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A novel fixation system for sacroiliac dislocation fracture: Internal fixation system design and biomechanics analysis

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ABSTRACT

Background: Although there were many different types of fixation techniques for sacroiliac dislocation fracture, the treat remained challenging in posterior pelvic ring injury. The purpose of this study was to evaluate the biomechanical effects of a novel fixation system we designed.
Methods: 12 human cadavers (L3–pelvic–femora) were used to compare biomechanical stability after reconstruction on the same specimens in four conditions: (1) intact, (2) cable system, (3) plate–pedicle screw system, and (4) cable system and plate–pedicle screw combination system (combination system). Biomechanical testing was performed on a material testing machine for evaluating the stiffness of the pelvic fixation construct in compression and torsion.
Finding: The cable system and plate–pedicle screw system alone may be insufficient to resist vertical shearing and rotational loads; however the combination system for unstable sacroiliac dislocation fractures provided significantly greater stability than single plate–pedicle or cable fixation system.
Interpretation: The novel fixation system for unstable sacroiliac dislocation fractures produced sufficient stability in axial compression and axial rotation test in type C pelvic ring injuries. It may also offer a better solution for sacroiliac dislocation fractures.

1. Introduction

As an outcome of vertical shearing force, sacroiliac dislocation fracture is classed as type C injury by Tile and results in rotatory and vertical instability (Tile, 1988). The key requirement of a successful sacroiliac injury repair is a functional intact alignment between the ilium, sacrum and lumbar spine that is strong enough to counterbalance translational and rotational forces. The goal of surgical fixation is the reconstruction of the spine–pelvic-junction to allow early weight-bearing and to facilitate nursing care, particularly for multiple injured patients.

Open reduction and internal fixation has been used frequently for posterior instability of the pelvis in recent years, and different types of fixation techniques have been described: iliosacral screws, sacral bars and plate osteosynthesis. However none of these techniques provide adequate fixation for early unrestricted weight-bearing status.

Triangular osteosynthesis (TOS) has recently been introduced to treat unstable pelvic ring injuries (Schildhauer et al., 1998; Schildhauer et al., 2001, 2003). This fixation technique combined a lumbopelvic distraction osteosynthesis (the vertical component) with a transverse fixation (iliosacral screw osteosynthesis or tension-band transiliac plate osteosynthesis; the horizontal component). This posterior stabilization uniquely provided significantly greater multiplanar stability than iliosacral screw fixation under in vitro cyclic loading conditions, which allowed early postoperative full weight bearing (Schildhauer et al., 2001). With the development of pedicle screw–rods system, there were many modified TOS techniques (Mouhsine et al., 2006).

Potential problems exist with TOS system. One is local complaints over the sacroiliac joint. Because the skin overlying the sacroiliac joint lacks an underlying muscle layer and the head of pedicle screws has high prominence, type C pelvic ring injuries also typically present soft tissue involvement, which tends to develop a pressure sore when the patient is in the supine position. Many authors reported a high incidence of skin problems over this site after the use of internal fixation devices. Another problem is the bending direction of the pedicle screw rod. In order to adapt to complex structure of lumbopelvic region, the rod should be bent to the exact angle according to screw position of the L4, L5 and iliac crest, although it's difficult to perform a bending procedure (Saiki et al., 2002; Schildhauer et al., 2006).

Building on TOS principle, we designed a novel fixation system for a vertical shear injury of sacroiliac (SJ) dislocation fracture: plate–pedicle screw system (No. ZL201020039574.7, CN PAT) and cable system (No. ZL201020107000.9, CN PAT). The system was a combination of lumbopelvic distraction osteosynthesis (plate–pedicle screw system) and transverse fixation (cable system) for the sacroiliac dislocation fracture. Biomechanical test finding revealed that it was a new operative

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concept to reduce and produce sufficient structural stability in type C pelvic ring injuries.

The purpose of this study was to discuss the novel fixation system's design principle and the biomechanics feature for sacroiliac dislocation fracture.

2. Methods

2.1. Specimen preparation

After the institutional review board approval, seven male and five female human cadaveric pelvic and lumbar spine specimens were obtained. The average age of the specimens was 37.5 years (range 25–45 years). Skeletal diseases were excluded based on premortem history and radiographic examination, the bone mineral density (BMD) was measured at L3–L5 by dual-energy X-ray absorptiometry (DEXA®, Dens scan 1000, Scanco Medical, Switzerland) with a slice thickness of 2 mm, and the average value was used as the specimen's BMD (Yu et al., 2009). No associated pelvic trauma or hidden pelvic fracture, no metastatic or primary neoplastic bone lesions or evidence of any other gross abnormalities was found after careful inspection.

The specimens were preserved for formal embalming with formaldehyde and stored in double-wrapped plastic bags at −20 °C. Before the experiment, the specimens were thawed for 24 h at room temperature. L3–pelvis–femora specimens were used in the current study. All soft tissue was removed except for ligamentous structures (anterior, interosseous, and posterior iliosacral ligaments, sacrotuberous and sacrospinous ligaments, iliolumbar ligaments, and symphysis pubis structures).

2.2. Internal fixation system design

We measured the angle according to screw position in the L4–L5 pedicle and iliac bone through the posterior–superior–iliac–spine (PSIS) in twelve cadaveric pelvic and lumbar spine specimens and inputted the datum into the computer. With the help of software Inventor 2010 (Autodesk company, USA), we designed the novel internal fixation system and produced them.

The novel fixation system included plate–pedicle screw system and cable system. The plate–pedicle screw system consisted of the plate nail (8 mm × 75 mm fully threaded; as an iliac screw), pedicle screws (7 mm × 50 mm USS screw), and the mixture frame of 3.5 mm three-hole reconstruction plate and a 5.5 mm pre-curved L-shape rod. There was a 35° anatomic angle between the reconstruction plate and rod. The mixture frame joined the plate nail and pedicle screws. The cable system consisted of a 2.5 mm cable, 4 mm fully threaded cap screw and 20 mm × 12 mm × 8 mm cube connector. The cable could pass through the connector and be tightened by the screw (stainless steel, Degebaer Medical Co. Ltd, Wuhan, China) (Fig. 1).

2.3. Sacroiliac dislocation fracture model design and reconstruction

An unstable sacroiliac dislocation fracture was surgically created by using an oscillating saw to osteotomize the pubic symphysis as well as the sacroiliac joint on the left side (OTA type 61-C2).

The pubic symphysis was internally fixed by a 3.5 mm 4-hole reconstruction plate. Unstable sacroiliac dislocation fractures were stabilized with three different techniques: single cable system; single plate–pedicle screw system; and cable system and plate–pedicle screw combination system.

In the single cable system condition, the technique for application of the cables was the same as that described for sacral rods by Tile (1994). Each cable was placed through the posterior pelvis in the area between the superior and inferior iliac spines and locked in place with two connectors at each end. In the single plate–pedicle screw system condition, the mixture frame of the Universal Spine System (USS) spinal fixation system and reconstruction plate was applied between the L4 and L5 pedicle and the ipsilateral posterior superior iliac spine (PSIS) and directed intraosseously toward the anterior inferior iliac spine (AIIS). The iliac screw technique was commonly used in fixation practice. In the cable system and plate–pedicle screw combination system condition, specimens were stabilized as cable fixation but underwent additional plate–pedicle screw lumbopelvic fixation, establishing the triangular osteosynthesis of the posterior pelvic ring as shown in Fig. 2. Plain pelvic anteroposterior radiographs were obtained after placement of the implants to confirm proper fixation.

2.4. Biomechanical testing

A round polyester resin platform was placed on the L3 superior endplate. In addition, a hemispherical groove was created using the loading bulb of a universal testing machine (Zwick Z100; Zwick/Roell Co. Ltd, Germany) before the platform shaping. A rig was custom-designed and used to fix the cadaveric femora into bilateral sleeves using 8-point locked screws to minimize the movement at the bone–metal interface. Each sleeve was fixed on a slider. There was a standard deep-groove linear guide for ball-bearings under the slider, which was set on a firm base of steel, and used to reduce friction.

Biomechanical testing was performed in a double-leg-stance model. The specimens were mounted in accustomed frame designed for axial compression and axial rotation test.

Each specimen was tested in four conditions after reduction and internal fixation: (1) intact, (2) cable system, (3) plate–pedicle screw system, and (4) cable system and plate–pedicle screw combination system (combination system). The test order was from the least to the most destructive.

Macroscopic fracture behavior was noted. If > 1 cm of fracture displacement occurred at the cranial ridge of the S1 foramen before completion of the load cycles, the specimen and fixation were considered to have failed, and the test was aborted.

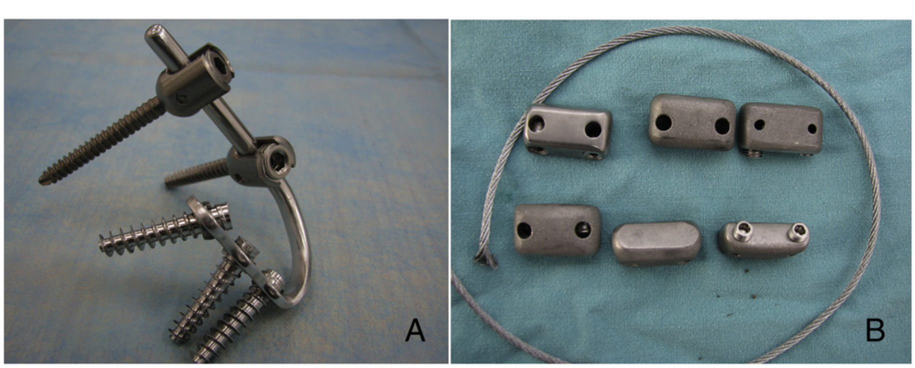

Fig. 1. Photograph showing the novel fixation system: A: plate–pedicle screw system; B: cable system.