Preoperative CT Simulation of Iliosacral Screws for Treating Unstable Posterior Pelvic Ring Injury

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Research Article

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Abstract

Background

Percutaneous iliosacral screw placement is an important surgical method for the treatment of pelvic unstable fractures, but either intraoperative X-ray screws or navigational screws may be misplaced. This study aimed to demonstrate a safe, effective, and rapid method for placing iliosacral screws for the treatment of unstable posterior pelvic ring injury according to preoperative computed tomography (CT) planning using simulated screws.

Methods

After preoperative CT simulation of iliosacral screws planning screw insertion point and trajectory, intraoperative percutaneous iliosacral screws were used to treat unstable pelvic posterior ring injury. The mechanism of injury, Tile classification, number of screw implants, operative time of each screw implantation, radiation exposure time of each screw implantation screw position, complications, and postoperative follow-up time were collected. Screw position grading was evaluated by Smith grading.

Results

A total of 24 screws were implanted in 21 patients (9 men and 12 women; mean age 41.3 years; range 14–71 years). Tile classification included: Tile B: 15 patients; Tile C: 6 patients. The mean placement time of each screw was 19.5 minutes (range 14–32 min); Radiation exposure time: 0.6 min (range 0.5–0.9 min); Two screws were inserted in 3 patients; One screw was inserted in 18 patients; According to Smith grading standard, grade 0: 20 cases; and Grade 1: 1 case; Mean postoperative follow-up time was 17.1 months (range 12–25 months); None of the patients showed nonunion.

Conclusions

Preoperative CT simulation of iliosacral screws for placement planning, screw trajectory, and intraoperative placement of screws is a safe method that can be used to reduce surgical time, radiation exposure, and accurate screw placement.

Background

With the continuous development of the social economy and the progress of the construction and transportation industries, pelvic injuries caused by high-energy injuries are becoming increasingly common[1]. Pelvic fractures are often accompanied by head injuries, chest injuries, and abdominal injuries, which cause great difficulty in the treatment of pelvic fractures, and also increase the disability rates and mortality[2]. There are several treatment options for pelvic fractures including conservative treatment, external fixation, open reduction, and internal fixation. Long-term bed rest during conservative treatment may lead to lung infection and deep venous thrombosis of the lower limbs, or unequal length of the lower limbs, and chronic pain may occur in later stages[3–5]. External fixation is often used to treat

patients with early hemodynamic instability or coexisting open wounds. Early fixation of the pelvis can reduce pelvic volume and bleeding, but later aseptic loosening of the screw may occur and patients could have difficulty in moving; therefore, it is generally not used for terminal fixation[6]. Open reduction and internal fixation can be reduced under direct vision to achieve anatomic stability, but the risk of incision infection, large injury, and bleeding is high[7]. Closed reduction of iliosacral screws for the treatment of posterior pelvic ring injuries has gradually become the mainstream surgical method[8]. It has the advantages of less injury, less bleeding, high patient acceptance, early postoperative activity, among others[8–10]. Early operation can also reduce the risk of adult respiratory distress syndrome (ARDS) and multiorgan failure (MOF)[11]. However, there are some limitations to iliosacral screws placement. Screw placement done completely using fluoroscopy and the surgeon's hand may lead to neurovascular injury. Patients with intestinal gas, osteoporosis, and obesity, may have unclear intraoperative fluoroscopy, which could result in screw perforation[12–14].

To reduce surgical complications and improve screw placement accuracy, iliosacral screws placement using intraoperative Two-dimensional (2D) or Three-dimensional (3D) navigation, such as intraoperative CT navigation, have been reported[11, 13, 15, 16]; however, the high cost of equipment has prevented the technology from being widely used[17]. Currently, adjustment of screw direction according to standard lateral radiographs of the sacrum and pelvic inlet and outlet views under intraoperative X-ray fluoroscopy is still adopted by most doctors[18]. This study aimed to simulate screw trajectory and mark insertion and exit points according to preoperative CT data to guide intraoperative iliosacral screw placement, which can effectively reduce screw perforation rate, intraoperative radiation exposure, operative time.

Methods

This study was approved by the ethics committee of Bengal Medical College (Number: BYYFY-2019KY03). From June 2019 to June 2020, a total of 108 patients with pelvic fracture were treated in our hospital. 21 patients were selected for percutaneous iliosacral screws internal fixation using preoperative CT simulated screws placement planning. We recorded the patient's sex, age, mechanism of injury, time of placement of each screw (from insertion of the guide wire to completion of the screw placement) and time of radiation exposure. Tile classification was performed based on preoperative pelvic radiographs and three-dimensional reconstruction of the pelvis. CT scan was performed 3–7 days postoperatively to determine the position of the screw. X-rays were reviewed at 1.5, 3, 6 and 12 months postoperatively, and once a year thereafter. Routine reviews included anteroposterior, and inlet and outlet pelvic radiographs to examine the screw position. According to the standards of screw position published by Smith et al.[19], the screw position was divided into four grades: grade 0, no perforation; grade 1, perforation less than 2 mm; grade 2, perforation of 2–4 mm; grade 3, perforation >4 mm.

One day postoperatively, the quadriceps femoris muscle function exercise of both lower limbs was performed; 3 days postoperatively, the patient could sit up; 7 days postoperatively, the patient could walk up in the bed without weight bearing; 2 weeks postoperatively, the patient could get out of bed with partial

weight; 1 month postoperatively, the patient could decide whether to get out of bed with with full weight bearing.

Placement of iliosacral screws

After admission, the patient underwent routine plain pelvic CT (Light speed VCT, GE, America) scan, and CT images of 0.625 mm thickness were obtained. CT images were imported into Mimics software (Materialise, Belgium) to obtain the patient's pelvic standard lateral views, and inlet and outlet views(Fig. 1a,b,c). Using the Multiplanar reconstruction (MPR) function in the software to simulate the screw, the screw diameter was set to 6.5 mm; a screw track was designed according to the patient's individual situation, such that the screw should be at a safe distance from the front, back, above, and below the sacrum. After setting the screw, X-ray simulation function was used to simulate the screw entry point and exit point on standard sacral lateral radiographs. At the same time, the screw track in standard sacral lateral and inlet and outlet radiographs was saved. Standard sacral lateral radiographs, inlet radiographs and outlet radiographs were artificially divided into nine stages. Standard lateral radiographs of the sacrum divided the first sacral vertebra into nine grids of 3×3 (classification criteria: three parts of the upper endplate of the first sacral vertebra, three parts of the lower endplate, three parts of the prevertebral cortex, three parts of the posterior cortex, connected with the corresponding bisector points of the upper and lower parts;Lateral radiographs(L),Fig. 1d). The pelvic inlet radiography divided the upper endplate of the first sacral vertebral body into nine grids(Inlet radiographs(I),Fig. 1e), and the outlet radiography divided the medial edge of the bilateral sacral foramina as the parallel tangent line of the middle sagittal line and the parallel tangent line of the upper edge of the bilateral sacroforamina with the horizontal line into nine grids(Outlet radiographs(O) Fig. 1f). In simulated radiographs, screw entry points were identified on standard lateral views of the sacrum(Fig. 1g), and needlepoints were marked on the inlet and outlet images(Fig. 1h,i). Screw tracks were simulated on lateral and inlet and outlet images according to preoperative planning.

According to the patient's preoperative CT three-dimensional reconstruction, the iliosacral screw trajectory was simulated. the patient's and the operating table position were adjusted so that the patient's body was placed in the center of the operating table parallel to the floor. After disinfection, the c-arm angle was adjusted to obtain standard lateral and inlet and outlet radiographs of the sacrum. The ground was marked and the rotation angle of the c-arm was recorded. On standard lateral radiographs of the sacrum, the guide needle tip was adjusted according to the pre-planned screw insertion point. After adjusting to the appropriate insertion point, the guide needle was gently hammered with a bone hammer to allow it to slightly enter the bone. At this point, the inlet and outlet views and the guide wire pointing at the inlet and outlet views to be the same as before were adjusted according to the preoperative planning. The bone hammer was gradually hammered into the area according to this angle, and fluoroscopy was performed again when the cortex was punctured to prevent the guide wire from changing the track. Standard lateral and inlet and outlet radiographs of the sacrum were taken again after the needle was inserted according to the preoperative trajectory. After measuring the required length of the screw with a needle tester, a screw (Synthes Gmbh, Switzerland) of proper length was inserted(Fig. 2).

Results

The data obtained in this study are presented in Table 1. Among the 21 patients, nine were male and 12 were female, with a median age of 41.3 years (range 14–72 years). Among them, 11 were injured in car accidents, 5 were injured due to falls from heights, 4 were injured due to heavy extrusion, and 1 was injured due to falling off a bicycle. The pelvic injury was divided into Tile B1 (2 cases), Tile B2 (9 cases), Tile B3 (4 cases), Tile C1 (5 cases), and Tile C2 (1 case). There were no major clinical complications or screw misplacement. A total of 24 iliosacral screws were implanted in 21 patients, including one unilateral two-screw S1 fixation, two bilateral one-screw S1 and 18 unilateral S1 one-screw fixations. The median time from initial preparation to completion of the first screw insertion was 19.5 minutes (range 14–32 min); radiation exposure time for each screw was 0.6 min (range 0.5–0.9 min).

Table 1
Patient information

Parameter	Value	Percent(%)
Mean age(years)	41.3	
Gender		
Male	9	42.8
Female	12	57.2
Mechanism of injury(cases)		
Traffic Accident	11	52.2
Fall	5	23.8
Bruise injury	4	19.0
Bicycle fall	1	5.0
Tile classification		
B	15	71.4
C	6	28.6
Screw placement position		
Left	12	57.1
Right	7	33.3
Bilateral	2	9.6
Per screw of operative time(min)	19.5	
Per screw of radiation exposure(min)	0.6	

After screw fixation, CT scan was routinely performed to check for screw condition. According to the Smith classification standard (Table 2), among the 24 screws, only one screw passed through the upper edge of the anterior foramen of the sacral, but did not cause any clinical symptoms. There are two reasons for this; first, the screw may be close to the upper cortical edge of the anterior foramen of the sacral and did not penetrate to the other side, and secondly, the anterior branch of the first sacral nerve moved upward and diagonally outward, with a certain safe distance from the upper edge of the anterior foramina of the sacral. All patients were followed up and a review of radiographs at 6 months postoperatively showed fracture union and no screw dislocation. All patients were followed up for a mean follow-up period of 17.1 months (12–25 months).

Table 2
Postoperation characteristics

Parameter	Value	Percent(%)
Smith Grade		
Grade 0	23	95.8
Grade 1	1	4.2
Grade 2	0	
Grade 3	0	
Mean Postoperative follow-up time(month)	17.1	

Discussion

Currently, using percutaneous iliosacral screw as a form of minimally invasive treatment of unstable posterior pelvic ring injury has gradually become the gold standard[8, 12, 20]. From the anatomy of the pelvis, both the ilium and sacrum are irregular bones, and the sacroiliac joint also has a certain angle with the central axis bone. Furthermore, there are anatomical variations in 30–40% of sacral vertebrae, and the safe area for screw placement varies greatly, which could cause potential safety hazards for clinical screw placement[18]. Despite the rapid development of imaging at the present stage, preoperative CT and intraoperative fluoroscopy provide us with a guarantee for safe screw placement; there is still no recognized guidance program for safe screw placement.

In 1987, Ebraheim et al.[21] creatively proposed the application of intraoperative CT-guided iliosacral screws placement, through which the surgeon could observe the sacral foramina and the sacral canal under the guidance of intraoperative CT fluoroscopy while placing screw, thus greatly reducing the risk of nerve injury. However, with the use of intraoperative CT fluoroscopic screw placement can expose the surgeon, the operating team, and the patient to a higher radiation dose. In 1995, Routt et al.[22] proposed the supine position of iliosacral screws insertion on the basis of previous studies and proposed the "standard lateral image of the sacrum". At the same time, the steps of screw placement were described in

detail on the inlet and outlet views of the pelvis, ushering in a new era for minimally invasive treatment of posterior pelvic ring injuries using X-ray screw placement. In 2004, Mosheiff et al.[23] used a 2D navigation fluoroscopy system to implant iliosacral screws, which confirmed that 2D navigation had higher surgical accuracy than traditional X-ray fluoroscopy when placing screws. The fluoroscopy time for each screw was reported to be about 2 min. However, the comparison of radiation exposure time with the traditional screw placement method was not described in detail. Additionally, 2D navigation equipment is complex and has a long learning curve. In 2013, Masaki et al.[24] used a 3D navigation system to treat pelvic posterior ring instability fractures and achieved a higher accuracy of screw placement, but the radiation exposure was higher than that of traditional X-ray inferior screw placement. The fluoroscopy time for each screw was reported to be about 1.5 min. In 2014, Matityahu et al.[16] compared iliosacral screw placement under traditional X-ray fluoroscopy, 2D navigation, and 3D navigation, and found that 3D navigation screw placement had more accurate screw placement than the previous two surgical plans. The author also believed that 3D navigation screw placement had more advantages in the variable sacral vertebra. Intraoperative CT fluoroscopic navigation and computer 2D/3D navigation can guide safer screw placement, but they have not been widely promoted because of their high technical requirements and expensive equipment[17]. In addition, intraoperative CT, 2D, and 3D navigation are mostly used to plan the screw's trajectory during the operation. Under different operating conditions and the surgeon's understanding of the patient's fracture at that time, the screw's trajectory was different as good planning was lacking[25, 26]. Currently, although many intraoperative navigation systems are applied in clinics, the traditional screw placement method is still widely used.

The treatment of unstable pelvic fractures is a substantial problem for clinicians. First, patients with high-energy injury often have multiple injuries throughout the body, and insufficient blood perfusion due to massive blood loss often aggravates tissues and organs injury. Secondly, the operation is complicated, laborious, and intraoperative bleeding in patients is a major concern. Finally, long recovery time has a negative impact on patients' mental, psychological, and physical recovery. Therefore, simplifying operations to reduce time, trauma, and surgical complications; and quick postoperative recovery have become the tireless pursuit of trauma orthopedic surgeons. Currently, there is no literature to clarify the screw trajectory of iliosacral screws, and it is only roughly planned that the screws are completely located in the bone. From the clinical work, it was found that the individual variation of patients also leads to the uncertainty of the insertion point, and different insertion points lead to a change in the angle and direction of the insertion[18]. This causes great difficulty in intraoperative screw placement. In this paper, we studied preoperative CT and trajectory planning screw into the needle point, and in software to simulate the sacrum standard side, pelvic inlet, and outlet X-ray radiography, used to guide intraoperative more accurate placement of iliosacral screws relative to traditional intraoperative fluoroscopy pelvic entrance, and decided to screw into the needle track, with fewer intraoperative fluoroscopy and safer screw placements. The study has the advantages of simplicity, convenience, low cost, with no need for major surgical equipment, and has comparable accuracy. It can shorten the learning curve of the operator, reduces the risk of screw penetration, and reduce the risk of neurovascular injury. This method still has its shortcomings. During the operation of iliosacral screws placement, the lateral, inlet and outlet views need

to be adjusted repeatedly, which may lead to loss of the Angle of the guide wire and could increase radiation exposure. Therefore, adequate surgical skills and experience are required. Not all screw trajectories were planned preoperatively. The number of cases in this study was small, and there was a lack of large sample cases.

Conclusion

Preoperative CT simulation of the iliosacral screw to guide intraoperative screw placement in the treatment of posterior pelvic ring instability injury is a rapid, efficient, and safe technique, but it requires detailed preoperative planning and screw placement under good fluoroscopy conditions. We describe a simple preoperative planning technique that increases the accuracy of iliosacral screw placement while reducing radiation exposure and surgical time, which makes it easy to be performed in hospitals without the need for expensive equipment.

Abbreviations

CT: Computed tomography

ARDS: Adult respiratory distress syndrome

MOF: Multiorgan failure

2D: Two-dimensional

3D: Three-dimensional

MPR: Multiplanar reconstruction

Declarations

Ethics approval and consent to participate This study was performed according to the Helsinki declaration and the study was approved by the ethics committee of Bengal Medical College (Number: BYYFY-2019KY03), and all patients provided written informed consent (The children under 16 have been consent from their parent or legal guardian).

Consent to Publish Patients signed informed consent regarding publishing their data and photographs.

Availability of data and materials The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests The authors declare that they have no competing interests.

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Authors' contribution Min Wu and Peishuai Zhao designed the study. Xiaopan Wang and Xiaotian Chen collected and analyzed the patient data. Min Wu and Jianzhong Guan performed the operation. Min Wu and Peishuai Zhao analyzed the results and prepared the manuscript. All authors read and approved the final manuscript.

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Statements All methods were performed in accordance with the relevant guidelines and regulations.

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contributions

Min Wu and Peishuai Zhao designed the study. Xiaopan Wang and Xiaotian Chen collected and analyzed the patient data. Min Wu and Jianzhong Guan performed the operation. Min Wu and Peishuai Zhao analyzed the results and prepared the manuscript. All authors read and approved the final manuscript.

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Figures

Figure 1

a. Simulated three-dimensional lateral view reconstruction of the sacrum (Lateral view, L) according to preoperative CT data of the patient; b. Inlet View (I); c. Outlet View (O); d. According to the standard lateral sacral image, the sacral 1 vertebral body was planned into 9 regions; e. According to the pelvic inlet image, the upper endplate of sacral 1 vertebral body was divided into 9 regions by taking the two vertices of the posterior edge of the upper endplate of sacral 1 vertebral body parallel to the sagittal line as the left and right boundaries; f. According to the pelvic outlet view, the anterior surface of sacral 1 vertebral body was divided into 9 regions with the medial edge of bilateral sacral 1 anterior foramen as the parallel tangent line of the middle sagittal line and the upper edge of bilateral sacral 1 anterior foramen as the parallel tangent line with the horizontal line; g. Simulated standard lateral X-ray images of the sacrum; h. Simulated standard inlet X-ray images; i. Simulated standard outlet X-ray image.

Figure 2

A 49-year-old male patient who experienced a traffic accident was diagnosed preoperatively with a pelvic fracture(Tile B2).According to preoperative CT simulation screw trajectory:sacrum lateral radiographs:insertion point:LC1;Inlet radiograph:screw trajectory:LC1-IC3;Outlet radiograph:screw trajectory: LC1-OB3.a.Preoperative CT three-dimensional reconstruction of the patient; b. Intraoperative fluoroscopic positioning screws were used to make needle points in the lateral radiographs of the sacrum; C. On the lateral radiographs of the sacrum, the insertion point of the guide wire was located in the preoperative location area(LC1); D. The guide needle on the Inlet views pointed to the area of the simulated screw exit point before surgery (IC3); E. The guide needle on the outlet views pointed to the area of the simulated screw exit point before surgery (OB3); F. Screw trajectory on intraoperative inlet radiographs; G. Intraoperative outlet radiographs screw trajectory; H. Postoperative CT cross-sectional screw trajectory; I. The patient can live normally 3 months after surgery.