

A novel computer navigation method for accurate percutaneous sacroiliac screw implantation

A technical note and literature review

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Abstract

The purpose of this study was to assess the accuracy of percutaneous sacroiliac screw (PSS) placement assisted by screw view model of navigation system for treatment of sacroiliac fractures.

Data pertaining to 18 consecutive patients with posterior pelvic ring fracture who received sacroiliac screw fixation between January 2015 and July 2018 at the Second Hospital of Jilin University were retrospectively analyzed. Kirschner wires were placed under the guidance of navigation's screw view mode. The position of the screws was evaluated by computed tomography (CT) scan postoperatively. Fracture dislocation of sacroiliac joint was measured in axial, sagittal, and coronal views of 3 dimensional (3D) CT images preoperatively, postoperatively and at the last follow-up visit. The duration of trajectory planning, guide wire implantation time, screw placement time, intraoperative blood loss, and incidence of screw loosening and clinical complications were also assessed.

A total of 27 screws were placed unilaterally or bilaterally into segments S1 or S2. Screw placement was rated as excellent for 88.9% of screws (n=24), good for 7.4% (n=2), and poor for 3.7% (n=1). Preoperatively, the average fracture dislocation of sacroiliac joint on axial, sagittal, and coronal views was 14.3mm, 9.6mm, and 7.4mm, respectively, and the corresponding postoperative figures were 5.6mm, 3.2mm, 4.1mm, respectively. The corresponding correction rates were 60.8%, 66.7%, and 44.6%, respectively. The mean duration of trajectory planning was 6.5 min (2.7–8.9 min). Mean screw implantation time was 32 min (range, 20–53 min), and the mean guide wire implantation time was 3.7 min (range, 2.1–5.3 min). No clinical complications such as neurovascular injury, infection or screw loosening were observed on follow-up.

The PSS placement under guidance of screw view model of navigation is a convenient, safe and reliable method.

Abbreviations: 3D = three dimensional, CT = computed tomography, PSS = percutaneous sacroiliac screw.

Keywords: accurate, navigation, percutaneous, sacroiliac screw

1. Introduction

Posterior pelvic ring injury treated with post-reduction percutaneous sacroiliac screw (PSS) fixation has become an effective method to stabilize sacral fractures and associated damage to posterior sacroiliac ligament.^[1–5] The traditional method for PSS fixation involves use of C-arm fluoroscopy to guide the position of guide wire in the inlet, outlet, and true lateral views.^[6] However, this method requires a highly skilled operator and typically has a long learning curve.^[7] Moreover, the procedure

involves considerable radiation exposure^[8,9] because of the need to repeatedly adjust the location of the guide wires. The reported incidence of screw malposition under fluoroscopic guidance ranges from 2% to 68%,^[10–13] and the reported rates of nerve injury range from 0.5% to 7.9%.^[10,11]

For PSS insertion, many kinds of computer aided technologies have been developed, such as computed tomography (CT)-based navigation,^[11] 2-dimensional (2D) fluoroscopic navigation,^[14,15] 3 dimensional (3D) fluoroscopic navigation systems,^[12,13,15] and robot-assisted navigation.^[3] However, these techniques also require detailed anatomical knowledge and extensive surgical experience. In this study, we assessed the outcomes achieved with use of a screw view model of navigation for PSS fixation in patients with sacroiliac joint fractures. The screw view model is a CT based technique with 3D reconstruction. The navigation monitor displays the static axial, sagittal, and coronal 3D anatomical images of sacroiliac joints with design screws. Use of this mode improves the accuracy and makes surgery easy and simple. To the best of our knowledge, the accuracy of PSS implanted under screw view model of navigation has not been investigated.

2. Patients and methods

2.1. Ethical approval

The study was approved by the Second Hospital of Jilin University, Changchun, China. (2018) Research and Inspection No. (297).

Editor: Johannes Mayr.

TY and SZ contributed equally to this work.

The authors have no conflicts of interest to disclose.

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Medicine (2019) 98:7(e14548)

Received: 20 October 2018 / Received in final form: 15 January 2019 /

Accepted: 18 January 2019

<http://dx.doi.org/10.1097/MD.0000000000014548>



Figure 1. A 39-year-old male patient (Case 10) sustained injury due to fall from height. (A) Preoperative X-ray shows pelvic ring fracture and right femoral neck fracture. (B) Postoperative radiography of pelvis. (C) Follow up X-ray shows no loosening of screws and good fracture healing.

2.2. Patients

In this study, we retrospectively analyzed the data pertaining to 18 patients (8 male, 10 female; mean age, 41.1 years) who received PSS fixation at the 2nd Hospital of Jilin University between January 2015 and July 2018. The cause of injury included road traffic accidents and fall from height. The indications for screw view mode navigation surgery for PSS were: First, patients without osteoporosis. Second, stable fracture of the sacroiliac joint with minimal dislocation. Third, in case of unstable sacroiliac joint fractures, it is essential to achieve accurate reduction before screw can be inserted. Fourth, patients who had received total hip replacement in the past were excluded.

All patients signed an informed consent form for operation preoperatively. The X-ray examinations were performed in all patients preoperatively, postoperatively, and at the last follow up visit (Figs. 1–6). All operations were performed by the same surgeon who was familiar with the navigation system, and had participated in more than 80 navigation surgeries as an operator of the navigation workstation and the mobile C-arm. Before this study, the surgeon had performed approximately 20 spine navigation surgeries already, but had only participated in 5 PSS fixation operations as an assistant. Intraoperative neurophysiologic monitoring was performed during all surgeries.^[16]



Figure 2. A 43-year-old male patient (Case 9) sustained injury due to fall from height. (A) Preoperative X-ray shows pelvic ring fracture. (B) Postoperative radiography of pelvis. (C) Follow up X-ray.



Figure 3. A 31-year-old male patient (Case 12) sustained injury due to fall from height. (A) Preoperative X-ray shows pelvic ring fracture. (B) Postoperative radiography of pelvis. (C) Follow up X-ray.



Figure 4. A 26-year-old female patient (Case 17) sustained injury due to fall from height. (A) Preoperative X-ray shows pelvic ring fracture. (B) Postoperative radiography of pelvis. (C) Follow up X-ray.

2.3. Literature review

We searched PubMed, CINAHL Plus, Cochrane and Embase databases to retrieve relevant English-language publications pertaining to navigational surgery based on 2D and 3D fluoroscopy published between January 1990 and July 2018 using combinations of the following keywords:

“percutaneous screw fixation,” “sacroiliac fracture,” “sacral fracture,” “posterior pelvic ring fixation,” “iliosacral screw fixation,” “sacroiliac screw fixation,” “fluoroscopy and sacroiliac screw fixation,” “two-dimensional (2D) navigation sacral fixation,” and “three-dimensional (2D) navigation sacral fixation”. The inclusion criteria were studies that reported the

imaging technology used and the results of PSS fixation for posterior pelvic ring injury. The exclusion criteria were literature pertaining to solely anatomical research and open reduction of posterior pelvic ring injuries. We then reviewed these studies for screw insertion time, guide wire implantation time, intraoperative blood loss, and incidence of surgical complications associated with use of these technologies.

2.4. Evaluation

The primary end point of the study was the accuracy of the position of sacroiliac screws, assessed using postoperative CT



Figure 5. A 54-year-old female patient (Case 16) sustained injury due to fall from height. (A) Preoperative X-ray shows pelvic ring fracture. (B) Postoperative radiography of pelvis. (C) Follow up X-ray.



Figure 6. A 47-year-old female patient (Case 2) sustained injury due to traffic accident. (A) Preoperative X-ray shows pelvic ring fracture. (B) Postoperative radiography of pelvis. (C) Follow up X-ray.

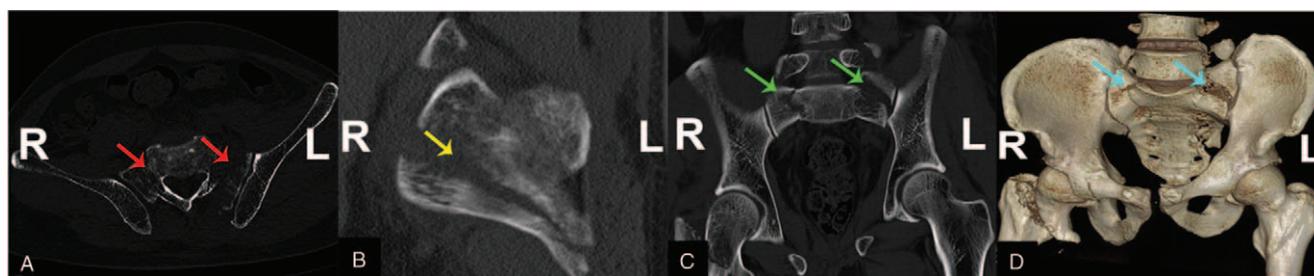


Figure 7. (A) Axial, (B) sagittal, (C) coronal, and (D) 3D images of sacroiliac CT (case 10) preoperative showing bilateral sacral fracture, right femoral neck fracture, and pubic rami fractures. The red, yellow, green and blue arrows indicate the respective fracture areas. CT = computed tomography.

scan. According to Gras et al^[14] the following criteria were used to assess screw position: excellent, no contact of screw with any cortical boundary of the sacrum and completely within the cortex of the sacrum; good, partial contact with cortical bone without perforation; poor, penetration of the cortical bone. Two radiologists who did not participate in the study performed CT analysis of screw location. The final screw position classification was determined by consensus among the 2 radiologists.

As a secondary end-point, fracture dislocation of the sacroiliac joint was measured in axial, sagittal and coronal positions on preoperative, postoperative and most recent follow-up 3D CT images (Figs. 7–14, Table 1), and the correction rate of fracture dislocation was calculated.

As a 3rd end-point, the duration of trajectory planning, the insertion time of the sacroiliac screw, the volume of blood loss, postoperative complications including neurovascular injury and

screw loosening were assessed. Although no control group was set up in this study, we compared our results with the results of the literature review (Table 2). Furthermore, the age and sex of patients, screw location, and sacral fracture zone were also recorded (Table 3).

2.5. Navigation planning

The 3D CT images of pelvis were obtained after traction and reduction of fracture. Scanning was performed caudal-cranially with 2 mm thick sections and data were stored in the Digital Imaging and Communications in Medicine (DICOM) format. The data were used for preoperative surgical planning on the navigation workstation. The navigation system provided multi-planar images, which helped determine the screw length, diameter, and the best trajectory for screw placement (Fig. 15). Generally, the length of the sacroiliac screw was no



Figure 8. Postoperative axial CT image (A) shows excellent position of the bilateral sacroiliac screws; fracture dislocation is obviously reduced on (A) axial, (B) sagittal, (C) coronal and (D) 3D CT images (case 10). The red, yellow, green and blue arrows indicate the respective fracture areas. 3D = three dimensional, CT = computed tomography.

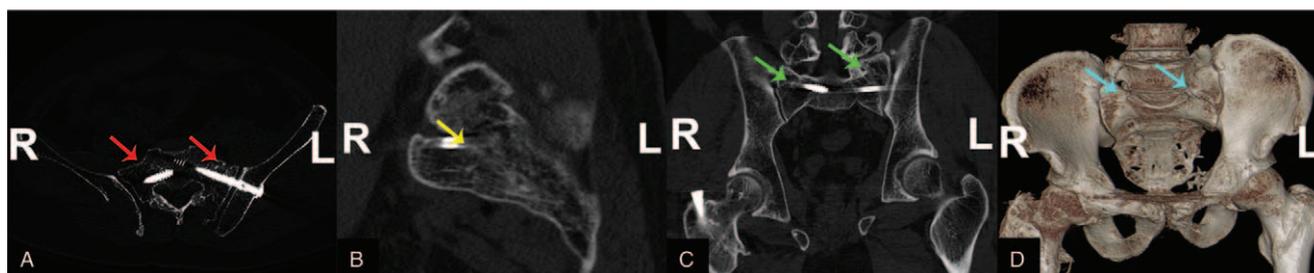


Figure 9. Follow up CT examination (case 10). (A) Axial image shows that the bilateral sacroiliac screws are in excellent position, and fracture dislocation has disappeared on (A) axial, (B) sagittal, (C) coronal and (D) 3D CT images. The red, yellow, green and blue arrows indicate good fracture healing. 3D = three dimensional, CT = computed tomography.



Figure 10. Axial CT images of case 9 examined (A) preoperatively, (B) postoperatively and (C) follow up. CT = computed tomography.

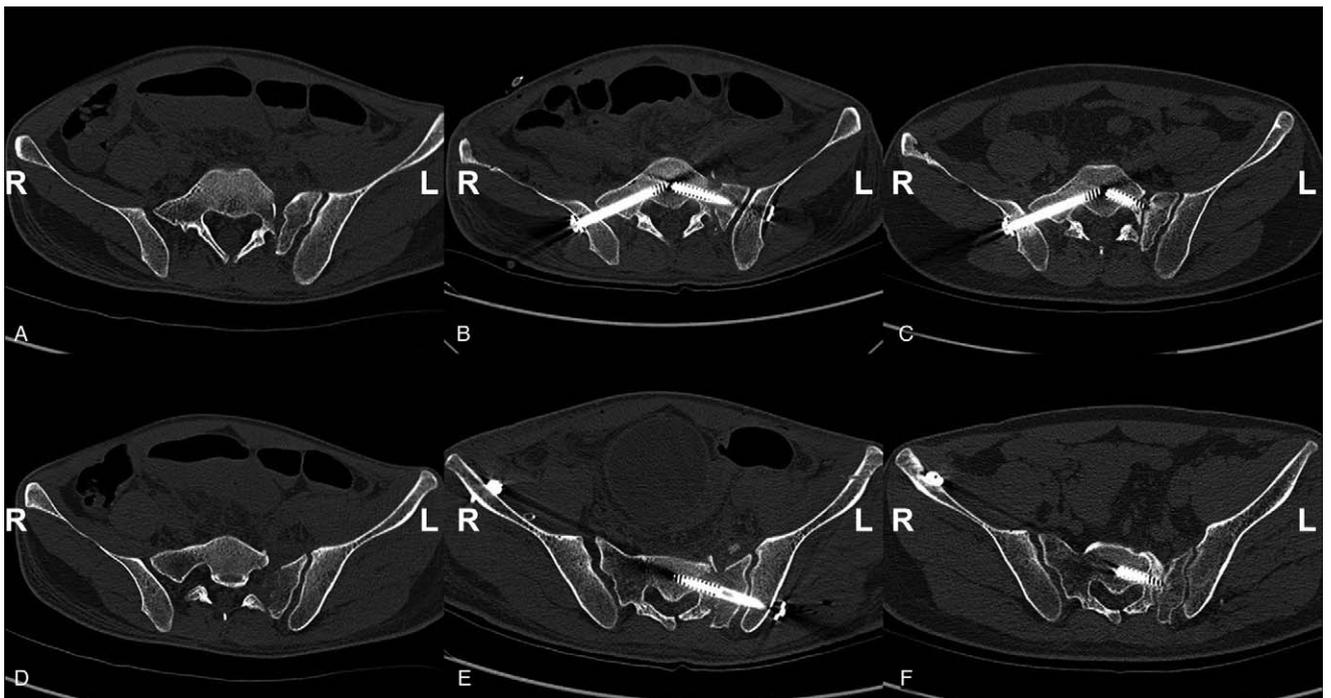


Figure 11. Axial CT images of case 12. (A, B, C) and (D, E, F) correspond to preoperative, postoperative, and follow up images of S1 and S2 respectively. CT = computed tomography.



Figure 12. Axial CT images of case 17 examined (A) preoperatively, (B) postoperatively and (C) follow up. CT = computed tomography.

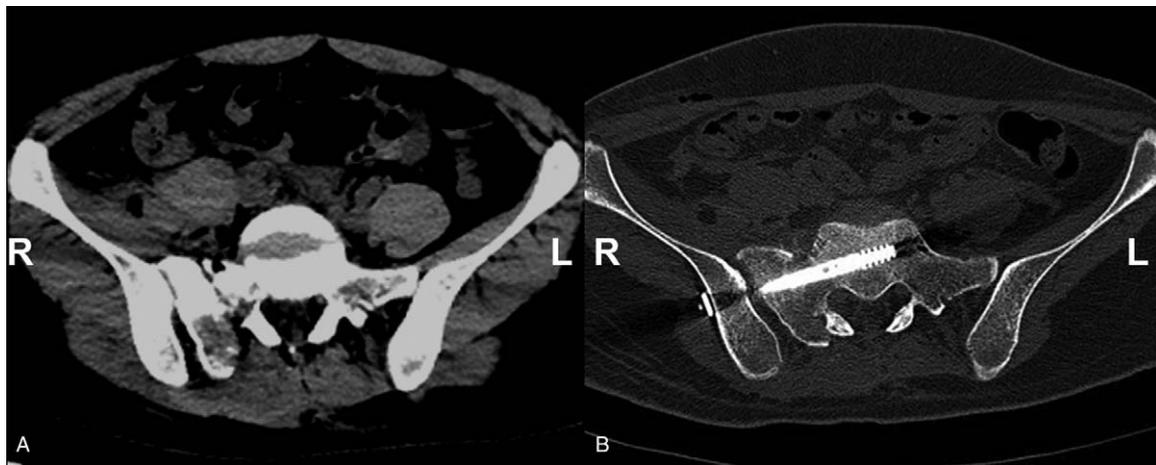


Figure 13. Axial CT images of case 16 examined (A) preoperatively and (B) postoperatively. CT = computed tomography.

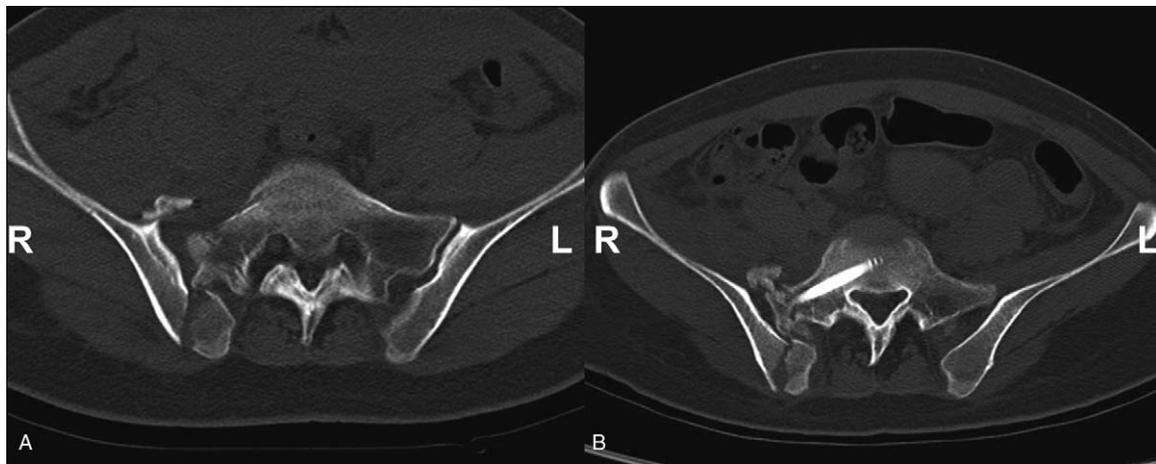


Figure 14. Axial CT images of case 2 examined (A) preoperatively and (B) postoperatively. CT = computed tomography.

more than 2-thirds of the transverse diameter of the vertebral body in the antero-posterior view;^[2] the body and the tip of sacroiliac screws were located in the cortical bone. The accuracy of navigation was checked preoperatively to confirm the normal functionality. On the night before the operation, the surgeon conducted simulation of the navigation application process in the operation room; any inaccuracy observed during simulation was corrected by appropriate calibration.

Table 1

Preoperative and postoperative mean fracture gap and postoperative correction rate of fracture dislocation.

	Maximum gap Axial (mm)	Coronal (mm)	Sagittal (mm)
Preoperative	14.3*	7.4	9.6
Postoperative	5.6†	4.1	3.2
Correction rate	60.8%	44.6%	66.7%

* Y-X.

† Y'-X'.

Correction rate=(preoperative maximum gap minus postoperative maximum gap)/preoperative maximum gap*100.

2.6. Surgical technique

The procedure was performed under general anesthesia (intubation: propofol, 200 µg/kg, Fresenius Kabi Deutschland GmbH, Bad Homburg v.d.H. Germany; fentanyl, 250 µg, RenFu LLC, YiChang, China; midazolam, 2 mg; maintenance: propofol, 0.2–0.5 mg/kg/h, Enhua Pharmaceutical Limited by Share Ltd, JiangSu, China). Short-acting muscle relaxants were administered only at the time of intubation. The patient was placed in the prone position.

First, a patient tracker (Stryker Leibinger GmbH & Co, Freiburg, Germany) was fixed on the iliac crest. The Navigation System II-CART II with SpineMap 3D 2.0 software (Stryker Navigation, Kalamazoo, MI) was used for the procedure. The system's C-arm tracker, patient tracker, and guide wire sleeve tracker were activated. Subsequently 190° scanning was performed at the center of the lumbosacral articular surface, 3D images of the sacroiliac joint region were obtained. The intraoperative images were matched with the preoperative CT images, to ensure accurate PSS insertion.

Second, the screw view mode was selected on the navigation workstation (Fig. 16), and the skin incision was performed under

Table 2
Summary of previous reports of surgical treatment for sacral fractures.

Study	Method	No. of patients	No. of screws	Accuracy rate	OT ^a	GWIT ^{†,a}	PA [‡]	BL ^b	Complications
Kim et al ^[18]	3D	29	31	77.4%	35.6	—	CT scan	—	There were seven perforations
Matityahu et al ^[21]	2D	18	25	68%	—	—	CT scan	—	—
Chui et al ^[11]	3D	38	59	99.3%	179	—	CT scan	141	Screws backed out
Fischer et al ^[19]	2D	38	100	98%	84.0±35.18	—	CT scan	50	2 screw loosening
Schep et al ^[20]	2D	12	48	93.8%	116	19.4	CT scan	—	Two patients had a posterior hematoma one patient had postoperative sensory deficit S2 sacral canal injury
Schep et al ^[20]	3D	12	48	97.9%	97	20.2	CT scan	—	

[†] Guide wire implantation time.

[‡] Position analyzed.

[§] Operation time.

[¶] Blood loss; ^a time; ^b mL.

the guidance of navigation, and not blindly based on experience. Otherwise, the muscle’s lateral tension is liable to induce pressure on the guide wire sleeve, which may lead to malpositioning of the screw. Then, the position of the guide wire sleeve device was moved until the direction of guide wire sleeve was completely consistent with the planned screw position. The image at the lower right-corner of the screen provides guidance for insertion of guide wire; the guide wire is not inserted until the area indicated by the yellow arrow turns green (Fig. 16). The relative spatial position of the patient’s tracker and pelvis should not change during surgery.

Finally, sacroiliac screws with washers were placed and tightened sequentially through the inserted guide wire, and finally x-rays were obtained. All patients underwent 3D CT scan within the 1st postoperative week.

3. Results

A total of 18 patients with posterior pelvic ring injuries received navigation aided surgery. Patient details are listed in Table 3. There were 23 sacral fractures (15 zone I and 7 zone II fractures

according to the Denis classification)^[17] and 3 sacroiliac joint dislocations. Most injuries were sustained in road traffic incidents (56%) or fall from height (44%).

A total of 27 screws were placed unilaterally or bilaterally into segments S1 or S2. In 11 patients, 11 screws were placed in unilateral S1, 6 screws were placed in 3 patients with bilateral S1, 4 screws were placed in unilateral S1 and S2 in 2 patients, 3 screws were placed in bilateral S1 and right S2 in 1 patient, and 3 screws were placed in bilateral S1 and left S2 in 1 patient (Table 3). The screw placement was rated as excellent for 88.9% screws (n=24), good for 7.4% (n=2) and poor for 3.7% (n=1). The overall excellent and good rate of screw placement is similar to that in the published literature (77.4%,^[17] 68%,^[18] and 93.8%)^[19] (Table 2).

The average fracture dislocation in the axial plane was 14.3 mm preoperatively and 5.6 mm postoperatively and the correction rate was 60.8%. The average fracture dislocation in the sagittal plane was 7.4 mm before surgery and 4.1 mm postoperatively (44.6% correction rate). The average fracture dislocation in the coronal plane was 9.6mm before surgery and 3.2 mm postoperatively (66.7% correction rate). Our reduction rate is comparable to that reported from a previous study in which the fracture gaps of sacroiliac fracture were reduced from 3.6±0.53 mm to 1.2±0.54mm.^[19] All patients exhibited good fracture healing at the last follow up visit.

The duration of trajectory planning was 6.5 min (range, 2.7–8.9 min). Mean screw implantation time was 32 min (range, 20–53 min) and mean guide wire implantation time was 3.7 min (range, 2.1–5.3 min). In previous reports, the time of guide wire implantation was 19.4 min and 20.2 min,^[20] which are significantly longer than our guide wire implantation time. The mean volume of intraoperative blood loss during our operation was 53 mL (range, 36–105 mL), which is comparable with that reported from previous studies (50 mL^[19] and 141 mL^[11]) (Table 2). No clinical complications such as neurovascular injury, infection or screw loosening were observed. The mean follow-up period in our cohort was 16.8 months (range, 12–36 months). Fracture classification is shown in Table 3.

4. Discussion

The PSS fixation under fluoroscopic guidance is an effective and widely used method for treatment of pelvic ring injury. The PSS implantation is a technically demanding procedure. An analysis of CT data showed that a deviation of surgeon’s hands by as little as 4 degrees may lead to insertion of the sacroiliac screw into the

Table 3
Basic characteristics of patients.

Case no.	Age, y	Sex	SFZ [†]	SP [‡]	FU [§] (month)
1	35	M	II (L)	S1 (L)	16
2	47	F	I (R)	S1 (R)	25
3	67	M	I (L)	S1 (L)	19
4	54	F	I (L)+II (R + Dis)	S1 (B)	12
5	42	M	I (L)	S1 (L)	14
6	18	M	I (B)	S1 (B)	16
7	35	F	II (R + Dis)	S1(R)+S2(R)	15
8	29	F	I (L)	S1 (L)	16
9	43	M	I (L)	S1 (L)	12
10	39	M	II (L+ Dis) + II(R)	S1 (B)	13
11	55	F	I (L)	S1 (L)	15
12	31	M	I(R)+II (L)	S1 (B)+S2(L)	17
13	39	M	I (L)+II(R)	S1 (B)+S2(R)	22
14	47	F	I (L)	S1 (L)	12
15	33	M	II (R)	S1(R)+S2(R)	36
16	54	F	I (R)	S1 (R)	18
17	26	F	I (R)	S1 (R)	13
18	45	F	I (L)	S1 (L)	12

[†] Sacral fracture zone.

[‡] Screw position.

[§] Follow up; M= male, F= female, S= sacrum, L=left, R=right, B= bilateral, Dis=displaced.

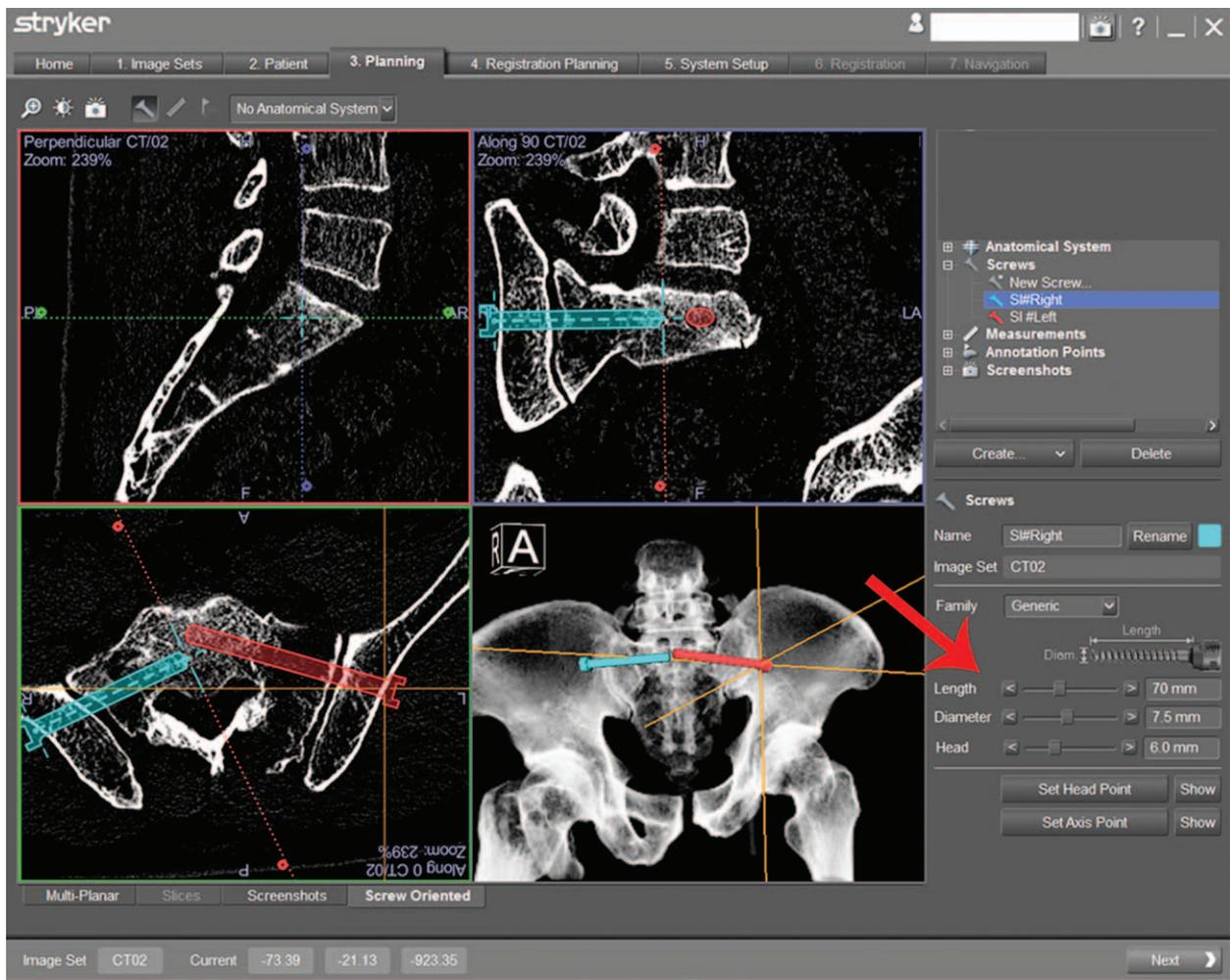


Figure 15. Screen shots for the navigation software interface illustrating the functionality to adjust the screw length and diameter (red arrow) and to determine the best trajectory for the screw.

S1 foramina or through the anterior cortex of the sacrum.^[22] We have explored a novel technique of screw view model for navigation to assist PSS insertion. Compared with the results of literature review (Table 2), our guide wire implantation time was shorter, and there was no significant difference with respect to the accuracy of screw placement, screw implantation time, or intraoperative blood loss. We did not encounter any instance of screw loosening on follow-up. In addition, the follow-up CT examination showed good healing at the fracture site. In our view, preoperative surgical planning and intraoperative application of screw view model are very important, and this opinion is consistent with that expressed by Takao M et al.^[4]

Fully understanding the posterior pelvic anatomy, variations and associated imaging is essential for performing safe surgery. Research indicates^[23] that the dysmorphic sacrum mainly includes the following characteristics: First, the outlet radiographic view presents the relative position of the upper sacrum and the iliac crest is in the same straight line. Second, the inlet radiographic view displays the cortical of the anterior ala is indentation. Third, CT scan shows a tongue-in-groove sacroiliac joint surface. Fourth, the outlet and lateral views of the sacrum show an acute alar slope oriented from cranial-posterior-central to caudal-anterior-lateral and anterior upper sacral foramina that

are not circular. The patient with a dysmorphic sacrum has a narrowed and oblique osseous pathway. Consequently, surgeons must be aware of the anatomy of dysmorphic sacrum to ensure the accuracy and safe placement of PSS. We hypothesize that preoperative surgery planning at computer navigation workstation is essential to assess the starting point, direction, position and length of the screw.

Compared with the traditional 3D mode of navigation or 2D fluoroscopic navigation, this screw view mode has the following characteristics: First, the 3D image of the navigation is in a static state, which confers an advantage to the surgeon. Adjusting the suitable implant trajectory in dynamic images is challenging as aiming at the end of the guide wire is difficult, and the guide wire entry path is liable to be deviated. Second, the surgeon only needs to carefully prepare the surgical design preoperatively, then follow the design path and implant the screws.

In our study, the excellent plus good rate of screw placement was 96.3% and there was only one screw that was poorly positioned; however, there were no complications. In a clinical study, perforation rate under 3D fluoroscopic navigation was as high as 31%,^[12] and the screw malposition rate was 60%.^[12] Compared to the reported screw accuracy rates of 40% to 99.3%,^[1,12,18–21] our technique does not exhibit any obvious

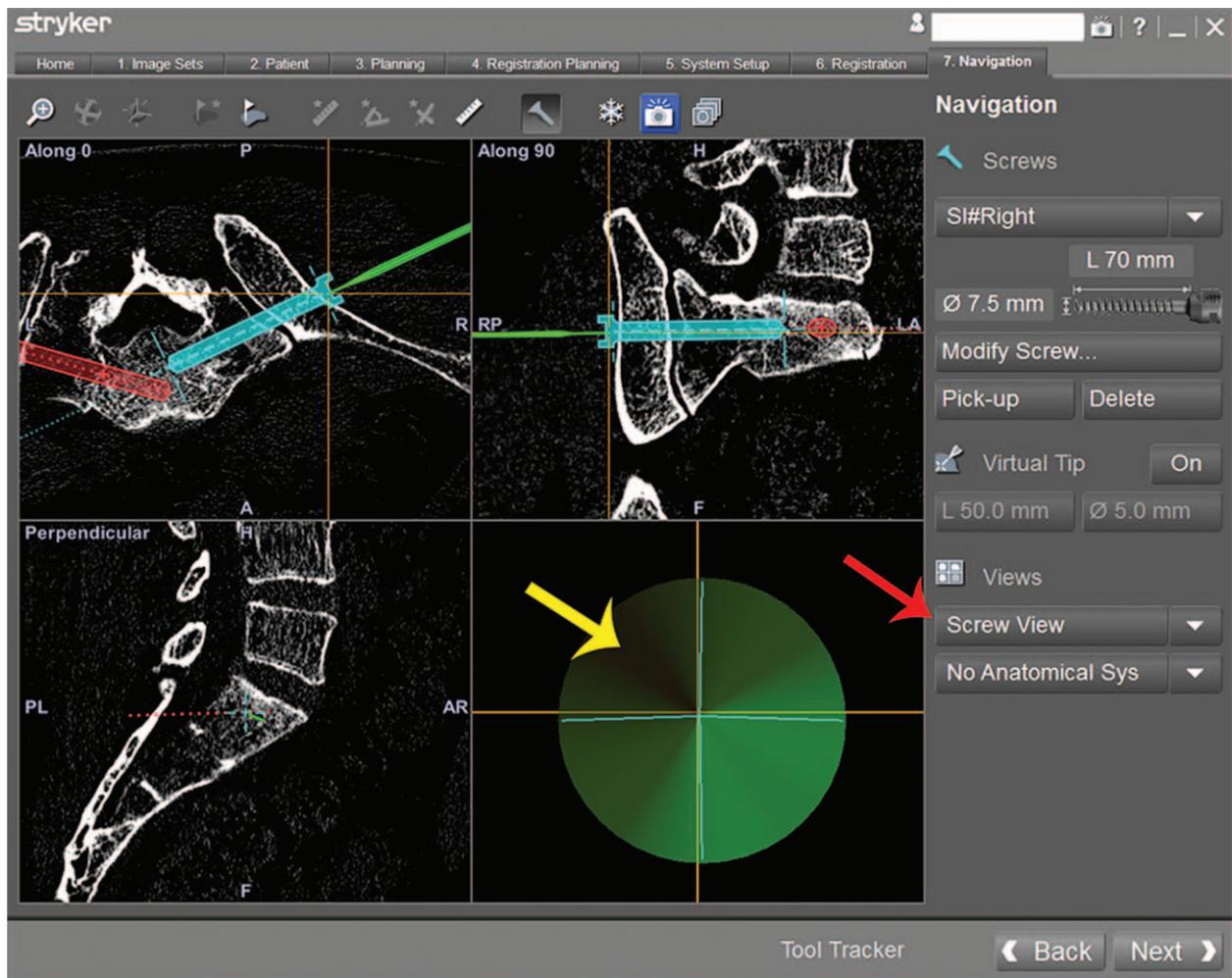


Figure 16. Screenshot of the user interface of the screw view mode (red arrow) of navigation. The image of the right lower corner shows green colour (yellow arrow), which indicates the best moment to implant a guide wire.

advantages. We attribute this positive result to the advantage conferred by screw view model guidance for PSS insertion.

With regard to operation time, use of fluoroscopic guidance was shown to be associated with significantly longer fluoroscopic time as compared to that with navigation guidance owing to the need to repeatedly check the guide-wire position in the former method.^[4] Although the navigation system is inherently complex, research suggests that navigation system does not require additional operation time for setup of the navigation devices.^[3] In our study, the mean screw implantation time was 32 min (range, 20–53 min) which included the time required for image acquisition, surgical design, guide wire insertion and screw implantation; the average guide wire insertion time was 3.7 minutes. The screw implantation time was not significantly different from that reported with use of conventional technique.^[3] However, the screw view mode of navigation not only shortened the guide wire insertion time but also reduced the number of guide wire attempts. We hypothesize that these positive results are attributable to the use of the screw view model of navigation for complete guide wire implantation in a single attempt.

Regarding fracture dislocation, our reduction rate was comparable to that reported from previous studies.^[19] Although the patients in this study did not achieve 100% reduction as

assessed by immediate postoperative 3D CT, the average correction rates in axial, sagittal and coronal views were 60.8%, 66.7%, and 44.6% respectively. However, all fractures had achieved bony union at the most recent follow-up. We attribute the good results to a satisfactory fracture reduction in the sagittal plane as well as in the coronary plane which were achieved preoperatively, and precise PSS insertion and compression fixation in axial plane performed intraoperatively.

Sacroiliac screw loosening is a typical complication of posterior pelvic ring fractures, which may be related to vertical shear forces^[17] and osteoporosis.^[24,25] The reported incidence of sacroiliac screw loosening is as high as 17.3%, and that of screw failure is 11.8%.^[17] Its prevention is crucial, as it has been shown to be associated with several complications, including screw breakage, pseudoarthrosis, and inadequate biomechanical strength. No instances of sacroiliac screw loosening were observed in our study, perhaps mainly due to the age of the patients is quiet young and all of them had good bone stock, and due to the short follow-up period, but also due to accurate screw implantation using screw view model of navigation. Furthermore, all sacroiliac screw implantation procedures were completed in a single attempt, which averted the need for multiple drill holes that may lead to screw loosening.

Osteoporosis related fragility fractures of the posterior pelvis ring are due to massive reduction of bone mass and quality,^[26,27] and already weakened bone eventually fracture under excessive stress.^[28] Because of poor physical condition and other diseases in the past, elderly patients need shorter operation time and minimally invasive surgical techniques. Therefore, PSS fixation is a good choice for the treatment of osteoporotic posterior pelvic ring fractures.^[29] However, there are some investigations demonstrating that in osteoporotic bone, a single sacroiliac screw fixation might not have sufficient mechanically^[30,31] and demonstrates a high incidence of screw loosening.^[26] In order to improve screw fixation in osteoporotic bone, Gruneweller et al^[32] proposed that the screws can be implanted with cement augmentation. However, bone cement leakage is considered a serious complication of this operation,^[33–36] which is likely to cause spinal cord or nerve root injury.^[35,36] So we chose young patients without osteoporosis for our investigation.

There are several limitations of our study. First, the range of indications for use of screw view model of navigation is narrow, as it is only suitable for sacroiliac joint fractures without displacement or for stable fractures. Secondly, radiation exposure was not calculated in this study; however, we believe that there was minimal radiation exposure of the staff in the operation room because all the staff were away from the operation room when the 3D images were acquired.^[11] Also, the radiation dose for examination of the position of guide wire and screw is very limited.^[11] Thirdly, the surgeon must be very familiar with the functionality of the navigation system, and always assess for any potential image drift, which may induce errors due to inaccurate navigation. Fourth, the lack of a control group and lack of biomechanical comparison is another limitation of our study.^[2]

In conclusion, the screw view model of navigation may facilitate safe and effective PSS implantation for stabilization of posterior pelvic ring injury.

Author contributions

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Writing – review & editing: Yang Qu, Jianwu Zhao.

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