Published in final edited form as:

Clin Biomech (Bristol, Avon). 2016 October ; 38: 35–41. doi:10.1016/j.clinbiomech.2016.08.008.

Mechanical Comparison of Iliosacral Reconstruction Techniques After Sarcoma Resection

Craig R. Louer, MD^a, Nader A. Nassif, MD^{b,c}, Michael D. Brodt, MS^a, Daniel J. Leib, MS^a, Matthew J. Silva, PhD^a, and Douglas J. McDonald, MD^a

^AWashington University School of Medicine, Department of Orthopaedic Surgery Campus Box 8233, 660 S. Euclid Ave, St. Louis, MO 63110, USA

^BNewport Orthopedic Institute, 22 Corporate Plaza Drive, Newport Beach, CA 92660, USA

^CHoag Orthopedic Institute, 16250 Sand Canyon Ave, Irvine, CA 92618, USA

Abstract

Background: Reconstruction of iliosacral defects following oncologic resection is a difficult clinical problem associated with a high incidence of failure. Technical approaches to this problem are heterogeneous and evidence supporting specific techniques is sparse. Maximizing construct stability may improve union rates and functional outcomes. The purpose of this study is to compare construct stiffness, load to failure, and mechanism of failure between two methods of iliosacral reconstruction in an ex-vivo model to determine if either is mechanically superior.

Methods: Eight third-generation composite pelvises reconstructed with a plate-and-screw technique were tested against seven pelvises reconstructed with a minimal spinal instrumentation technique using axial loading in a double-leg stance model.

Findings: The pelvises from the plate group demonstrated higher stiffness in the direction of applied load (102.9 vs. 66.8 N/mm; $p=0.010$) and endured a significantly larger maximum force (1416 vs. 1059 N; $p=0.015$) than the rod group prior to failure. Subjectively, the rod-reconstructed pelvises were noted to be rotationally unconstrained while pivoting around their single point-of fixation in each segment leading to earlier failure.

Interpretation: Plate-reconstruction was mechanically superior to spinal instrumentation in the manner performed in this study. More than one point of fixation in each segment should be achieved to minimize the risk of rotational deformation.

Keywords

pelvis; sarcoma; iliosacral reconstruction; spinal instrumentation; oncology; mechanics

Corresponding Author: Craig R. Louer, MD. louerc@wudosis.wustl.edu.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

1. Introduction

The surgical treatment of primary pelvic malignancies located in the ilium continues to be a challenging problem in modern orthopedics. When appropriate, the oncologic surgeon may resect the tumor and associated pelvic structures while preserving the ipsilateral lower extremity[12]. Enneking et. al. classified resections of the innominate bone based on location, with Type-I resections involving the ilium proximal to the peri-acetabular region[8]. The modifier Type-IS has denoted inclusion of the sacral ala and the sacroiliac joint in the resection[12]. In properly selected children and adults, these procedures result in improved functional outcomes compared to traditional hemipelvectomy[13, 16].

Following resection of these lesions, reconstruction is often considered to restore pelvic ring continuity. Small defects between the anterior ilium and the remaining sacrum can generally be ignored or addressed with rudimentary fusion attempts where the gap is closed by hinging anteriorly from the pubic symphysis[12]. Larger defects often must be addressed with a form of interposition biologic graft stabilized with a form of fixation that allows for adequate stability until the graft can incorporate[12]. Failure to restore iliosacral stability may result in torsional and axial pelvic instability, limb shortening, and abnormal hip biomechanics, which has resulted in poor clinical outcome scores[16–18]. In children, this may also lead to secondary acetabular dysplasia.

Healing of interposition grafts is challenging due to the high mechanical forces in this anatomic area, the requirement for union at two separate sites, high incidence of wound complications such as infection or necrosis due to extensive dissection, and the common need for concomitant chemotherapy or radiation. While the type of interposition graft used has been a focus of a number of case series[2, 5, 14, 15, 18–20], the type of fixation used for this type of reconstruction is a vital consideration that has not been rigorously studied. The most common method of fixation in the literature is some form of plate and screw fixation[15, 19], though screws alone have been used in many cases[2, 3, 5]. Traditional plate and screw constructs often necessitate significant soft-tissue stripping and bony exposure to apply. Furthermore, screws have a limited array of positions and orientations available to properly fit through a plate, all of which may be unsuitable when working in a difficult anatomic region with bone quality that is often compromised by the disease process.

More recently, spinal instrumentation with polyaxial screws and connecting rods has been utilized to bridge this gap in a number of different configurations. While some constructs involve extensive dissection as high as the third lumbar spine pedicle[19], we have advocated for a minimal spinal instrumentation technique to minimize dissection and theoretically preserve more local blood supply. This technique was demonstrated in a prior case study with comparable clinical results to standard spinal fixation[14]. A successful reconstruction must satisfy two requirements: initial fixation must be rigid enough to reduce motion at the graft-pelvis interfaces to allow for bony union, and fixation must be strong enough to resist catastrophic failure in the time prior to graft healing where it is responsible for the majority of posterior pelvic stability.

The purpose of this study is to compare the time-zero mechanical properties of traditional plate-and-screw fixation to minimal spinal instrumentation in the setting of iliosacral reconstruction with interposition strut graft following Type-IS pelvic resection in a composite pelvis model. Specific outcome measures will include construct stiffness, load to failure, and method of failure. This data will provide surgeons with a quantitative assessment of common fixation methods for these reconstructions, as well as insight into possible improvements.

2. Methods

2.1 Preparation of the models

Sixteen third-generation composite bone pelvic models (Pacific Research Laboratories, Inc., Vashon Island, WA, USA) were obtained and prepared for testing. The models were obtained with a completely solid symphysis pubis of composite bone. We felt it important to have the possibility of some motion through the symphysis to best approximate native pelvis mechanics. After resection of the symphysis with a motorized burr, the symphysis was reconstructed with one transverse 4.5mm diameter cortical screw and a superior 6-hole 3.5mm plate with four 3.5mm screws into the pubic rami (Synthes, Inc., West Chester, PA, USA), then reinforced with polyurethane adhesive/sealant (3M 5200, 3M Inc., St. Paul, MN, USA; Figure 1A). A six-centimeter defect was created in the left hemipelvis using a band saw. The proximal cut was vertically directed through the sacral ala just lateral to the sacral foramina. The distal cut was made in a more oblique fashion just above the acetabulum on a line from the anterior inferior iliac spine directed posteriorly into the sciatic notch.

Eight pelvises were reconstructed with plate and screw constructs. A 9-hole 4.5mm reconstruction plate (Synthes, Inc.) was bent to span the defect, then fixed with two 4.5mm screws in the cut end of the sacrum with three screws into the posterior column (Figure 1B). Eight pelvises were reconstructed with spinal instrumentation. As previously described[14], a single 7.5mm diameter multiaxial pedicle screw (K2M Inc., Leesburg, VA, USA) was placed into the cut surface of the left sacral ala into the sacral body and another was placed into the cut surface of the ilium and passing through the posterior column of the acetabulum into the ischium. These were then connected with a 5.5mm titanium rod, which was bent and cut to fit the screw orientation and defect size (Figure 1C). Composite bone grafts were cut to length to span the defect and were wedged into the cut ends of the sacrum and ilium bones in each reconstructed model, similar to the clinical scenario. No screws were placed into the graft in either reconstruction method to replicate our surgical technique as closely as possible[14]. Given the lack of fixation as well as the necessary horizontal orientation of the grafts, the grafts are not thought to contribute to construct strength at time-zero, and all deforming forces are resisted solely by the implants. The plate and screw reconstructed pelvises used composite bone resembling the fibula, while the spinal instrumented pelvises used composite bone fashioned from the iliac crest for purposes of demonstrating the graft choice in our modified reconstruction [14].

2.2 Testing apparatus

Reconstructed pelvic models were placed onto a custom loading jig designed to simulate doubleleg stance (Figure 2A). Two bipolar hip hemi-arthroplasty prostheses, which articulated with the acetabula of the models, were firmly mounted on a fixed platform along with an anterior rod that braced the pubic symphysis and prevented rotation in the sagittal plane. An Instron 5866 materials testing system (Instron, Norwood, MA, USA) with a hemispherical attachment was used for application of load to the superior sacrum. Reflective tape markers were placed on the bony pelvis at consistent locations both anterior and posterior to the defect, and a Qualisys motion-capture system (Goteborg, Sweden) was used to track 3D marker positions (Figure 2B & C).

2.3 Testing protocol

Initial loading was applied from 0–25N for five cycles to allow for construct settling. A displacement-controlled load was then applied downward at 0.5mm/s. Displacement was applied until failure, noted mathematically by a sudden yield in the force-displacement curve, and practically by bone fracture, implant fracture, or screw pull-out[9]. High-resolution video of the testing event was recorded for later review and subjective analysis into failure mechanisms. One of the rod-reconstructed pelvises was excluded from analysis as the testing setup malfunctioned and compromised the model.

2.4 Power analysis

A sample-size analysis was performed prior to study initiation using baseline vertical-displacement stiffness data from a pilot study of eight models. To achieve a power of 0.8 at a 0.05 level of significance using the two-sided unpaired t-test, it was determined we would need 7 pelvic models per group. We obtained and tested an extra model for each group as a contingency.

2.5 Data analysis

Two relative marker displacements were determined: the vertical displacement representing how much motion occurred in the loading direction, and the absolute change in 3D distance between the two markers representing the relative motion across the defect (Figure 3). Force was recorded simultaneously through a force transducer built into the Instron 5866. A custom written MATLAB (MathWorks, Natick, MA, USA) script was used to synchronize the force and marker data to calculate maximum force as well as stiffness of the structure using vertical and 3D displacements of the reflective markers. We report the following outcomes: vertical stiffness, 3D gap stiffness, and maximum force (Figure 4). Maximum force represents total load-bearing capacity of the specimens before yielding.

2.6 Statistical Analysis

The distributions of the continuous variables were tested for normality using the Kolmogorov-Smirnov test. Load-to-failure, displacement (vertical), and displacement (3D) were normally distributed among all models and were compared between groups using the student's t-test with an $\alpha=0.05$. All statistical analyses were performed using SPSS 20, (IBM Corporation, Armonk, NY, USA).

3. Results

Quantitative outcomes are summarized in Table 1. The plate-fixation group had significantly higher stiffness in resisting vertical displacement compared to the rod-fixation group (102.9 vs. 66.8 N/mm; $p=0.010$). In contrast, the 3D stiffness did not differ between groups (968.3 vs. 893.4 N/mm; $p=0.844$). The plate-fixation group also tolerated significantly higher maximum forces than rod-fixation group (1416 vs. 1059 N; $p=0.015$).

Upon review of the video data, distinct differences were noted between the mechanics of the constructs when loaded (Figure 5). With plate fixation, as force was applied posteriorly in the pelvic ring over the sacrum, it caused posterior rotation of the entire pelvic ring in the sagittal plane around the fulcrum of the femoral heads. The plate in the iliosacral defect effectively linked the left hemi-pelvis to move as a unit with the rest of the pelvis until eventual failure. In the rod-reconstructed pelvis, posterior force over the sacrum resulted in a similar rotational moment of the right hemi-pelvis and sacrum—however the left hemipelvis motion was not sufficiently linked through the reconstruction site. Rotation and displacement instead occurred through the iliosacral defect and the left hemi-pelvis remained relatively fixed as the rest of the pelvis rotated. This resulted in increased compensatory torque through the pubic symphysis, which failed earlier in this group (Figure 5).

Inspection of the models demonstrated a similar final common pathway of failure. Either through peri-prosthetic fracture or from symphyseal diastasis, every pelvis failed, to some degree, at the pubic symphysis (Figure 6). There was not an appreciable difference in the method of anterior failure between fixation types: four in the rod group and five in the plate group had parasymphyseal fracture, while three constructs from each of the rod and plate groups had diastasis without fracture. In addition to anterior failure, two constructs in the plate group experienced partial implant pull-out of both sacral screws. None of the spinal instrumentation from the rod group had evidence of implant pull-out.

4. Discussion

In this study, we sought to compare the mechanical properties of traditional plate-and-screw fixation to minimal spinal instrumentation in the setting of iliosacral reconstruction with interposition graft following Type-IS pelvic resection. Our outcomes included construct stiffness in multiple dimensions, load to failure, and qualitative observation of loading response and mechanism of failure.

In this study, we found that both constructs had similar 3D stiffness, yet the rod-reconstructions demonstrated inferior stiffness in the loading (vertical) direction. 3D displacement represents the distance between the two reflective markers, and was observed to represent gapping or translation between ilium and sacral segments. However, if the segments move relative to each other, yet the distance between the markers remains unchanged (as in rotation), the 3D displacement measurement would not characterize this well. Isolating the vertical displacement vector enabled us to detect changes between the two markers' positions even if the distance between them did not change. Our results

demonstrating variable vertical stiffness in the context of relatively small amounts of 3D displacement (high stiffness) are consistent with our review of the video data that demonstrates increased relative rotation of the two segments within the rod group. The rod-reconstructed pelvises are thought to be more vulnerable to this type of displacement due to a single point of fixation in each segment.

We chose a double-leg stance model as our method of mechanical testing. Additionally, we used composite pelvic bone rather than cadaver pelvises for our reconstructions. While both have precedent as acceptable techniques in biomechanical studies[9, 6, 11, 7, 21], there are limitations whenever simplifying a complex biologic problem to an ex-vivo experiment. Composite models have been shown to have similar mechanical parameters to human bone, although their ability to mimic the behavior of the implant-bone interface is less established. Their use allows for consistency between each model tested, and unlike cadaver specimens that are often from donors of advanced age with osteoporosis, they may more accurately represent the younger patients with sarcoma who typically receive these reconstructions. One potential issue with composite pelvic models that we have anecdotally noted is the difficulty in replicating the biomechanics of fibrous articulations, such as that found in the native pubic symphysis. Composite pelvic models are available with either fused or incompetent pubic symphyses, both of which led to abnormal behavior in our pilot testing. For this reason, we settled on a modification of the symphysis involving taking down the entirely rigid articulation, and subsequently stabilizing the symphysis with a semi-rigid plate and screw construct as is often done in the trauma setting to address symphysis diastasis

Despite inherent limitations of an ex-vivo model, we believe that our experimental model is relevant to the clinical scenario, due to similar behavior observed during loading and eventual failure. In our clinical series, we observed chronic iliosacral instability resulting in non-unions at the implant-sacrum interface, and eventual failure of the pubic symphysis via instability, splaying or a torsional deformity[14]. We feel that our pelvis models with semi-rigid pubic symphyses behaved similarly to native symphyses on the basis that our models failed in a similar manner to our clinical observations and at comparable loads to other ex-vivo studies. Cadaver experiments on posterior pelvic ring fixation in the trauma setting demonstrated failure between 819 and 1066N[10], which is comparable to our mean load-to-failure of 1059N and 1416N for each group. Additionally, the 1183N calculated physiologic pelvic load of an average 70kg patient lies within this range[4, 7].

Plainly, an in-vivo study comparing these reconstruction methods in affected patients would avoid many of the shortcomings and compromises that are necessary when using mechanical models. However, clinical studies for this problem are difficult to perform in a standardized fashion due to the heterogeneous patient population and the relative infrequency of pelvic reconstructions following Type-I or Type-IS resections. Those that have been done are Level III evidence or worse, and the variation in treatment protocols and small sample-sizes make direct comparisons unreliable[2, 3, 5, 14, 15, 18, 19]. The high rates of wound complications, reoperation for disease recurrence, or functional deficits from adjacent nerve resection are all reflected in clinical scores and may obscure the assessment of the reconstruction. A direct comparison of mechanical strength, as conducted here, eliminates

these external variables and contributes valuable information on the best clinical practice in this scenario.

A rigorous mechanical study on the performance of iliosacral reconstructions is valuable because existing studies are sparse and of limited applicability. A prior study investigated the mechanical differences of five different constructs for iliosacral deficiency, including: 1) polyaxial screws with rods alone, 2) plus bone graft, 3) plus cement, 4) plus cement and bone graft, or 5) monoblock reconstruction [1]. The spinal fixation construct with bone graft and cement had the best performance with cyclic loading, although the clinical impact of their findings were limited by a model utilizing fixed high-molecular-weight polyethylene (HMWPE) blocks, instead of bone or composite, which neglects the impact of the bone-implant interface [1]. In addition, using a model with a fixed “ilium” and “sacrum” that eliminates any torsional forces effectively ignores a vital contributing force to construct failure that was observed in our experimental scenario utilizing a pelvic ring, as well as the clinical setting [14].

In the present study, the plate constructs performed better than the rod constructs in maximum load-to-failure testing. In the clinical scenario, this is akin to resistance to “catastrophic” failure of the construct: i.e. a patient who stumbles during their post-operative rehabilitation and places undue force on the construct. The difference found would appear to be clinically relevant as the average force tolerated by the rod constructs (1059N) was below the calculated pelvic force in a 70kg patient (1183N), while the plate constructs tolerated higher forces (1416N). The plate constructs also were superior in stiffness in the vertical direction, which would have implications for bony healing in the clinical scenario. The ideal stiffness for maximum bony healing depends on the bone being considered and its microenvironment, and is unknown for this specific anatomic location. However, inadequate stability is known to result in fibrous non-unions and sub-optimal clinical outcomes[9]. Although demonstrative that minimal gapping occurs in either construct, 3D displacement likely has minimal clinical relevance in this study, as it was not sensitive in detecting rotational displacement. In our clinical series of six patients, only one patient had bony fusion at the sacral interface with the graft[14]. In light of the analysis presented here, it seems the decreased vertical stiffness with the rod-reconstructed technique may contribute to the development of such fibrous non-unions.

Despite the superior mechanical performance of the plate construct, the minimal spinal instrumentation technique may have significant biological advantages in that it involves minimal bony stripping and soft-tissue dissection outside the area of oncologic resection, therefore theoretically improving perfusion at the necessary osteosynthesis sites as well as decreasing operative times[14]. Our observations were not consistent with inherent failure of the implant, but instead suggested rotational failure at the implant-bone interface. With the information available from our trials, we are unable to determine which of the two constructs’ inherent strength is superior. However, we ultimately conclude that choice of implant should be less motivated by inherent device strength, but rather by the construct’s ability to achieve optimal sacral fixation. Modifications such as increasing rod thickness, therefore, would be unlikely to change these results. However, spinal reconstruction constructs could be improved by adding more fixation points on either side of the defect

with an additional polyaxial screw to resist rotation. In our experience, obtaining implant purchase on the sacral side of the defect can be challenging and unreliable, whether using multi-axial pedicle screws or traditional 4.5mm cortical screws. These results have made it apparent that when two adequate points of fixation cannot be accomplished in the cut edge of the sacrum, it may be worthwhile to increase exposure to obtain another fixation point.

5. Conclusions

In summary, we performed a direct comparison between two common methods of posterior pelvic ring fixation following iliosacral tumor resections and demonstrated mechanical advantages to fixation with plate and screws over minimal spinal instrumentation. The spinal instrumentation construct, with a single fixation point in both the sacrum and posterior column, failed through a rotational mechanism resulting in decreased stiffness and load-to-failure. It is critical to consider this method of failure when reconstructing these defects, as the large mechanical forces in this area may lead to earlier construct failure. Future studies could investigate proposed changes in surgical technique, and our clinical practice has now evolved to consider these points when using the spinal instrumentation reconstruction technique.

Acknowledgements

We would like to thank Dr. Jacob Buchowski for his assistance in preparation of spinal testing constructs. Dr. Louer is aided by a grant from the Orthopaedic Research and Education Foundation (OREF), with funding provided by Exactech.

8. References:

1. Aach M , Gebert C , Ahrens H , Dieckmann R , Gosheger G , Hardes J , Wessling M . The primary stability of pelvic reconstruction after partial supraacetabular pelvic resection due to malignant tumours of the human pelvis: a biomechanical in vitro study. *Med. Eng. Phys* 2013;35:1731–1735. [PubMed: 23999384]
2. Akiyama T , Clark JCM , Miki Y , Choong PFM . The non-vascularised fibular graft: a simple and successful method of reconstruction of the pelvic ring after internal hemipelvectomy. *J. Bone Joint Surg. Br* 2010;92:999–1005. [PubMed: 20595122]
3. Beadel GP , McLaughlin CE , Aljassir F , Turcotte RE , Isler MH , Ferguson P , Griffin AM , Bell RS , Wunder JS . Iliosacral resection for primary bone tumors: is pelvic reconstruction necessary? *Clin. Orthop* 2005;438:22–29. [PubMed: 16131865]
4. Bergmann G , Deuretzbacher G , Heller M , Graichen F , Rohlmann A , Strauss J , Duda GN . Hip contact forces and gait patterns from routine activities. *J. Biomech* 2001;34:859–871. [PubMed: 11410170]
5. Chang DW , Fortin AJ , Oates SD , Lewis VO . Reconstruction of the pelvic ring with vascularized double-strut fibular flap following internal hemipelvectomy. *Plast. Reconstr. Surg* 2008;121:1993–2000. [PubMed: 18520887]
6. Cristofolini L , Viceconti M , Cappello A , Toni A . Mechanical validation of whole bone composite femur models. *J. Biomech* 1996;29:525–535. [PubMed: 8964782]
7. Dawei T , Na L , Jun L , Wei J , Lin C . A novel fixation system for sacroiliac dislocation fracture: internal fixation system design and biomechanics analysis. *Clin. Biomech* 2013;28:129–33.
8. Enneking WF , Dunham WK . Resection and reconstruction for primary neoplasms involving the innominate bone. *J. Bone Joint Surg. Am* 1978;60:731–746. [PubMed: 701308]
9. Gardner MJ , Silva MJ , Krieg JC . Biomechanical testing of fracture fixation constructs: variability, validity, and clinical applicability. *J. Am. Acad. Orthop. Surg* 2012;20:86–93. [PubMed: 22302446]

10. Gorczyca JT , Varga E , Woodside T , Hearn T , Powell J , Tile M . The strength of iliosacral lag screws and transiliac bars in the fixation of vertically unstable pelvic injuries with sacral fractures. *Injury* 1996;27:561–564. [PubMed: 8994561]
11. Heiner AD , Brown TD . Structural properties of a new design of composite replicate femurs and tibias. *J. Biomech* 2001;34:773–781. [PubMed: 11470115]
12. Hugate R , Sim FH . Pelvic reconstruction techniques. *Orthop. Clin. North Am* 2006;37:85–97. [PubMed: 16311114]
13. Kollender Y , Shabat S , Bickels J , Flusser G , Isakov J , Neuman Y , Cohen I , Weyl-Ben-Arush M , Ramo N , Meller I . Internal hemipelvectomy for bone sarcomas in children and young adults: *surgical considerations*. *Eur. J. Surg. Oncol. J. Eur. Soc. Surg. Oncol. Br. Assoc. Surg. Oncol* 2000;26:398–404.
14. Nassif NA , Buchowski JM , Osterman K , McDonald DJ . Surgical technique: Iliosacral reconstruction with minimal spinal instrumentation. *Clin. Orthop* 2013;471:947–955. [PubMed: 23065355]
15. Nishida J , Shiraishi H , Okada K , Ehara S , Shimamura T . Vascularized iliac bone graft for iliosacral bone defect after tumor excision. *Clin. Orthop* 2006;447:145–151. [PubMed: 16505711]
16. O'Connor MI , Sim FH . Salvage of the limb in the treatment of malignant pelvic tumors. *J. Bone Joint Surg. Am* 1989;71:481–494. [PubMed: 2703507]
17. Pring ME , Weber KL , Unni KK , Sim FH . Chondrosarcoma of the pelvis. A review of sixty-four cases. *J. Bone Joint Surg. Am* 2001;83-A: 1630–1642. [PubMed: 11701784]
18. Sabourin M , Biau D , Babinet A , Dumaine V , Tomeno B , Anract P . Surgical management of pelvic primary bone tumors involving the sacroiliac joint. *Orthop. Traumatol. Surg. Res. OTSR* 2009;95:284–292. [PubMed: 19482533]
19. Sakuraba M , Kimata Y , Iida H , Beppu Y , Chuman H , Kawai A . Pelvic ring reconstruction with the double-barreled vascularized fibular free flap. *Plast. Reconstr. Surg* 2005; 116:1340–1345. [PubMed: 16217477]
20. Wang J , Tang Q , Xie X , Yin J , Zhao Z , Li Z , Zou C , Huang G , Shen J . Iliosacral resections of pelvic malignant tumors and reconstruction with nonvascular bilateral fibular autografts. *Ann Surg Oncol* 2012;19:4043–51. [PubMed: 22948770]
21. Yinger K , Scalise J , Olson SA , Bay BK , Finkemeier CG . Biomechanical comparison of posterior pelvic ring fixation. *J Orthop Trauma* 2003;17:481–7. [PubMed: 12902785]

Highlights:

- Plate-and-screw constructs performed better than spinal instrumentation constructs.
- A single point-of-fixation in each segment predisposes to rotational displacement.
- Increased motion through the defect resulted in failure at the pubic symphysis.
- Implant-bone interface, not implant strength, chiefly defines construct stability.
- Reconstructive techniques should prioritize quality sacral and iliac fixation.

Figure 1:

Photos of the composite pelvic models demonstrating A) pubic symphysis reconstruction technique used in all models, as well as the two different iliosacral reconstruction methods tested: B) allograft with plate, and C) allograft with polyaxial screws and rod. Of note: black spray-paint was used to reduce interference of the metal implants with the reflective sensors for the motion tracking system.

Figure 2:
 Photos of the experimental setup demonstrating the A) custom jig for double-leg stance, B) jig with a pelvis model loaded, and C) motion-capture camera setup. White arrows in frame B demonstrate location of reflective markers for motion-analysis.

Figure 3:

Photo of rod-reconstructed pelvis demonstrating the distances measured and used in statistical analysis. 3D displacement was thought to be sensitive to “gapping” of the defect, while poor at detecting rotation. Vertical displacement was sensitive in detecting rotation of the ilium relative to the sacrum.

Figure 4:
Representative force versus displacement graphs for both plate and rod constructs. Stiffness was calculated in the initial linear portion of the graph before any yielding occurred. Maximum force was the highest force the specimen achieved before final failure.

Figure 5:

Selected video frames demonstrating the behavior of reconstructed pelvises during axial loading. The plate construct (left frames) is shown with a black line parallel to the cut ilium surface. As load is applied, the entire pelvis rotates as a unit clockwise around the femoral heads such that the cut ilium surface now has increased posterior slope (white line) compared to its starting position.

When load is applied to the rod construct (right frames), the sacrum and right hemipelvis rotate posteriorly, like in the plated constructs. However, the left hemipelvis does not tilt in concert with the rest of the pelvis, due to decreased rigidity through the rod construct. Thus, the left hemipelvis is unlinked to the rest of the pelvis and there is no increase in slope of the cut ilium surface relative to its starting position.

Figure 6:

Selected photos of failed pelvic models demonstrating methods of failure. A & B: White arrows demonstrate fractures through the pubic rami. C: Symphysis distraction resulting in anterior failure. D: Sacral screw pullout in a plate-reconstructed model.

Table 1:

Results of mechanical testing of reconstructed pelves

	Plate	Rod	P-value*
Stiffness (Vertical) (N/mm)	102.9 (28.0)	66.8(17.1)	0.010
Stiffness (3D) (N/mm)	968.3 (848.0)	893.4(312.3)	0.844
Maximum Force (N)	1416(239)	1059 (243)	0.015

Results presented as mean (SD).

* Student's t-test used for statistical comparisons.

Bold results considered significant.