

Biomechanical Comparison of Two Kinds of Internal Fixation in a Type C Zone II Pelvic Fracture Model

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Abstract

Background: Unstable pelvic fractures are complex and serious injuries. Selection of a fixation method for these fractures remains a challenging problem for orthopedic surgeons. This study aimed to compare the stability of Tile C pelvic fractures fixed with two iliosacral (IS) screws and minimally invasive adjustable plate (MIAP) combined with one IS screw.

Methods: This study was a biomechanical experiment. Six embalmed specimens of the adult pelvis were used. The soft tissue was removed from the specimens, and the spines from the fourth lumbar vertebra to the proximal one-third of both femurs were retained. The pubic symphysis, bilateral sacroiliac joints and ligaments, bilateral hip joints, bilateral sacrotuberous ligaments, and bilateral sacrospinous ligaments were intact. Tile C pelvic fractures were made on the specimens. The symphysis pubis was fixed with a plate, and the fracture on the posterior pelvic ring was fixed with two kinds of internal fixation in turn. The specimens were placed in a biomechanical machine at a standing neutral posture. A cyclic vertical load of up to 500 N was applied, and displacement was recorded. Shifts in the fracture gap were measured by a grating displacement sensor. Statistical analysis used: Paired-samples *t*-test.

Results: Under the vertical load of 100, 200, 300, 400, and 500 N, the average displacement of the specimens fixed with MIAP combined with one IS screw was 0.46, 0.735, 1.377, 1.823, and 2.215 mm, respectively, which was significantly lower than that of specimens fixed with two IS screws under corresponding load ($P < 0.05$). Under the vertical load of 500 N, the shift in the fracture gap of specimens fixed with MIAP combined with one IS screw was 0.261 ± 0.095 mm, and that of specimens fixed with two IS screws was 0.809 ± 0.170 mm. The difference was significant ($P < 0.05$).

Conclusion: The stability of Tile C pelvic fractures fixed with MIAP combined with one IS screw was better than that fixed with two IS screws.

Key words: Biomechanics; Internal Fixation; Pelvis; Unstable

INTRODUCTION

Pelvic fractures are uncommon injuries that account for 7–8% of fractures in adults, associated with high energy traumas such as motor vehicle accidents and falls.^[1] Approximately, 68.3% of pelvic fractures are complex and serious unstable fractures, and the mortality rate is up to 19%.^[2,3] Selection of a fixation method for unstable pelvic fracture remains a challenging problem for orthopedic surgeons. Sixty percent of pelvic stability is related to the posterior pelvic ring.^[4,5] Therefore, treatment of an unstable fracture must restore the stability and continuity of the posterior pelvic ring.

Minimally invasive internal fixation is a definitive method. Due to the development of surgical fixation techniques, it has a great improvement to treat this kind of injuries, including percutaneous iliosacral (IS) screws,^[6] posterior transiliac plating,^[7] triangular osteosynthesis,^[8] and minimally invasive

adjustable plate (MIAP).^[9] These fixations are used in a clinical practice commonly and have a lot of advantages. However, none is proved to be the best method in clinical and experiments.

IS screw fixation into the first sacral body is one of the most frequently used methods with satisfactory results. However, IS screw fixation is a highly technical procedure that requires extensive surgical experience and always needs a long learning curve.^[10,11] Doctors and patients are exposed to large amounts

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Received: 09-11-2014 **Edited by:** Peng Lyu and Jian Gao
How to cite this article: Wu T, Chen W, Zhang Q, Zheng ZL, Lyu HZ, Cui YW, Cheng XD, Zhang YZ, Yang YJ. Biomechanical Comparison of Two Kinds of Internal Fixation in a Type C Zone II Pelvic Fracture Model. *Chin Med J* 2015;128:2312-7.

Access this article online

Quick Response Code:



Website:
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DOI:
10.4103/0366-6999.163377

of radiation during IS screw insertion.^[12,13] Some investigators reported that the average fluoroscopy time for IS screw fixation ranges from 26 s to 5.7 min using a C-arm.^[11,14,15] In addition, this construct has been shown to be clinically unreliable for percutaneous IS screw fixation of unstable sacral fractures in which there was a residual gap at the fracture site.^[16] In recent years, Chen *et al.* introduced a novel MIAP,^[9] which was based on the structural characteristics of the posterior pelvic ring (Patent No. ZL201010130312.6) [Figure 1]. Chen *et al.* constructed vertical sacral fracture models, which were fastened to an Electroforce 3520-AT Bose biomechanical testing machine in sitting position and fixed with three kinds of internal fixation. They demonstrated the translation and rotation stiffness of these fractures fixed with MIAP were inferior to that fixed with two IS screws, but the difference was not significant.^[17] Clinically, to avoid long-term complications associated with bed rest, patients treated with internal fixation were asked to walk earlier because of strong fixation. Therefore, we hypothesize that the fractures fixed with MIAP combined with one SI screw are stabler than that with two SI screws. The aim of this biomechanical experiment was to compare the stability of posterior pelvic ring disruptions fixed with these two kinds of internal fixation and provide a basis for the clinical application.

METHODS

The study was approved by the Hospital Ethics Committee of the Third Hospital of Hebei Medical University (Shijiazhuang, Hebei, China).

Preparation and preservation of specimens

Six embalmed adult male cadaver pelvises (provided by the Department of Anatomy of Hebei Medical University) were used for biomechanical investigations. The average age of the specimens was 41.3 years (range, 28–52 years). The inclusion criteria for pelvis specimens were as follows: (1) Specimens that were proven to have osteoporosis using an osteocore 3 dual energy X-ray osteodensitometer (Medilink Company, Parc de la Mediterranee, France) were excluded.

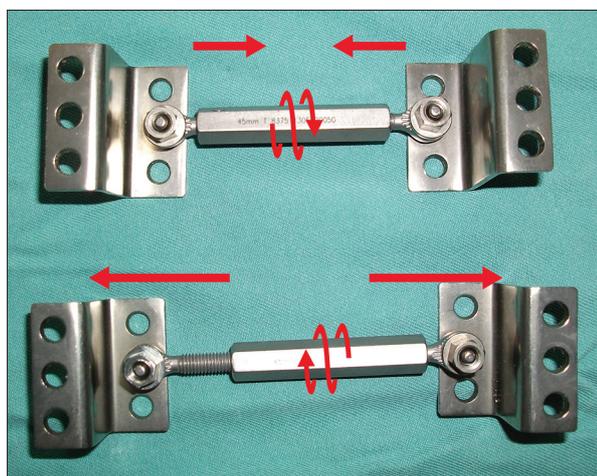


Figure 1: Structure of minimally invasive adjustable plate for posterior pelvic ring injuries.

(2) Specimens from patients with tuberculosis, rheumatism, cancer and other diseases, and anatomic variations were excluded. (3) The fourth and fifth lumbar vertebrae must be intact, and both femurs must be amputated at the transition of the upper to the middle third. All specimens were prepared by removing the soft tissues. Ligaments (anterior, posterior, interosseal sacroiliac ligament, sacrospinous ligament, and sacrotuberous ligament) were left intact. (4) Hip joints and pubic symphysis must be intact. The specimens were packaged and stored at -20°C . The frozen specimens were melted at room temperature 12 h before the experiment.

Structure of minimally invasive adjustable plate

The MIAP (Tianjin Zhengtian Medical Instrument Company Ltd., Tianjin, China) is composed of an adjustable connection bar and two Z-shaped brackets. Each Z-shaped bracket consists of an upper wing, lower wing, and web plate. The connection is made up of a hexagonal tube and two custom-made eye bolts, which can be stretched or shortened by rotating the hexagonal tube. The Z-shaped bracket was positioned with the upper wing on the dorsal surface of the posterior superior iliac spines and the lower wing close to the dorsal surface of sacrum. Some long cancellous screws were inserted through the holes of the upper and lower wings to secure the Z-shaped bracket on the ilium and sacrum, respectively.

Modeling Type C pelvic ring injury and fixation of specimens

In Tile C fractures, the anterior and posterior pelvic rings are disrupted, leading to translation and rotation instability. Anteriorly, a symphysis pubis rupture was made by cutting through the symphysis pubis, which was stabilized with a four- or five-hole plate placed on the cranial aspect of the symphysis. Posteriorly, a Denis Type II fracture was manipulated by an oscillating saw passing through the left sacral foramen. After the reduction of sacral fractures, two kinds of internal fixation were implanted.

In this study, two kinds of internal fixation were used in turn as follows:

1. MIAP combined with one SI screw group: The posterior side of the ilium and sacrum was exposed, and an appropriate MIAP (Tianjin Zhengtian Medical Instrument Company Ltd) was chosen. Some long cancellous screws were inserted into the sacrum and ilium. And then, one 2.0-mm Kirschner wires was inserted through the ipsilateral external surface of the ilium and into the first sacral vertebral body. Fluoroscopy (anteroposterior, inlet, and outlet views) was used to confirm appropriate screw placement. One 7.3-mm cannulated, partially threaded, and cancellous IS screw (Tianjin Zhengtian Medical Instrument Company Ltd) was inserted into the first sacral vertebral body along Kirschner wire. Computed tomography (CT) scan was used to confirm appropriate screw placement [Figure 2]
2. Two IS screws group: To remove the MIAP. The other 2.0-mm Kirschner wire was inserted according to

the above method. Fluoroscopy was used to confirm appropriate screw placement. Then, the other 7.3-mm cannulated, partially threaded, and cancellous IS screw was also inserted into the first sacral vertebral body. CT scan was used to confirm appropriate screw placement [Figure 3].

Measurements

Bilateral distal femurs of the specimens were fixed in the homemade clamp using Type II denture-based self-curing denture acrylic. The pelvic specimens were fastened in the Electroforce 3520-AT Bose biomechanical testing machine (BOSE Corporation, Eden Prairie, USA) at a standing neutral position. And both anterior superior iliac spines and ventral surface of the pubic symphysis were covered by the same plane. The L4 vertebral body was fixed in the homemade clamp. The positioning pins of a grating displacement sensor (Guangzhou Lokshun CNC Equipment Ltd., Guangzhou, China) were set to enclose an angle parallel to the posterior inferior iliac spine (PIIS) and perpendicular to the fracture gap, which was fastened to the testing machine. After each kind of internal fixation was implanted, a vertical load of 200 N was applied to eliminate creep. The vertical cyclic load was between 0 and 500 N and increased at a rate of 10 N/s. The cyclic load was applied in 20 cycles. In the last three cycles, the displacement of the specimens was recorded at vertical loads of 100, 200, 300, 400, and 500 N by the testing machine. Shifts in the fracture gap were recorded at a vertical load of 500 N by the grating displacement sensor.

The pelvic fracture model was constructed and fixed by the same researcher. Designing the direction and location of the internal fixation prior to implantation and using X-ray fluoroscopy after the procedure can reduce the influence of pre-fixation on subsequent operations.

Statistical analysis

Data are presented as mean \pm standard deviation (SD). All statistical analyses were performed using SPSS version 16.0 software (SPSS Inc., Chicago, IL, USA). Displacement and shifts in the fracture gap were compared by paired-samples *t*-test. Significance was set at $P < 0.05$.

RESULTS

During the experimental period, the specimens were fixed at a neutral position without any obvious obliquity or fracture. Loosening, breakage, and avulsion of the internal fixation were not observed. Displacements were recorded by the BOSE biomechanical workstation under vertical load and shifts in the fracture gap were simultaneously recorded by a researcher. The load-displacement scatter graph of the specimens was a smooth straight line, which indicates that the deformation observed in the specimens was elastic [Figure 4].

Under the vertical load of 100, 200, 300, 400, and 500 N, the average displacement of the specimens fixed with two IS screws was 0.692, 1.249, 1.669, 2.061, and 2.421 mm,

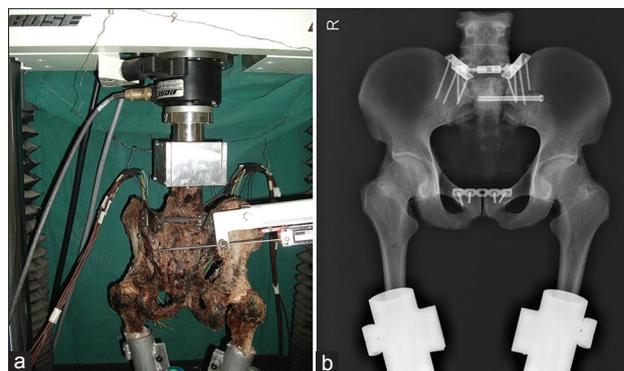


Figure 2: Posterior pelvic ring fixed with minimally invasive adjustable plate combined with one iliosacral screw. (a) Posterior view of the specimen and grating displacement sensor; (b) Anteroposterior radiograph of the pelvis.

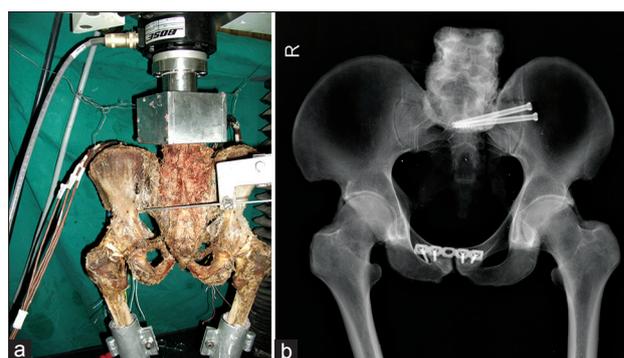


Figure 3: Posterior pelvic ring fixed with two iliosacral screws. (a) Posterior view of the specimen and grating displacement sensor; (b) Anteroposterior radiograph of the pelvis.

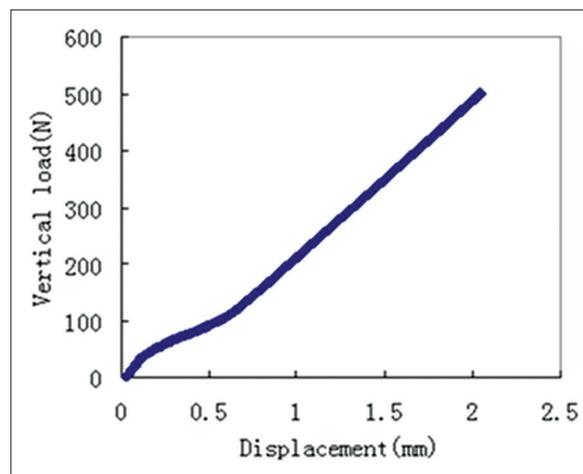


Figure 4: Load-displacement scatter graph of the specimens indicates that the deformation of specimens was elastic.

respectively. And the average displacement of the specimens fixed with MIAP combined with one IS screw was 0.46, 0.735, 1.377, 1.823, and 2.215 mm, respectively, which was significantly lower than that of specimens fixed with two IS screws under corresponding load ($P < 0.05$) [Table 1].

Under the vertical load of 500 N, the shift in the fracture gap of specimens fixed with MIAP combined with one IS

Table 1: Displacement of the pelvis fixed with two kinds of internal fixation under vertical load (mean±SD, n = 6)

Load (n)	Two IS screws (mm)	MIAP combined with one IS screw (mm)	t/P
100	0.692 ± 0.261	0.460 ± 0.112	3.036/0.029
200	1.249 ± 0.451	0.735 ± 0.083	2.901/0.034
300	1.669 ± 0.509	1.377 ± 0.330	3.764/0.013
400	2.061 ± 0.578	1.823 ± 0.496	6.697/0.001
500	2.421 ± 0.613	2.215 ± 0.625	10.269/<0.001

IS: Iliosacral; MIAP: Minimally invasive adjustable plate.

screw was 0.261 ± 0.095 mm, and that of specimens fixed with two IS screws was 0.809 ± 0.170 mm. The difference was significant ($P < 0.05$).

DISCUSSION

Unstable pelvic ring injuries are always intricate and challenging problems for traumatologists and orthopedic surgeons because of the associated significant morbidity and mortality. Early reduction and rigid fixation are very important for the successful management of this lesion. With the rapid development in medical technology, minimally invasive options have become available for this procedure. Percutaneous placement of IS screws is an attractive procedure with the well-known advantage of providing a sufficient biomechanical stability.^[10] However, this construct has been shown to be clinically unreliable.^[16] MIAP was also applied using a minimally invasive procedure, and the incidence of iatrogenic injury involving blood vessels and nerves was low.^[9,17,18] Chen *et al.* indicated that posterior pelvic ring disruption fixed with MIAP was as stable as that fixed with two IS screws.^[17] In order to achieve greater stability, we propose a new method, MIAP combined with one SI screw, for treating the posterior pelvic ring fractures. In this study, we designed a biomechanical experiment to compare the stability of posterior pelvic ring disruptions fixed with the two methods under physiological conditions.

High-energy fractures of the pelvis are vertically and rotationally unstable injuries. Posterior injuries are composed of a dislocation or fracture of the sacroiliac joint or vertical fracture of the sacrum. Anteriorly, the injury may consist of disruption of the symphysis pubis or unilateral or bilateral fractures of the pubic rami. In this study, we manufactured a Tile C pelvic fracture, the most frequent sacral fracture, by cutting the sacrum through the sacral foramen using an oscillating saw and cutting the symphysis pubis using a scalpel.^[16] Some scholars considered that conservative treatment is most effective when the separation of the symphysis pubis was <2.5 cm.^[19] However, clinical research showed that fixing posterior pelvic ring simply was prone to the inclination of pelvis, pain, and nonunion.^[20] Therefore, some scholars advocated open reduction and fixation.^[21] In this study, we fixed the symphysis pubis using a four- or five-hole plate. Given that the sacroiliac complex has an important load-bearing function, it could

be fixed by rigid internal fixation after reduction to achieve better effects.^[22] In our study, compared with two IS screws fixation, we tested a new method, MIAP combined with one SI screw, for attaining the most rigid fixation. In order to avoid inaccuracies caused by implanting sequence of internal fixation, each specimen was fixed by MIAP and one IS screw firstly. And then, we removed the MIAP and inserted the second IS screw into the first sacral vertebral body.

We fixed the samples at a standing neutral position and used a peak load of 500 N, which corresponded to the average weight of the upper body of an adult.^[23,24] Twenty cycles were carried out to determine the stability of posterior pelvic ring fixed with two kinds of internal fixation. Schildhauer *et al.*^[25] performed 10,000 cycles, whereas Sagi *et al.* only examined ten cycles in biomechanical tests.^[26]

Under vertical load, the shifts in the fracture gap in Tile C injuries were not limited to vertical (z-axis) shifts but also included rotational (x-axis) and translational (y-axis) shifts.^[27] Shifts arising along three axes were calculated, and the shifts in the fracture gap on the level of the PIIS were measured using the grating displacement sensor, which was used to reflect the stability of pelvic fractures fixed with two kinds of internal fixation. The vertical displacement recorded by the biomechanical testing machine reflected the total displacement of the entire structure, however the two kinds of internal fixation were fixed in the same specimen in turn, therefore, our data were comparable.

The results of this study indicate that using two IS screws and MIAP combined with one SI screw in the treatment of Tile C pelvic ring injuries restore most of the stability of the pelvic ring. The MIAP conforms to the anatomical structure of the posterior pelvic ring, which is used to fixate the posterior pelvic ring fractures without prebending. It is functioned as a suspension bridge structure similar to the sacroiliac complex^[9] that plays a very important role in the human skeletal system by linking up the trunk and lower limbs. Biomechanical study suggested that the longitudinal sacral fractures fixed with MIAP were as stable as that with two IS screws under vertical and torsional load.^[17] Under 600 N vertical load, the maximal displacement of the pelvis fixed with MIAP was 1.30 mm on average, similar to the average displacement of 1.27 mm fixed with two IS screws; the torque required for 4° rotation of the pelvis fixed with MIAP was 7.81 nm on average, similar to the average torque of 7.82 Nm. The MIAP was a minimally invasive procedure and easy to perform. It was attached to the dorsal part of sacroiliac joints and fixed the ilium and sacrum through long cancellous screws. MIAP can be used to reduce separated or compressed fractures by rotating the connection bar. Chen *et al.* treated patients with Denis Type II sacral fractures using MIAP, and yielded satisfactory clinical outcomes.^[9,18]

Two IS screws placed in the first sacral vertebral body to stabilize the posterior pelvic ring was considered to be the strongest fixation.^[28] Currently, it is being applied more and more widely. IS screw fixation is considered as a “central

fixation” technique that provides strong fixation because IS screw placement into the S1 body penetrates through three layers of cortical bone.^[29-31] Although some biomechanical studies suggested that two IS screws provided better fixation than only one screw for stabilizing the posterior pelvic ring,^[32,33] placing of the single screw was considered sufficient.^[34]

Therefore, MIAP combined with one IS screw, equal to posterior fixation combined with central fixation, can provide an excellent biomechanical stability. In our study, we found that the stability of the posterior pelvic ring fixed by MIAP combined with one screw was better than that fixed by two IS screws.

Percutaneous two IS screws fixation has such advantages as short incisions, low soft tissue complications, and less blood loss. However, two IS screws fixation remains a technically difficult manipulation because of limitations of medical facilities, clinical experience, and variations of the anatomical structure. Although computer-navigated IS screw insertion can reduce the operation time, malposition rate, and radiation exposure,^[15] its widespread application has been limited because the huge facilities and expensive equipment are required. C-arm fluoroscopy is still commonly used in practice, under which it is difficult to identify “safe zone.” Sacral dysmorphism is not rare, occurring in 30–40% of adult patients,^[35] and the upper sacral safe zone is 36% smaller than that in normals.^[36] The screw misplacement rate was 2.05–13.00% because of skeletal deformity or malreduced.^[37,38] Routine one IS screw insertion into the first sacral vertebral body was safe, but the placement of two IS screws was considered to be difficult. In addition, IS screw cannot effectively reduce the compressed sacral fractures. In our approach, MIAP was implanted firstly, which can be used to reduce separated or compressed fractures. And then, one IS screw was inserted easily for increasing the stability of pelvis. This procedure is helpful in promoting its widespread application in most hospitals in the world.

Our study had several limitations. We implanted two kinds of internal fixation in the same specimen in turn to reduce the influence caused by skeletal age and bone, but the implantation and removal of internal fixation were bound to affect the strength of posterior pelvic ring. In addition, only six specimens were used in this study because the acquisition of a large number of specimens was difficult. In future study, we should increase the sample size and compare the stability of the posterior pelvic ring fixed with these kinds of internal fixation.

In conclusion, the stability of Tile C pelvic fractures fixed with MIAP combined with one IS screw was better than that fixed with two IS screws under vertical load. This new method could be used in the clinical treatment of longitudinal fractures of the posterior pelvic ring.

Financial support and sponsorship

This study was funded by the grants from the National

Natural Science Foundation of China (No. 81271975) and from Hebei Provincial Health Bureau (No. ZL20140290).

Conflicts of interest

There are no conflicts of interest.

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