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A biomechanical study of standard posterior pelvic ring fixation versus a posterior pedicle screw construct

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ABSTRACT

Objectives: The purpose of this study was to biomechanically test a percutaneous pedicle screw construct for posterior pelvic stabilisation and compare it to standard fixation modalities.
Methods: Utilizing a sacral fracture and sacroiliac (SI) joint disruption model, we tested 4 constructs in single-leg stance: an S1 sacroiliac screw, S1 and S2 screws, the pedicle screw construct, and the pedicle screw construct + S1 screw. We recorded displacement at the pubic symphysis and SI joint using high-speed video. Axial stiffness was also calculated. Values were compared using a 2-way ANOVA with Bonferroni adjustment ($p < 0.05$).
Results: In the sacral fracture model, the stiffness was greatest for the pedicle screw + S1 construct ($p < 0.001$). There was no significant difference between the pedicle screw construct and S1 sacroiliac screw ($p = 1$). For the SI joint model, the S1 + S2 SI screws had the largest overall load and stiffness ($p < 0.001$). The S1 screw was significantly stronger than pedicle screw construct ($p = 0.001$).
Conclusions: The pedicle screw construct biomechanically compares to currently accepted methods of fixation for sacral fractures when the fracture is uncompressible. It should not be used for SI joint disruptions as one SI or an S1 + S2 are significantly stiffer and cheaper.

Introduction

The treatment of unstable pelvic ring injuries continues to evolve. Posterior pelvic ring injuries commonly involve the ilium, sacroiliac (SI) joint, sacrum, or a combination [1]. The incidence of unstable sacral fractures in these injuries is between 17.4% and 30.4% as reported in several large series [2,3]. The mechanism is usually high-energy trauma, although in the setting of marked osteopenia and pathologic lesions, can be caused by low-energy. The stabilisation of these injuries can be difficult even in a patient with adequate bone stock and no concomitant medical comorbidities [4–8]. This treatment is further complicated when a patient presents with insufficient bone quality, comminution or a pathologic fracture [6–8]. These patients are usually not candidates for large open or lengthy procedures [6–8]. An anterior internal fixator has been employed that utilises the supra-acetabular screws connected to a subcutaneous rod for structural stability of the anterior ring. This techniques still incorporates posterior ring stabilisation using either percutaneous or open techniques in unstable pelvic ring injuries [9–13].

Many treatment methods have been studied for posterior pelvic fixation, including external fixation, open reduction internal fixation using plates, tension band constructs, or transiliac bars, and percutaneous Sacroiliac screws (SI) [4,5,14–27]. Currently, the standard of care for unstable sacral fractures involves closed reduction with percutaneous SI screw placement [17–20]. Recently, spinopelvic fixation (SPF) and triangular osteosynthesis (TOS) techniques have been shown to have improved properties over standard SI screw fixation in terms of vertical stability and sagittal plain rotation [28–33]. Not all patients, due to a variety of factors including congenital anomalies or poor bone stock, can be appropriately stabilised with percutaneous techniques [6,8,28,29]. We employed a percutaneous technique with, custom spinal implants in a manner similar to anterior subcutaneous pelvic fixation without lumbar spine instrumentation.

The purpose of the study was to evaluate the biomechanical properties of established percutaneous methods of fixation for vertically and rotationally unstable pelvic ring injuries, and

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compare them to a posterior pedicle screw construct used alone and in combination with an SI screw. By looking at the magnitude of load required to cause a specific deformation (stiffness of the constructs) and displacements at the pubic symphysis and at the fracture site, the following questions were posed: were two screws (one into S1 and one into S2) biomechanically superior to one S1 screw; is this pedicle screw construct alone superior to the SI screw constructs; is a combination of the pedicle screw construct and one SI screw superior to the SI screw constructs?

Materials and methods

Fracture model

In a 3rd generation composite pelvis model (Sawbones, Vashon, WA, USA), we examined two different unilateral vertically and rotationally unstable pelvic ring injuries; one with a pure SI joint dislocation (OTA type 61-C1.2.a2.c5) and another with an ipsilateral transforaminal sacral fracture (OTA type 61-C1.3.a2.c5). For the transforaminal fracture model, a saw was used to osteotomise an intact composite pelvis through the right sacral neural foramina creating a 1-cm bone loss, and through the pubic symphysis. The pure SI joint dislocation model was shipped from the company with an intact left SI joint, and disrupted right SI joint and pubic symphysis. The composite pelvis model has been shown to allow for more controlled and repeatable testing, as each specimen has the same properties [34–37]. The model simulates natural cortical bone using short e-glass fibres and epoxy resin pressure injected around a foam core to represent the cancellous bone of an average-sized adult male. Six composite pelvises were tested. Three composite pelvises were tested with the sacral fracture model with the 4 stabilisation methods applied in a random order. Three composite pelvises were tested with the SI joint dislocation model but only 3 stabilisation methods applied in random order were tested. This was because one construct (Pedicle screw construct by itself) was so inferior in this model that it was futile to continue testing it.

Fixation construct

Construct S1 was a standard 6.5-mm $\times$ 100-mm partially threaded (32-mm) cannulated cancellous SI screw (Synthes, Paoli, PA, USA) placed under fluoroscopy and direct visualisation posteriorly from the ilium into the body of the first sacral vertebrae without anterior cortex penetration [19,20]. The screw was placed perpendicular [28] to the sacral fracture line or SI joint, and a 7 in.-pound torque screwdriver [27,38] was used to achieve equal compression in the SI dislocation model. No compression was applied in the sacral fracture model. The screw and washer were sunk to the level of the bone.

Construct S1S2 utilised two SI screws, one into the S1 vertebral body, and the other into the S2 vertebrae (The S2 screw was 80 mm). Once again, a 7 in.-pound torque screwdriver was used in the SI dislocation model. No compression was applied in the sacral fracture model. The screw and washer were sunk to the level of the bone.

The pedicle screw construct, utilised two 7.0-mm $\times$ 80-mm titanium polyaxial pedicle screws and a 6.0-mm stiff titanium rod (Click'X Pedicle Screw System, Synthes, Paoli, PA, USA). Under direct visualisation and fluoroscopy using Judet oblique views, a 4.5-mm drill was placed with the starting point at the posterior-superior iliac spine (PSIS) directed towards the anterior–inferior iliac spine (AIIS). After drilling, the pedicle screw was inserted, with the same method repeated at the contralateral PSIS. The two screws were seated to the level of the bone by sinking them into the PSIS. A straight rod of appropriate length was placed in the screw heads, and locking caps applied. The construct was compressed using a small c-clamp attached to the rod and compressor instruments from the spinal system; the locking caps were then tightened with a 7 in.-pound torque screwdriver in the SI dislocation model. No compression was applied in the sacral fracture model. Care was taken to cause no deformation at the SI joint or pubic symphysis during compression of the construct.

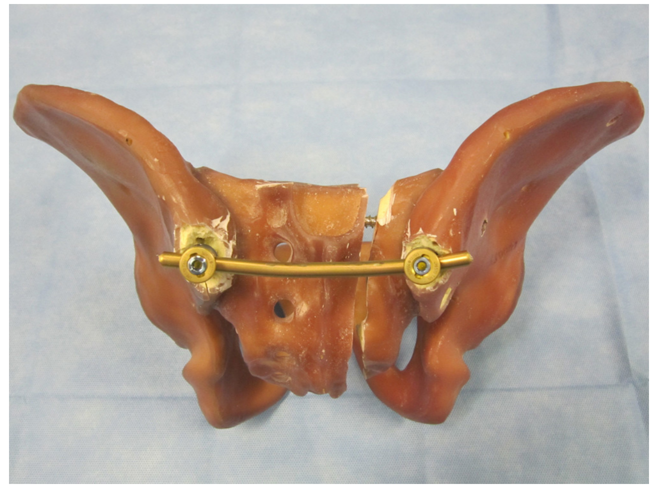

Fig. 1. Posterior view of novel device + S1 screw in a composite pelvis.

The pedicle screws + S1 device (Fig. 1) is a combination of two constructs: one SI screw into the S1 vertebral body and the pedicle screw construct.

Testing

We created a single-leg stance model (Fig. 2) based on previous reports [15,27,39,40]. Each pelvis was securely mounted through the sacrum at the S1 level to a servo hydraulic testing machine (Instron Model 8500, Canton, MA, USA). The sacral mount was free to pivot in all planes to eliminate loading artifact. The anatomic standing vertical relationship of the anterior-superior iliac spine (ASIS) and pubic symphysis was maintained. For the femur, we used a 52-mm hemiarthroplasty, which freely articulated with the acetabulum. The femoral component was potted using Bondo putty (3M, St. Paul, MN, USA) in a position of 15° of adduction and 15° of anteversion to simulate single-legged stance, and the distal femur rigidly fixed to a laterally mobile base plate with confines on both sides. The abductor musculature and vectors were simulated using cables attached to the pelvis with two drill holes at the gluteus ridge, and a pulley system at the level of the greater trochanter on the prosthesis [27,41]. The chains were tightened manually and stabilised the hemi pelvis against rotation.

Markers were placed at the fracture site and at the pubic symphysis. The markers were small white dots, uniform in size, placed at the superior and inferior aspects of the bilateral SI joints, and at the superior and inferior portion of the anterior pubic symphysis. A high-speed digital video camera (HG-2000, MotionXtra Inc., San Diego, CA, USA) aimed at the markers, recorded images at 125 frames per second.

A vertical compressive displacement of 7 mm was applied through the sacral mount at the rate of 10 mm/s. This was chosen based on previous studies [25,26], and pilot data showing a more reproducible measurement of construct stiffness. For each pelvis, the constructs were applied in random order. The testing was repeated five times per construct to look for any degradation in the mechanical properties of the construct with repeated testing of the same pelvis. Each construct was re-tightened between tests.

For each loading cycle, force and displacement data were recorded by a 32-bit Instron MAX V9.3 at 1 kHz, and connected to a