

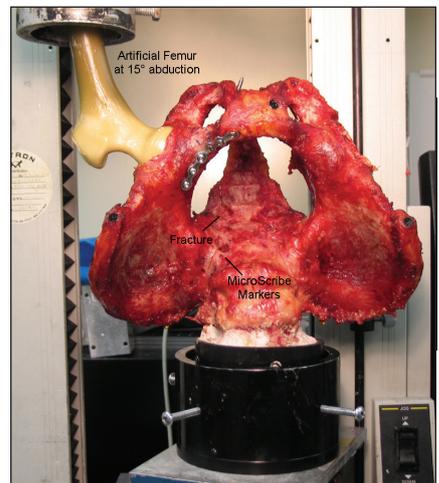
# Comparison of Two-transsacral-screw Fixation Versus Triangular Osteosynthesis for Transforaminal Sacral Fractures

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## abstract

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Transforaminal pelvic fractures are high-energy injuries that are translationally and rotationally unstable. This study compared the biomechanical stability of triangular osteosynthesis vs 2-transsacral-screw fixation in the repair of a transforaminal pelvic fracture model. A transforaminal fracture model was created in 10 cadaveric lumbopelvic specimens. Five of the specimens were stabilized with triangular osteosynthesis, which consisted of unilateral L5-to-iliac lumbopelvic fixation and ipsilateral iliosacral screw fixation. The remaining 5 were stabilized with a 2-transsacral-screw fixation technique that consisted of 2 transsacral screws inserted across S1. All specimens were loaded cyclically and then loaded to failure. Translation and rotation were measured using the MicroScribe 3D digitizing system (Revware Inc, Raleigh, North Carolina). The 2-transsacral-screw group showed significantly greater stiffness than the triangular osteosynthesis group (2-transsacral-screw group, 248.7 N/mm [standard deviation, 73.9]; triangular osteosynthesis group, 125.0 N/mm [standard deviation, 66.9];  $P=.02$ ); however, ultimate load and rotational stiffness were not statistically significant. Compared with triangular osteosynthesis fixation, the use of 2 transsacral screws provides a comparable biomechanical stability profile in both translation and rotation. This newly revised 2-transsacral-screw construct offers the traumatologist an alternative meth-



**Figure:** Mounted specimen showing MicroScribe 3D digitizing system (Revware Inc, Raleigh, North Carolina) markers.

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od of repair for vertical shear fractures that provides biplanar stability. It also offers the advantage of percutaneous placement in either the prone or supine position.

**V**ertical shear fractures of the pelvis are uncommon high-energy injuries that are vertically and rotationally unstable. Stabilization of these pelvic ring injuries has better long-term functional outcomes and decreases morbidity and mortality.<sup>1</sup> Methods of fixation for posterior pelvic ring injuries include anterior plating, transiliac plating/bars, spinopelvic fixation, and iliosacral screws.<sup>1-9</sup> Iliosacral screw fixation has been shown to provide comparable stability to other traditional posterior pelvic ring fixation methods. Screws can be placed percutaneously in the supine position,<sup>10,11</sup> which minimizes patient transfer, soft tissue damage, and blood loss.<sup>4,6,12-14</sup> In addition, this technique has been reported to have a low rate of complications.<sup>11</sup> Recent studies have shown that iliosacral screw fixation is sufficient for most posterior pelvic ring injuries; however, there is a subset of pelvic fractures that require greater stability.<sup>11,15-18</sup>

Triangular osteosynthesis provides superior fixation strength compared with iliosacral screw fixation.<sup>19</sup> Josten et al<sup>20</sup> reported that triangular osteosynthesis provides increased stability for vertically unstable pelvic fractures. This technique combines unilateral lumbopelvic osteosynthesis for vertical stabilization and iliosacral screw fixation for horizontal stabilization.

The goal of this study was to compare the biomechanical characteristics of a new 2-transsacral-screw fixation technique in which each screw crosses both sacroiliac joints and the sacrum vs triangular osteosynthesis fixation in a vertically unstable cadaveric pelvic fracture model. The authors hypothesized that the added fixation achieved by the second transsacral screw traversing both sacroiliac joints is comparable to that of triangular osteosynthesis.

## MATERIALS AND METHODS

Ten fresh-frozen cadaveric pelvises (78.4±8.7 years) without gross evidence of pathology were obtained for this study. Each specimen consisted of an intact sacrum, bilateral ilium, and vertebral levels L3-L5. They were carefully examined for preexisting pathology, and tissue dissection was performed, with removal of all nonstructural soft tissue elements. The anterior and posterior sacroiliac ligaments, anterior longitudinal ligament, interspinous ligaments, L5-S1 facets, supraspinous ligaments, and pubic symphysis were kept intact.

To assess bone quality, a 5-cm segment from the right iliac crest, proximal to the anterior superior iliac spine, was sampled. Each sample was cleaned and dried under a heat lamp, leaving the cortex and trabeculae intact. The samples were scanned, and using the software program NIH Image (National Institutes of Health, Bethesda, Maryland),<sup>21</sup> the trabeculae/air ratio was calculated (**Table 1**). After matching for the trabeculae/air ratio, size, and age, each specimen was randomly assigned to 1 of 2 groups: triangular osteosynthesis and 2-transsacral-screw fixation.

### Triangular Osteosynthesis Fixation

An oscillating saw was used to create a vertical osteotomy through the left superior and inferior rami and sacral foramina. A 6-hole, 3.5-mm pelvic reconstruction plate (Synthes USA, Paoli, Pennsylvania) was contoured and anatomically reduced the left superior ramus. The left inferior ramus osteotomy was not stabilized. Posteriorly, a titanium polyaxial pedicle screw (5.5 mm; Alphatec Spine, Carlsbad, California) was placed in the left L5 pedicle, followed by placement of a uniaxial fixed iliac screw (7.5 mm; Alphatec Spine) in the posterior superior iliac spine. A collinear reduction clamp was used to reduce the transforaminal osteotomy and insert a guide pin across the sacrum, starting from the outer cortex of the left ilium and ending in the S1 body. The osteotomy

was stabilized with a cannulated iliosacral screw (6.5 mm, 16-mm thread; Synthes USA) with a washer. The screw was placed so that it terminated in the S1 body, as described by Matta and Saucedo.<sup>7</sup> The pedicle screw and iliac screw were then connected with a rod, and set screws were placed and tightened according to the manufacturer's specified technique.

### Two-transsacral-screw Fixation

Left superior rami, inferior rami, and transforaminal osteotomies were created in the 2-transsacral-screw specimens with the same technique as for the triangular osteosynthesis group described earlier. The superior rami osteotomy was stabilized with the contoured pelvic reconstruction plate. The left inferior ramus osteotomy was not stabilized. The collinear reduction clamp was used to reduce the transforaminal osteotomy and insert 2 guide pins through the left ilium, S1 body, and contralateral ilium. The osteotomy was stabilized with 2 cannulated transsacral screws (6.5 mm, 16-mm thread; Synthes USA) with washers (**Figures 1-2**).

### Specimen Mounting

All specimens in both repair groups were mounted in the same manner. Three custom-designed threaded rods were axially inserted into the vertebral bodies of L3-L5, eliminating motion at the L3-L4 and L4-L5 intervertebral disks. A 5.1-cm drywall screw was inserted into the right pubic tubercle, and this was used to suspend the specimen on a custom-designed device that aligned the pubic symphysis and anterior-superior iliac spine in the same coronal plane. While this device was used, the vertebral segments from L3-L4 were potted in a precut 10.2-cm polyvinyl chloride pipe. The vertebrae were secured to the polyvinyl chloride pipe using 11 threaded screws (either 5.1 cm or 7.6 cm) inserted from multiple directions and then potted with plaster of Paris (DAP Products Inc, Baltimore, Maryland).

Table 1

Specimen Profile

Triangular Osteosynthesis				Transiliac-Transsacral			
Specimen	Sex	Age, y	Trabeculae/Air, %	Specimen	Sex	Age, y	Trabeculae/Air, %
TO1	F	77	27.1	TTS1	F	75	28.6
TO2	F	78	36.9	TTS2	F	86	25.1
TO3	F	90	42.7	TTS3	F	86	35.6
TO4	M	64	29.8	TTS4	M	72	34.4
TO5	M	69	43.2	TTS5	M	87	49.4
Mean (SD)		75.6 (9.9)	35.9 (7.3)			81.2 (7.1)	34.6 (9.3)

Abbreviations: F, female; M, male; SD, standard deviation; TO, triangular osteosynthesis; TTS, 2-transsacral-screw fixation.

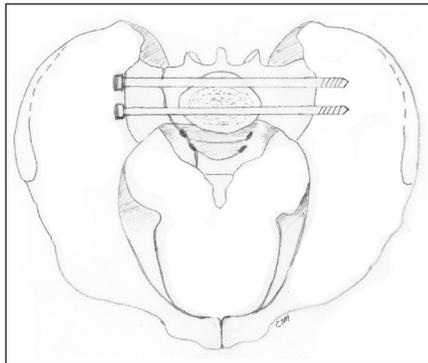


Figure 1: Transsacral inlet view.

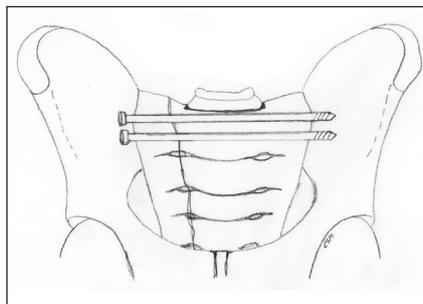


Figure 2: Transsacral outlet view.

Digitizing Markers

Because the specimens varied in size, using the MicroScribe 3D digitizing system (Revware Inc, Raleigh, North Carolina), a local coordinate system was customized for each specimen. The MicroScribe system can digitize a point in 3 dimensions (Cartesian coordinate system). The left and right anterior-superior iliac spines and the right pubic tubercle were the standardized landmarks used to create the local coordinate system.

On each specimen, 7 pairs of reference points about the fracture lines were identified; these points were exactly 5 mm medial and lateral to the fractures. The paired points were the anterior and posterior sacral ala, the superior S1 foraminal ridge, the inferior S1 and S2 foraminal ridges, the superior ramus, and the inferior ramus. Indentations were scored in the cortex for each point. Having the indenta-

tions on the cortical bone allowed the tip of the MicroScribe system to be reliably positioned on the specimen throughout the experiment.

Biomechanical Testing

All pelvic specimens were tested using the Instron materials testing apparatus (Instron Model 4411; Instron Load Cell, S/N 010, 5000 N, resolution 0.005 N, accuracy 0.25%; Instron, Canton, Massachusetts). The pelvis was inverted, placed on an x-y translator, and loaded through the left acetabulum with an artificial femur set at 15° abduction (Figure 3). Once the specimen was mounted onto the Instron apparatus and prepared for testing, a preload of 5 N was applied axially. The specimen was then preconditioned by cyclically loading from 5 to 100 N for 10 cycles at a rate of 50 mm/min. Each specimen underwent stepwise loading from a load of 25 to 400 N in 25-N increments. For each load, the

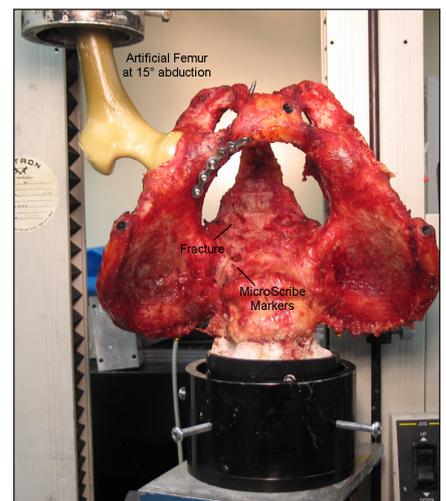


Figure 3: Mounted specimen showing MicroScribe 3D digitizing system (Revware Inc, Raleigh, North Carolina) markers.

specimen underwent 3 cycles from the preload of 5 N to the set load. At the third cycle, all 7 pairs of markers were digitized at the third loading cycle. If the specimens had not yet reached catastrophic failure with a 400-N load, the load was increased in 25-N increments until catastrophic failure occurred.

From the digitized markers, translation and 3-dimensional rotation of the fracture displacement and rotation in the coronal, transverse, and sagittal planes were calculated (accuracy, 0.3 mm; 0.3°). Stiffness was calculated using displacement at the inferior ridge of S1. Cyclical stiffness was defined as stiffness of 300 to

Table 2

Stiffness Data			
Testing Mode	TO <sup>a</sup>	TTS <sup>a</sup>	P
Cyclic, N/mm	125.0 (66.9)	249.7 (73.6)	.02
Total, N/mm	111.5 (45.4)	132.0 (46.9)	.46
Failure, N/mm	30.1 (18.0)	43.8 (25.8)	.40

Abbreviations: TO, triangular osteosynthesis; TTS, 2-transsacral-screw fixation.  
<sup>a</sup>Mean (standard deviation).

400 N. Failure stiffness was the stiffness before catastrophic failure. Total stiffness was defined as stiffness across all loads. Clinical failure was defined as the load when displacement of greater than 5 mm at the S1 foramen was measured. Ultimate load was defined as the load before catastrophic failure occurred. On completion of biomechanical testing, all specimens were dissected and disarticulated to verify hardware placement.

**Statistical Analysis**

Because of the small sample size of 5, a nonparametric Mann-Whitney U test for comparing 2 independent samples was used to compare the biomechanical characteristics of the 2 constructs. The variables compared from each of the repairs were extracted from the cycles of interest and the load to failure testing. The level

of statistical significance was set at  $P < .05$ .

Post hoc power analysis based on averages and standard deviations (SDs) of each parameter determined that the minimum number of specimens needed to show statistical significance based on a power level of 0.8 was 15 for failure torsional stiffness, 56 for failure stiffness, and 88 for total stiffness. All other parameters required a sample size greater than 100 to show statistical significance.

**RESULTS**

Both treatment groups consisted of 3 women and 2 men. The average age for the triangular osteosynthesis group was 75.6 years (SD, 9.9; median, 77; range, 64-90) and the average age for the 2-transsacral-screw group was 81.2 years (SD, 7.1; median, 86; range, 72-87) (Table 1). Cyclical stiffness of the 2-transsacral-screw recon-

struction group was greater than that of the triangular osteosynthesis group. This difference was statistically significant (triangular osteosynthesis group, 125.0 N/mm [SD, 66.9]; 2-transsacral-screw group, 249.7 N/mm [SD, 73.6];  $P = .02$ ). However, this study did not measure statistical difference for total stiffness or failure stiffness (Table 2).

There was no statistical difference in ultimate load (triangular osteosynthesis group, 665 N [SD, 172]; 2-transsacral-screw group, 675 N [SD, 172];  $P = .75$ ). One of the specimens in the triangular osteosynthesis group and 3 in the 2-transsacral-screw group reached catastrophic failure before reaching clinical failure (Table 3). Also, there was no statistical difference in rotation across the fracture (Table 4). When comparing constructs, there was no statistical difference in cyclical torsional stiffness, failure torsional stiffness, or total torsional stiffness.

There was no predictable mode of failure among the specimens; however, all of the specimens showed lateral displacement of the sacrum on failure. Four of the specimens in the triangular osteosynthesis group and all of the specimens in the 2-transsacral-screw group showed rotational deformation in the sagittal plane. Two specimens in each group had screw

Table 3

Failure Data					
Triangular Osteosynthesis			Transiliac-Transsacral		
Specimen	Clinical, N	Ultimate, N	Specimen	Clinical, N	Ultimate, N
TO1	650	725	TTS1	(2.7 mm) <sup>a</sup>	625
TO2	900	900	TTS2	(3.7 mm) <sup>a</sup>	550
TO3	400	425	TTS3	(4.4 mm) <sup>a</sup>	575
TO4	(4.6 mm) <sup>a</sup>	625	TTS4	575	650
TO5	625	650	TTS5	900	975
Mean (SD)		665 (172)			675 (172)

Abbreviations: SD, standard deviation; TO, triangular osteosynthesis; TTS, 2-transsacral-screw fixation.  
<sup>a</sup>Reaching ultimate failure before clinical failure (displacement at ultimate failure).

Table 4

Rotation Data						
Dimension	Rotation at 400 N			Rotation at Ultimate Failure		
	TO <sup>a</sup>	TTS <sup>a</sup>	P	TO <sup>a</sup>	TTS <sup>a</sup>	P
3D	7.5 (4.0)	3.4 (3.3)	.12	12.7 (4.3)	13.1 (10.9)	.94
Coronal plane	13.6 (10.9)	4.4 (3.6)	.11	22.5 (11.7)	23.6 (11.3)	.89
Transverse plane	6.3 (5.2)	2.9 (3.6)	.26	11.6 (4.1)	13.7 (13.7)	.75
Sagittal plane	4.0 (2.2)	2.2 (2.1)	.20	6.7 (4.4)	6.2 (5.70)	.88

Abbreviations: 3D, 3-dimensional; TO, triangular osteosynthesis; TTS, 2-transsacral-screw fixation.

<sup>a</sup>Degrees, mean (standard deviation).

back out and failure of anterior pelvic ring fixation. Three specimens in each group pivoted about the superior ramus osteotomy but did not experience clinical failure at this site (Table 5).

Postexperimental dissection verified screw placement for all specimens. All of the screws were in the correct position; specifically, all of the iliosacral and transsacral screws were in, or crossed, the S1 body and did not violate the neuroforamina.

### DISCUSSION

This study compared the biomechanical stability of a new 2-transsacral-screw fixation technique with triangular osteosynthesis in a biomechanical pelvic fracture model. Although Beaulieu et al<sup>3</sup> clinically showed the placement of a single transsacral screw as an effective method for treating sacral fractures and pelvic malunions, previous studies showed a significant advantage in initial stability with triangular osteosynthesis compared with a single iliosacral screw terminating in the S1 body.<sup>19</sup> The findings of the current study did not refute the advantages of triangular osteosynthesis, but rather verified the similarity in stability with the new 2-transsacral-screw technique without the inherent risks associated with spinal instrumentation.

Although the biomechanical profiles of 2-transsacral-screw and triangular osteosynthesis fixation were similar, the 2-transsacral-screw group showed different

Table 5

Modes of Failure and Direction of Rotation			
Specimen	Anterior Ring Failure	Posterior Ring Rotation	
		Sagittal	Coronal
TO1	Screw/plate	Flex	None
TO2	Pivot	Flex	None
TO3	Pivot	Flex	None
TO4	Screw/plate	None	None
TO5	Pivot	Flex	None
TTS1	Pivot	Flex	None
TTS2	Screw/plate	Flex	ER
TTS3	Pivot	Ext	ER
TTS4	Pivot	Flex	ER
TTS5	Screw/plate	Flex	None

Abbreviations: ER, external rotation; Ext: extension deformity in the sagittal plane; Flex: flexion deformity in the sagittal plane; Pivot: rotation at the superior ramus osteotomy without gross failure; Screw/plate, screw back out or plate failure; TO, triangular osteosynthesis; TTS, 2-transsacral-screw fixation.

cyclical stiffness compared with the triangular osteosynthesis group. In this unstable pelvic fracture model, cyclical stiffness of 400 N, which is approximately equivalent to the upper body weight of an adult,<sup>22</sup> represents the physiologic force repeatedly loaded on the sacrum in the absence of fracture healing. Previous literature and the experimental design dictated the authors' choice of loading to optimize the testing parameters and data acquisition.<sup>4,12-14,19,22-26</sup> Using a load of 400 N, the current study showed that 2-transsacral-screw fixation has greater physiologic stiffness than trian-

gular osteosynthesis fixation.

In this study, ultimate failure load and clinical failure load were not statistically different between the 2 groups. This finding suggests that the initial postoperative stability achieved (before healing) is similar with either method of fixation. The added stability achieved with multiple transsacral screws in the current study is likely due to the biplanar stability of 2 screws and the additional cortical purchase in the contralateral ilium.

In addition to axial instability, a vertical shear fracture is rotationally unstable.

During loading, there are 2 different moments acting on the fracture: a moment originating from the lumbar vertebrae onto the sacrum and an opposite moment extending from the femoral head to the ilium. These asymmetric counteracting moments result in potential rotation at the fracture site. According to Schildhauer et al,<sup>24</sup> a key requirement for successful posterior pelvic ring stabilization is a functionally intact relationship among the ilium, sacrum, and lumbar spine that is strong enough to counterbalance axial and rotational forces. The authors measured rotation about the fracture at various loads. A resultant rotation was measured about the fracture, and it was broken down into sagittal, transverse, and coronal components. When comparing the aggregate (rotation in all planes) rotation and the rotational components, there was no significant difference in rotation between the 2 constructs. Placement of a single iliosacral screw does not protect against rotational forces. Rather, it becomes the axis of rotation and the main mode of failure. However, as shown in this study, a second transsacral screw provides biplanar stability and counteracts rotational forces. Therefore, this additional screw is believed to provide more stable fixation, which in some studies has been shown to correlate with improved functional results.<sup>11</sup>

In a patient with polytrauma, positioning and soft tissue compromise can limit surgical options. Transsacral screws have the advantage of being placed percutaneously in the supine position, avoiding the risks associated with an open procedure.<sup>9,11,15-17,27</sup> Routt et al<sup>10</sup> pioneered the safe placement of iliosacral screws and described various technical and radiographic guidelines for placing percutaneous iliosacral screws in the supine position.<sup>10,11,15-17,28,29</sup> Gardner and Routt<sup>29</sup> recently published a series in which they placed transsacral (transiliac-transsacral) screws in 56 patients with no complications. Nevertheless, transsacral screws

across the S1 segment cannot be used in all pelvises. Some pelvises cannot accommodate 2 screws because of sacral dysmorphism.<sup>16</sup> In such cases, a transsacral screw across the S2 body can be safely placed. Also, sacral malreduction decreases the “safe window” for placement of iliosacral screws. Reilly et al<sup>30</sup> found that in zone 2 sacral fractures, cranial displacement of greater than 5 mm substantially decreased the space available for iliosacral screw placement.

Although lumbopelvic fixation provides adequate biomechanical stability, the technique has many technical limitations and potential complications. It must be performed in the prone position, which may be difficult in the patient with polytrauma.<sup>31</sup> Potential complications include implant loosening or breakage, local infection, wound dehiscence, and implant prominence requiring hardware removal.<sup>19,24,32-34</sup> In addition, many authors who advocate triangular fixation recommend a second procedure to remove the spinal instrumentation.<sup>19,34</sup>

The advantage of lumbopelvic stabilization lies in the option to insert a vertical rod from the pedicle of L5 to the ilium. Placement of the rod more parallel to the long axis of the spine increases rotational stability. In this study, there was significant variability in the relationship between the L5 pedicle and the ilium, creating a rod position that was more perpendicular to the long axis of the spine than was initially anticipated. This variability may negate the potential advantage of lumbopelvic fixation in some patients. Clinically, in these instances, lumbar fixation in the L4 pedicle may be necessary.

Previous studies have applied various models to test the biomechanical stability of pelvic ring fixation.<sup>12,13,15,16,18,19,22-24,26,35</sup> More recently, Schildhauer et al<sup>19,24,25</sup> applied the single-limb model. They argued that the double-leg-stance model does not account for the bending loads across the fracture that occur during gait. Schildhauer et al<sup>19</sup> used a single-limb-stance model

because it isolated the load at the osteotomy site and created the worst-case scenario for the authors’ pelvic model. The single-leg stance, because of its asymmetry, generates large axial and rotational moments across the pelvis. Moreover, postoperatively, the patient with pelvic fracture will not put equal forces on both limbs because of pain as well as surgeon-imposed weight bearing restrictions. In this asymmetric arrangement, the fracture must sustain considerable shear and bending moments.<sup>36</sup> Thus, the single-limb stance models early postoperative weight bearing. Furthermore, inverting the specimen eliminated contralateral limb weight and abductor forces, allowing the specimen to move in the direction of least resistance.

The study had some weaknesses. Because of concern that the native femur would fracture before pelvic construct failure occurred, an artificial femur was used for axial loading. To standardize the model and minimize variables, the authors used a single artificial femur for all specimens. Ideally, the authors would have preferred to load the pelvis axially with the femur set at neutral; however, because each specimen was unique in size, the abduction was increased to 15° to avoid hip dislocation. As a consequence, by using the same artificial femur, there was some variability of the joint reactive forces between the specimens. Finally, this cadaver study could not replicate the role of passive muscle restraints of the pelvis. Also, the artificially created shear fracture does not have the interdigitation of fracture parts as a traumatic fracture.

## CONCLUSION

Two-transsacral-screw pelvic fixation offers greater cyclical stiffness and comparable ultimate strength to triangular osteosynthesis in a vertically unstable pelvic fracture model. The results of this study reflect the biomechanical stability of the repairs in a controlled laboratory setting, which may not directly correlate clini-

cally. Further clinical studies are needed to determine whether there is a clinical difference between the 2 constructs. In clinical practice, the authors predominantly use the 2-transsacral-screw technique to stabilize the posterior pelvic ring in vertical shear pelvic fractures. In the authors' hands, triangular osteosynthesis is reserved for patients with spinopelvic dissociation, where 2 transsacral screws often cannot be placed safely. However, the authors believe that both techniques can be effective in pelvic fracture fixation and should be part of the pelvic surgeon's armamentarium.

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