Comparison of Efficacy between 3D Navigation-Assisted Percutaneous Iliosacral Screw and Minimally Invasive Reconstruction Plate in Treating Sacroiliac Complex Injury

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Summary: The clinical efficacy was compared between 3D navigation-assisted percutaneous iliosacral screw (3DPS) and minimally invasive reconstruction plate (MIRP) in treating sacroiliac complex injury and the surgical procedures of 3DPS were introduced. A retrospective analysis was performed on 49 patients with sacroiliac complex injury from March 2013 to May 2017. Twenty-one cases were treated by 3DPS, and 28 cases by MIRP. Intraoperative indexes as operative time, blood loss, incision length, length of hospital stay and postoperative complications were respectively documented. Quality of reduction was postoperatively evaluated by Matta radiological criteria, and clinical effect was assessed by Majeed scoring criteria at the last follow-up. Operative time and hospital stay were significantly shortened, and blood loss, and incision length were significantly reduced in 3DPS group as compared with those in MIRP group (P<0.05). No statistically significant difference was found between 3DPS group and MIRP group in the assessment of reduction and function (P>0.05). It was concluded that both 3DPS and MIRP can effectively treat the sacroiliac complex injury, and 3DPS can provide an accurate, safe and minimally invasive fixation with shorter operative time and hospital stay.
Key words: sacroiliac complex injury; 3D navigation-assisted system; percutaneous iliosacral screw; minimally invasive reconstruction plate

Sacroiliac complex (SIC), as a vital structure of posterior pelvis ring, plays a main role in sustaining stability of pelvis. How to effectively treat the injury of SIC has been challenging the doctors. Conservative therapies require longer time for decubitus, which causes high potential risks involving dysfunction of organs, deep vein thrombosis (DVT) and other mortal complications. Although open reduction and internal fixation including minimally invasive reconstruction plate (MIRP) could shorten the operative time, such surgery characterized by obvious trauma and bleeding has higher requirement for physical condition[1]. Along with the advent of minimally invasive techniques, 3D navigation-assisted percutaneous iliosacral screw (3DPS) has been increasingly applied for this injury due to its mini-trauma, high biomechanics intensity, stable fixation[2, 3]. Owing to the special anatomic structure of sacroiliac complex, patients associated with SIC injury are always expected to use the iliosacral screw with more reasonable diameter and effective length. 3D navigation-assisted technique could improve the accuracy in those aspects above. We retrospectively analyzed 49 patients with SIC injury who had been treated with 3DPS or MIRP from March of 2013 to May of 2017. This paper aims to compare the efficacy of the two techniques and introduce the surgical procedures of 3DPS.

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1 MATERIALS AND METHODS

1.1 Clinical Data

This clinical research proposal had obtained the agreement from the PLA General Hospital of Central Theater Command (the medical ethical committee of the corresponding author's hospital). Informed consents had been obtained from all participants.

Twenty-one cases in 3DPS group (15 males and 6 females with mean age of 42.5±4.6 years old) and 28 cases in MIRP group (20 males and 8 females with mean age of 40.7±6.8 years old) with the SIC injury had been collected from March of 2013 to May of 2017. Injury mechanisms included road traffic accidents (15 cases), falls from a height (5 cases) and crush trauma (1 case) in 3DPS group. According to Tile classification systems for pelvic fractures, there were 2 cases of Tile B2, 6 cases of Tile B3, 5 cases of Tile C1, 6 cases of Tile C2, and 2 cases of Tile C3 fractures[4]. Among them, 5 cases involved dislocation of sacroiliac joint, 10 cases experienced fracture of Denis Ⅰ area and 6 cases of Denis Ⅱ area (including 1 patient suffering hip injury of Morel-Lavallée)[5]; Nine cases had fracture in bilateral ramus superior and inferior ossis pubis, 7 cases in unilateral ramus superior and inferior ossis pubis, 2 cases in acetabulum, 7 cases in four limbs, 2 cases of separation of symphysis pubis, 2 cases having lesion with lumbosacral trunk, 3 cases of trauma of skull, 3 cases of ventrum injury. The conditions of patients were defined by Revised Injury Severity Score (RISS)[6] as follows: 11 cases of moderate injury, 7 cases of severe injury, and 3 cases of grave injury. There were 19 cases of road traffic accidents, 6 cases of falling from a height and 3 case of crush injury in MIRP group. According to Tile classification systems, there were 3 cases of Tile B2, 8 cases of Tile B3, 7 cases of Tile C1, 7 cases of Tile C2, 3 cases of Tile C3 fractures. Among them, 7 cases involved dislocation of sacroiliac joint, 10 cases experienced fracture of Denis Ⅰ area and 11 cases suffered Denis Ⅱ area; 5 cases had fracture in bilateral ramus superior and inferior ossis pubis, 13 cases in unilateral ramus superior and inferior ossis pubis, 1 case in acetabulum, 9 cases in four limbs, 3 cases having lesion with lumbosacral trunk, 1 case of trauma of skull, and 2 cases of ventrum injury. The conditions of patients were defined by RISS as follows: 15 cases of moderate injury, 9 cases of severe injury, and 4 cases of grave injury.

1.2 Preoperative Management

Vital signs were the first consideration to the patients with trauma of pelvis. X-ray including the anterioposterior, inlet, outlet and oblique plane and CT 3D reconstruction could assist in confirming the whole lesion of pelvis and preoperative planning. Fractures or injuries from other parts have been treated respectively first. Skeletal traction of supracondyle of femur (6–8 kg) was essential while the displacement existed, and if traction failed to treat dislocation of iliosacral joint and fracture of acetabulum, internal fixation had been recommended from anterior approach of pelvis before those surgeries. The average duration of preoperative management for those managements was 8.2±2.3 days.

1.3 Surgical Strategies

1.3.1 3DPS Operation All iliosacral screws were placed percutaneously except one patient with Morel-Lavallée injury. Patients with single screw were placed in a supine position, with two screws in a prone position after anesthesia on the radiolucent table. Registration for navigation equipment was the first step of procedure. Pelvis of each patient was scanned by CT and data were transferred to 3D navigation system (Stryker, USA) to provide clear structure of iliosacral joint on screen with cross section, coronal, sagittal plane as well as the 3D picture of pelvis. A line was drawn between anterior and posterior superior iliac on the skin, and the entry point was marked at the rear of one third of this line. Induced navigated drill sleeve on the skin could generate virtual guide pin (green arrow in typical case, fig. 1) though whole bone. Adjustment of the induced navigated drill sleeve from posterior to anterior direction could simulate the route to make sure virtual guide pin was utterly contained in the bone and the largest length and diameter were achieved (7.33 mm). Then the real guide pin with the diameter of 2.5 mm was properly inserted along the navigated sleeve with the assistant of fluoroscopy including the pelvis anterioposterior, inlet, outlet, plane and sacral lateral positions. Once the guide pin was correctly placed, the length of the pin out of the bone was measured for deciding the length of screw. In the next step, hollow drill was applied to create an entrance. The cannulate screw (Waston, China) with large diameter (7.33 mm) was inserted along the guide pin with a pad and the guide pin was removed finally.

1.3.2 MIRP Operation The surgical procedures of MIRP group were as follows. Firstly, the injury of anterior pelvic ring could be fixed by percutaneous tunnel reconstruction plate or pubic screws. Thereafter, patients were adjusted to the prone position. The bilateral posterior iliac crests were viewed as the bony mark to make a curved incision, which was about 3 to 5 cm long, and the skin was cut until to the periosteum. The fracture fragments and dislocation of sacroiliac joint could be exposed by extraperiosteal stripping. For patients with neurological manifestations of lumbosacral trunk, the sacrum holes should be enlarged and the instruments were also helpful for reduction of fractures or dislocations. In order to prevent the skin being squeezed when the posterior iliac crest was fixed by plate, the square fracture fragment from the posterior iliac crest was cut out, and a subcutaneous tunnel was created behind sacrum by the periosteal stripper. Then, the reconstruction plate was pre-contoured according to the trial molding, and 3 to 4 screws preferably penetrated into the contralateral cortical bone were fixed on the bilateral posterior iliac crest. Finally, the reduction of fracture, the length of the plate and screws were checked by C-arm. And the incision was flushed and sutured after acquiring satisfied fluoroscopy (fig. 2).

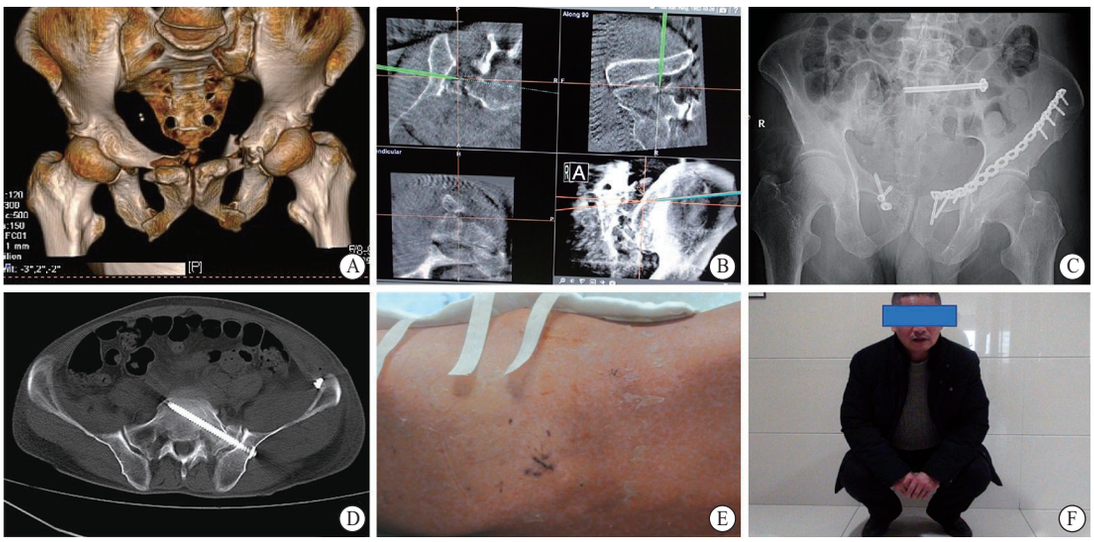

Fig. 1 Typical case in 3DPS group
Male, 62 years old, traffic accident injury for pelvis fracture of Tile C2 (bilateral ramus superior and inferior ossis pubis and left sacrum fracture with Denis Ⅱ area) undergoing internal prestabilization from anterior ring and unilateral 3DPS. A: preoperative 3D reconstruction of traumatic pelvis; B: intraoperative 3D picture. The green virtual guide pin shows the enter point and direction of route. C and D: postoperative X-ray (C) and CT (D) of pelvis, plate and 3DPS; E: minimal incision; F: good function at last follow-up

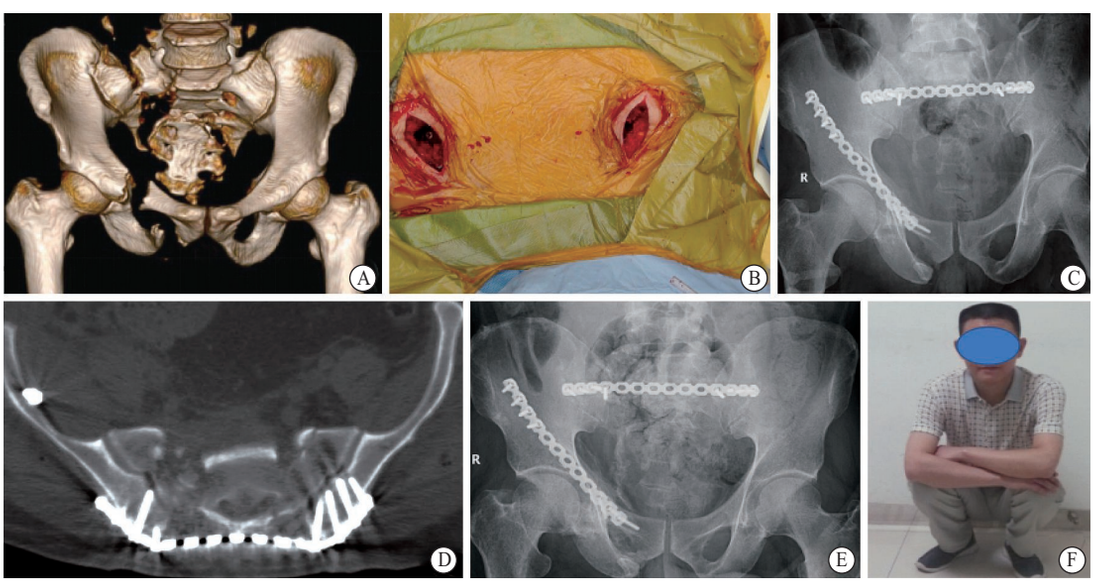

Fig. 2 Typical case in MIRP group
Male, 45 years old, traffic accident injury for pelvis fractures of the Tile C3 (unilateral ramus superior and inferior ossis pubis and bilateral sacrum fracture with Denis Ⅱ area) undergoing minimally invasive reconstruction plate internal fixation. A: preoperative 3D reconstruction of pelvis fracture; B: intraoperative incision; C and D: postoperative pelvic X-ray (C) and CT (D) 3D reconstruction used to evaluate fracture reduction and position of plate and screw; E: the X-ray of pelvis 3 months after operation; F: The patient's function recovered well after follow-up.

1.4 Postoperative Management

The antibiotics was given to patient in the 48-h postoperative period. Oral medicine was used to prevent DVT for 35 days. Fluoroscopy and CT were applied on the 3rd postoperative day in confirming the reduction condition and position of screws. Then Matta radiological evaluation was carried out. Anti-osteoporotic medicine was continuously given after patients were discharged from the hospital if patient had osteoporosis. Meanwhile, each patient was informed the exercise instruction of rehabilitation and revisit schedule during the follow-up. Symptom, sign, function, and image files were sufficiently collected timely at each follow-up. The Majeed scoring criteria were recorded in the last follow-up.

1.5 Assessment of Therapeutic Effect

Postoperative reductions were assessed by Matta radiology criteria[7]: excellent (≤4 mm), good (5–10

mm), fair (11–20 mm), and poor (>21 mm). At the last follow-up, the pelvic function was assessed according to the Majeed scoring criteria[8]. Five factors were assessed and scored: pain (30 points), standing (20 points), sitting (10 points), sexual intercourse (4 points) and performance at work (36 points). Meanwhile, the five factors of the assessment were divided into four clinical grades: excellent (>85 points), good (70–84 points), fair (55–69 points), and poor (<55 points). Statistical data were analyzed by using SPSS 14.0 statistical software. Format like mean±standard deviations (SD) was utilized, and *T*-test was used for measurement data normally distributed. Meanwhile, the excellent rate based on Matta radiological and Majeed scoring criteria was compared with Chi-square. $P<0.05$ was regarded as statistically significant difference.

2 RESULTS

Seventy-seven screws in 21 cases of 3DPS group were placed without neurovascular lesion. The mean surgical time in 3DPS group (43.31±6.78 min) was significantly shorter than in MIRP group (132.46±28.28 min, $P<0.05$). The average blood loss in 3DPS group was significantly reduced as compared with that in MIRP group (16.43±3.17 *vs.* 135.00±23.96 mL, $P<0.05$). The mean incision length in 3DPS group was significantly shorter than in MIRP group (11.19±2.46 *vs.* 90.21±11.54 mm, $P<0.05$). The mean hospital stay in 3DPS group was significantly shorter than in MIRP group (12.48±1.47 *vs.* 23.29±4.97 days, $P<0.05$) (table 1). Two screws did not achieve a satisfactory position during the surgery in 3DPS group. Contralateral cortical bone of S1 centrum in one case was perforated about 2 mm in 3DPS group (fig. 3). Despite the perforation, the patient had not developed any neurologic symptom. We concluded that the misplacement was induced by the bending of the guide pin. The other one suffered the breaking of the lateral iliac plate by the pad of screw (fig. 4). One patient complicated with fracture of acetabulum and partial irritation of lumbosacral trunk underwent internal fixation with plate and screws from anterior approach firstly and cannulate screw for injury of SIC later on. His neural symptom disappeared about 3 months later after the treatment of medicine and acupuncture. One patient with Morel-Lavallée injury achieved final recovery after postoperatively undergoing open debridement with deep drainage and VSD. Postoperative Matta radiological criteria showed that the excellent rate was 95.24% in 3DPS group and 89.28% in MIRP group ($P>0.05$) (table 2). All patients were followed up for 15.4±3.4 months. One screw moved backward for 1 cm in 3DPS group at the 1st month of follow-up, and this abnormal situation was controlled by immobilization with nonbearing heavy gesture (fig. 5). This patient revealed no abnormal symptom and acquired final good function. One case lost the follow-up. The Majeed standard of pelvic function evaluation at the last follow up showed the excellent rate with 95.24% in 3DPS group and 96.30% in MIRP group ($P>0.05$) (table 2).

3 DISCUSSION

Recently, along with the development of traffic and building industry, SIC injury has became more common than before, which created huge risk to patient and challenged the doctors[9]. Conservative treatments always require long-term rest on bed, which could induce some morbidities. Therefore, the surgery was recommended. MIRP from posterior approach was widely used in the treatment of SIC injury. It was a bridge fixation from the posterior sacrum. The reconstructed

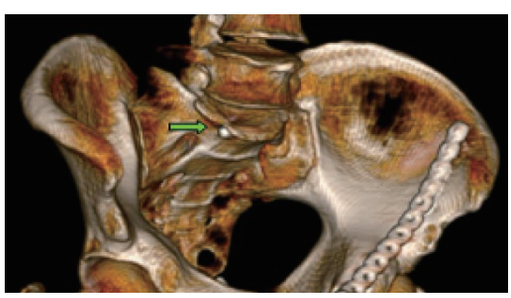

Fig. 3 Perforation of screw into the contralateral cortical bone of S1 centrum for 2 mm (green arrow)

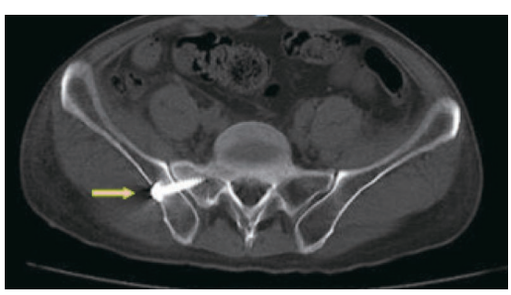

Fig. 4 The pad of screw breaking lateral iliac plate (yellow arrow)

Table 1 Comparison of intraoperative and postoperative observational indexes between the two groups

Groups	*n*	Operation time (Mean±SD, min)	Blood loss (Mean±SD, mL)	Surgical incision length (Mean±SD, mm)	Hospital stay (Mean±SD, days)
3DPS	21	44.31±6.78	16.43±3.17	11.19±2.46	12.48±1.47
MIRP	28	132.46±28.28	135.00±23.96	90.21±11.54	23.29±4.97
T	-	–13.95	–22.47	–30.79	–9.46
P	-	0.000	0.000	0.000	0.001

Table 2 Comparison of postoperative reduction quality and functional score between the two groups

Groups	Matta evaluation criteria			Pelvic function Majeed score		
	Excellent	Good	Poor	Excellent	Good	Poor
3DPS	14	6	1	11	9	1
MIRP	19	6	3	15	11	1
Chi-Square		0.567			0.118	

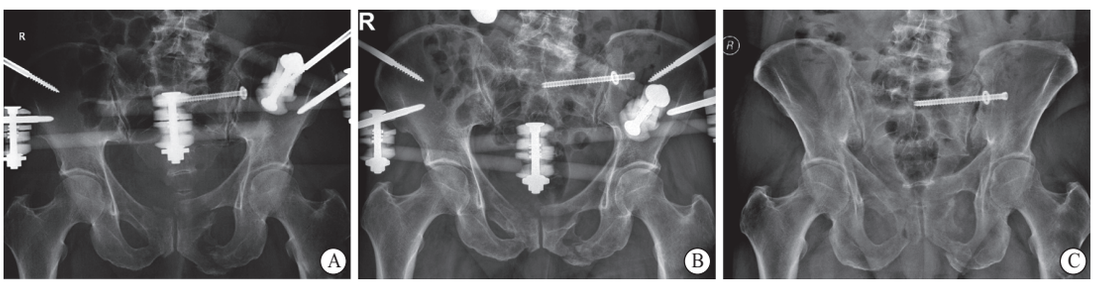

Fig. 5 A: Fixation with ISCS and external fixation; B: The ISCS moved backward for 1 cm at the 1st month of follow-up period; C: The 3DPS has kept immobilization with reasonable intervention until bone healing.

plate was able to appropriately attach to the posterior superior iliac by being pre-bended and shaped. This internal fixation could simultaneously manage the bilateral sacroiliac complex injury. Meanwhile, it could provide no compression on the pupil and fistula, which could avoid the risk of neurovascular injury[10]. Moreover, MIRP has wider indications not only for sacroiliac joint dislocation, Denis Ⅰ or Ⅱ fractures, but also for Denis Ⅲ fractures[11]. Although open surgery could repair stabilization of pelvis posterior ring and reduce the duration for patient on the bed, patient with well body constitution was the premise. Nevertheless, this requirement may be beyond the reach of most elderly patients who are always associated with age-related internal secretion and cardiovascular diseases. Furthermore, the sacrum might fail to guarantee a firm fixation from the plates, once the severe fracture occurred. Intraoperative blood loss, surgical trauma and longer recovery time were un-avoided issues. Meanwhile, the plate rupture, as a severe complication, has been remaining a concern in terms of previous study[1].

Compared with MIRP, iliosacral screw fixation was a reliable method in the stabilization of unstable pelvic fractures which provided well results on the severe pelvic fractures and SIC injuries with low rates of complications and the minimally invasive nature[12]. Matta *et al*[7] had reported that iliosacral screw had more advantages than plates and sacrum intrasacral rod in the biomechanical force for the unstable pelvic ring injuries. Iliosacral screw with adequate length and diameter in the bone could provide adequate strength to sustain the stability of pelvis posterior ring[13, 14]. Some studies even applied bone cement combined with sacroiliac screw in order to increase the strength of sacroiliac screw, steady of pelvis ring and relieve symptom of pain[15, 16]. Along with the development of technique, navigation with screw combined with bone cement was applied for this injury, and some researches have presented firm fixation yet without satisfied position of screws[17–19]. Additionally, further long-term effect of bone cement reinforced technique remained uncertain.

Complex anatomy of pelvic ring and high possibility of variation near lumbosacral region enhanced the difficulty for the correct placement of iliosacral screw. Various planes of fluoroscopy were used for insertion of screws, but an obvious shortage of that was the loss of view of sacral foramina. Therefore, screw placement with high accuracy by solitary fluoroscopy still challenged doctors. In spite of CT-guided iliosacral screw being introduced before, this technique, without 3D navigation system, required patient to remain unchanged position from preoperative CT scanning to screw insertion. A comparative study from Amiot *et al* had pointed out that 16%–40% of malposition occurred for iliosacral screw under the sheer fluoroscopy, but the rate of that reduced to 5% while the 3D navigation had been applied[20]. SIC injury is always associated with comminuted fracture of sacrum, which would definitely raise risk for screw insertion if only the fluoroscopy was utilized. Consequently, the screw might fail to firmly fix bone for lack of sufficient length and diameter. Scholars[21] have performed the operation of screw insertion utilizing the human pelvis model in order to compare the different length of screws under X-ray and 3D navigation. Conclusion had came out that the length of screw in 3D navigation group reached 89 mm on average which was much longer than X-ray group with 57 mm.

Iliaosacral screw without proper type will

significantly decrease its force even if it was safely located at position from right enter point and insertion angle, which have been previously proved by Wang *et al*[22]. Only if screw was located at correct position and possessed enough force at same time can it be regarded as the ideal internal fixation. Meanwhile, 3D navigation system enabled surgeons to preoperatively design the route of screw with individuation and operatively control whole procedure with visualization. Screw could be set at optimal position with the largest length and diameter in accordance with 3D navigation system. Therefore, percutaneous iliosacral screw with assistance of 3D navigation just was capable of meet requirements mentioned above for various SIC injuries. With help of 3D navigation system, preoperative CT and intraoperative X-ray, 21 cases associated with SIC injury had underwent the treatment by percutaneous iliosacral screw. Apex of each screw could almost reach the contralateral wall of sacrum without perforation except that one case threaded out approximate 2 mm because the guide pin was bent in the bone. Twenty-seven iliosacral screws averagely acquired 87.3±5.4 mm in length.

To the current authors' knowledge, there is no well-validated measures dedicated to doctors for management of the fracture of pelvis with Morel-Lavallée injury, and the best time for the surgical therapy is still controversial[23]. Firstly, accurate diagnosis for injury of Morel-Lavallée was premise. Patients always had been placed in a supine position for skeletal traction since they entered hospital. Surgeons might mainly focus on the bone condition and ignore the soft tissue lesion under skin of bottom. The Morel-Lavallée in our study had been ignored until fluctuation on buttocks was found even when they were laid on the operation table. This was indeed a lesson we needed to mention. Apart for the diagnosis of injury of Morel-Lavallée, the treatment of that was still an issue. Conventionally, debridement combined with VSD is always firstly performed, and surgery for pelvis fracture is carried out after soft tissues have utterly recovered on the second step. Nevertheless, long time of recovery of soft tissue, in reality, was likely to delay the best surgery opportunity of fracture. For this Morel-Lavallée injury, open debridement with deep drainage and VSD were adequately carried out before the application of 3DPS for her concurrent SIC injury. This patient eventually acquired satisfied result (fig. 6).

Although the SIC injury could benefit from navigation-assisted percutaneous iliosacral screw, there were still some issues that required further attention. Main notices were mentioned as follows in accordance with whole present procedure and corresponding articles review: (1) Satisfied reduction of sacroiliac joint and sacrum was the premise of utilization of 3DPS, otherwise any abnormal biomechanism of pelvis induced by relative migration of the iliosacral structure might eventually cause failure of this surgical fixation. (2) The real guide pin with small diameter should be avoided and extra pressure was not recommended to be put on the drill while the pin was inserted along the navigated sleeve. Because both may lead to the curve of pin, and the screw followed the pin would induce to perforation for the contralateral wall of sacrum. (3) Guide pin was easy to perforate contralateral cortex of sacrum due to the osteoporosis in elderly patients. Three monitoring points located at sacroiliac joint (2.0–3.0 cm from entrance point), lateral edge of sacrum (4.5–5.5 cm), midline of sacrum (7.0–8.0 cm) were set with the assistance of X-ray to observe the

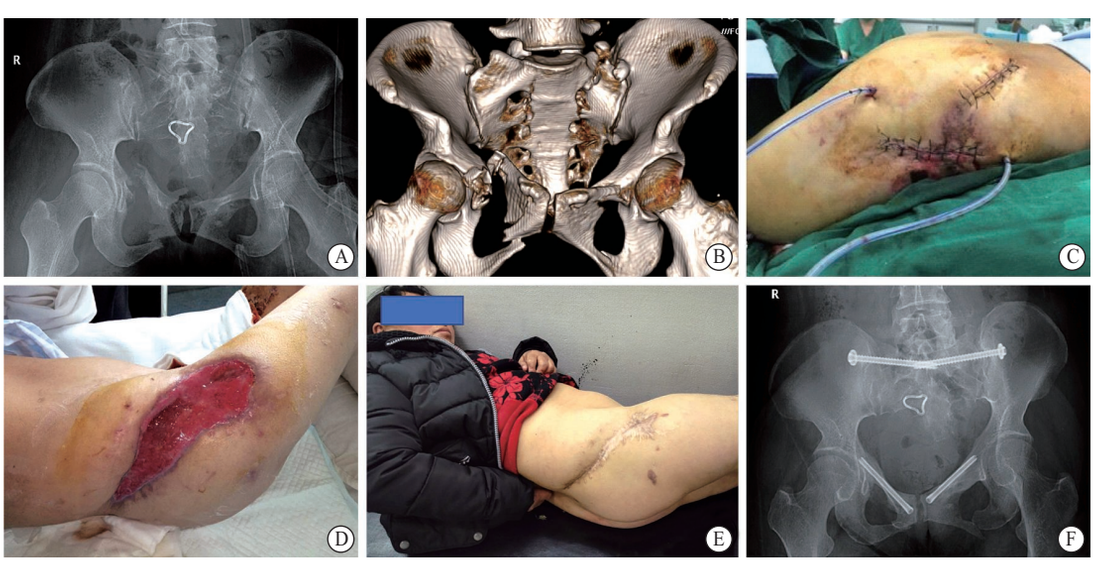

Fig. 6 Female, 65 years old. A–F: traffic accident causing pelvis fracture of Tile C3, Denis Ⅱ area with Morel-Lavallée injury on right bottom. We performed open debridement with deep drainage and VSD meanwhile fixed sacroiliac complex with 3DPSs. Despite patient underwent debridement and VSD twice, she achieved satisfied result finally.

insertion process for reducing the possibility of such complication. (4) Commonly, pad of appropriate size was utilized on the tail of screw when dislocation of sacroiliac joint and obvious malposition of sacrum occurred. Under this condition, the pad was able to enhance the effect of compression when screw threaded into bone which could prevent the tail of screw from breaking the cortex of ilium. (5) Apart from 3D navigation system, fluoroscopic control during the insertion was needed too. The former supplied the accurate and safe measurement from pictorial aspect, and the latter was used in actual operation. It was easy for surgeons to lose control when they inserted the screw without monitoring if the patient had suffered osteoporosis. Such iatrogenic damages as lesion of external and internal cortex of ilium and neurovascular element located at contralateral part of sacrum could be avoided by the scientific method combined with 3D navigation system before screw inserting and fluoroscopy monitoring during that.

In summary, both 3DPS and MIRP internal fixation could effectively treat the SIC injury. However, the shorter surgery duration, less blood loss, shorter hospital stay and the minimally invasive nature are the advantages of 3DPS. Nevertheless, some items need to be specially noticed during the 3DPS surgical procedure, and its indication also raises concern.

Conflict of Interest Statement

There are no conflicts of interest.

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