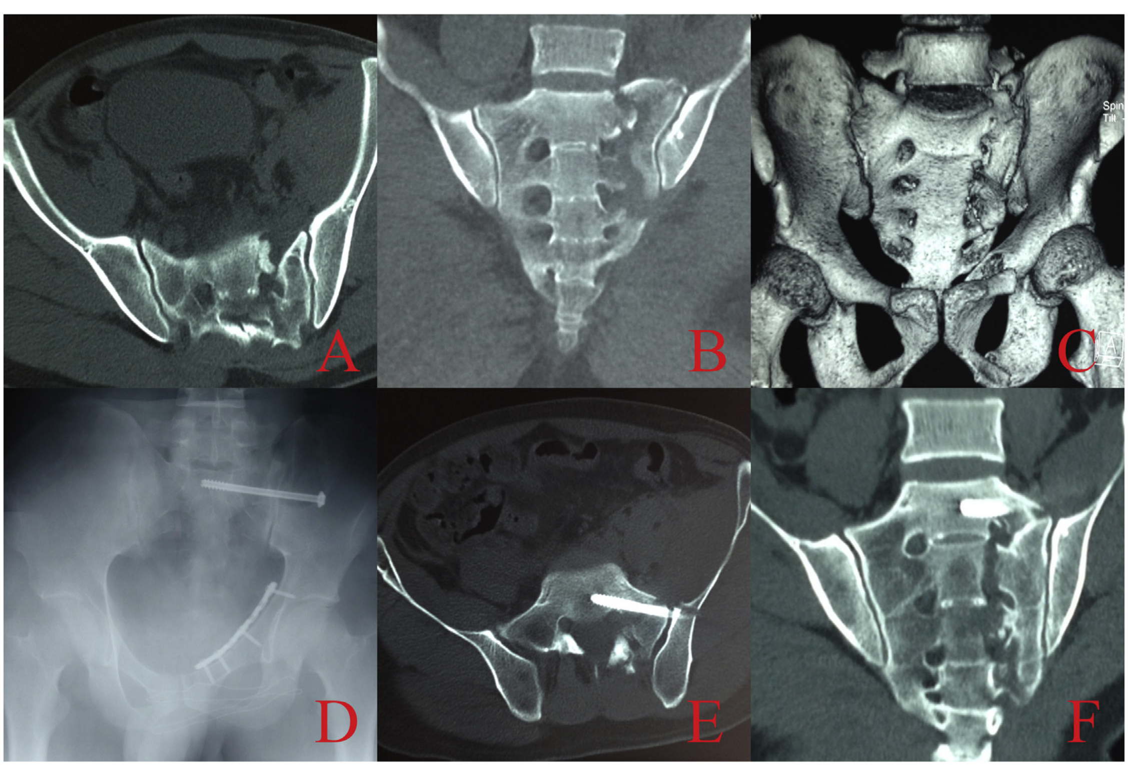

Fig. 4. One patient fixed with sacroiliac screw was presented. A–B, preoperative CT scans; C, preoperative three-dimensional reconstruction; D, postoperative anteroposterior projection; E–F, postoperative CT scans.

technique, the reduction procedure with MIAP offers numerous advantages, and this procedure is another widely employed technique to manage Zone II sacral fractures in our institution (Fig. 5). Moreover, MIAP could be applied to fix sacral dysmorphism fractures because screw fixation was performed in the bilateral PSISs.

Sacral neurologic injury associated with sacral fracture may lead to long-term disability in trauma victims if the damaged nerves did not obtain adequate decompression. However, direct exposure of the sacral nerve is technically demanding and may lead to a high rate of complications. Closed decompression of damaged nerves can be achieved by MIAP because of its effective reduction ability. Recovery of relative symptoms was obtained for some sacral fractures with neurologic injury in our institution.

The device, which functioned as a suspension bridge structure, could restore the integrity of the posterior pelvic ring [8]. Moreover, a biomechanical study demonstrated that sacral fractures fixed with MIAP could obtain a more stable fixation effect than those fixed with a tension band plate under torsional and vertical load [8]. Fixation failure associated with MIAP was not observed in the study.

Favourable clinical results can be obtained through the MIAP procedure, which is easy to perform. Fluoroscopy-guided screw placement could be avoided given the lack of important vessels or nerves in areas of screw insertion. However, compared with group A, no advantages regarding surgical time or blood loss were noted. The reason for this lack of a difference may involve the exchanging position and re-sterilization in surgical procedures. The MIAP is located in the subcutaneous layer, and soft tissue complications (hematoma and infection) may be noted postoperatively, especially in thin patients. Then, air-cushion bed should be applied within two weeks postoperatively to avoid related soft tissue complications.

There are some limitations in this study. Patients who fixed with tension band plates or the lumbopelvic technique were not included as control groups. The study had a small sample size and a relatively short follow-up period, which may reduce the persuasiveness of the findings. As a retrospective study, the patients were not randomly divided into two groups. Additionally, bilateral sacral fractures were excluded in this study, thus, the results may not be generalized to all Zone II sacral fractures. More patients should be recruited to further explore the treatment of sacral fractures.

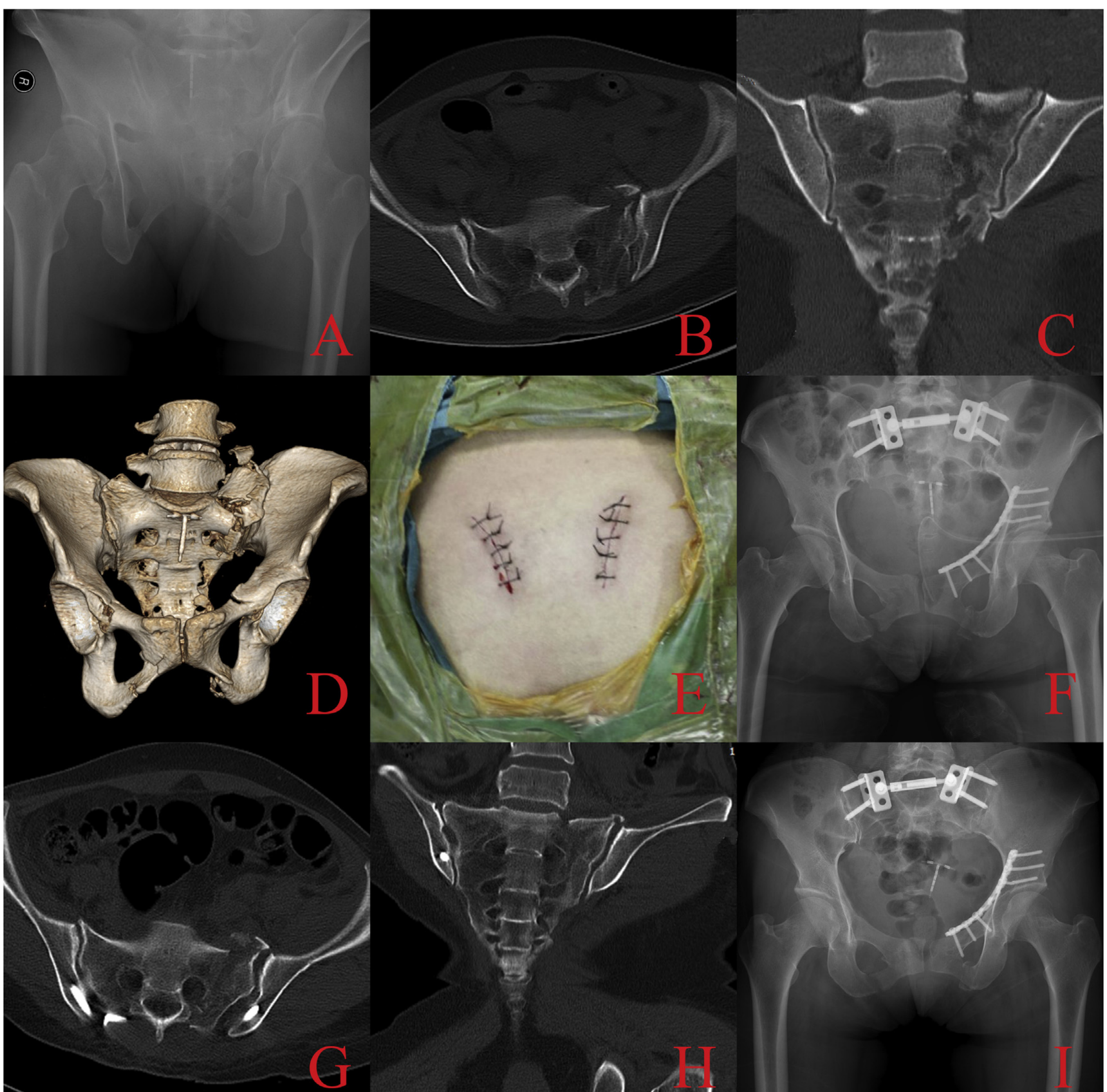

Fig. 5. A patient treated with MIAP was presented. A, preoperative anteroposterior view; B–C, preoperative CT scans; D, preoperative three-dimensional reconstruction; E, surgical incisions of MIAP technique; F, postoperative anteroposterior projection; G–H, postoperative CT scans; I, anteroposterior radiograph at 6 months postoperatively.

Conclusion

MIAP has a fixation effect and exhibits reduction potential for Zone II sacral fractures. Favourable radiographic and functional results could be obtained through the MIAP technique, which is easy to conduct without pre-contouring. Compared with the unilateral S1 sacroiliac screw technique, repeated projections and iatrogenic sacral injury can be avoided.

Conflict of interest

All authors declare that they have no conflicts of interest.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.injury.2019.02.011.

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