Propensity for Hip Dislocation in Normal Gait Loading Versus Sit-to-Stand Maneuvers in Posterior Wall Acetabular Fractures

Meir Marmor, MD, Erik McDonald, BS, Jenni M. Buckley, PhD, and Amir Matityahu, MD

Abstract

Treatment of posterior wall (PW) fractures of the acetabulum is guided by the size of the broken wall fragment and by hip instability. Biomechanical testing of hip instability typically is done by simulating the single-leg-stance (SLS) phase of gait, but this does not represent daily activities, such as sit-to-stand (STS) motion.

We conducted a study to examine and compare hip instability after PW fractures in SLS and STS loading. We hypothesized that wall fragment size and distance from the dome (DFD) of the acetabulum to the simulated fracture would correlate with hip instability and, in the presence of a PW fracture, the hip would be more unstable during STS loading than during SLS loading. Incremental PW osteotomies were made in 6 cadaveric acetabula. After each osteotomy, a 1200-N load was applied to the acetabulum to simulate SLS and STS loading until dislocation occurred.

All hip joints in the cadaveric models were more unstable in STS loading than in SLS loading. PW fragments at time of dislocation were larger ($P<.001$) in SLS loading (85% ± 13%; range, 81%-100%) than in STS loading (40% ± 7%; range, 33%-52%). Mean (SD) DFD at time of dislocation was 15.0 (3.5) mm (range, 14.4-19.6 mm) in STS loading and 5.3 (4.3) mm (range, 0.1-10.0 mm) in SLS loading ($P<.04$). There was more hip instability in STS loading than in SLS loading. In STS loading, hips dislocated with a PW fracture size of 33% or more and a DFD of 20 mm or less.

A displaced posterior wall (PW) acetabular fracture is a common entity that can have a relatively poor outcome.[1-6] Treatment is generally guided by the size of the broken wall fragment and by hip instability.[5,7,8] Criteria based on computed tomography (CT) have been suggested for predicting hip instability after PW fractures.[7,9-11] However, clinical studies evaluating patients under anesthesia demonstrated that CT-predicted stable hips may be clinically unstable and CT-predicted unstable hips may be clinically stable.[5,7-9] History of hip dislocation is also a poor predictor of hip instability.[7] Roof arc angle measured on radiographs and subchondral arc measured on CT represent the distance from the fracture line to the acetabular dome.[11] Both indexes correlated with hip stability after acetabular fractures, excepting PW fracture, for which wall fragment size was the recommended index for determining hip instability.[11]

Almost all previous biomechanical tests of acetabular fractures have been performed by simulating the single-leg-stance (SLS; maximal load) position of normal gait. However, this position may not represent significant loads that occur during activities of daily living. A report by the National Center for Health Statistics revealed that in 2005, 39.9% of adults spent most of their daily activity sitting.[12] During STS motions, the hip joint undergoes loading that is significantly different from the loading that occurs during the SLS phase of the normal gait cycle.[13,14] The joint contact force during STS motion (eg, when rising from a chair) loads the acetabulum posteriorly relative to normal gait with roughly 3 times the peak pressure on nearly a quarter of the contact surface.[15] At 40% of the STS cycle, a maximum hip flexion angle of 98.9° is seen (mean, 95°) with forces directed at the posterior aspect of the acetabulum that reach 190% of body weight.[16] Mean peak pressures on the acetabulum are 9 MPa (STS cycle) and 3.3 MPa (brisk walking).[15]

We conducted a study to examine and compare hip instability in SLS and STS loading after PW fractures. We hypothesized that wall fragment size and distance from the dome (DFD) of the acetabulum to the simulated fracture would correlate with hip instability and that in the presence of a PW fracture, the hip would be more unstable during STS loading than during SLS loading.

Materials and Methods

Seven intact fresh-frozen cadaveric pelvic girdles with attached femurs were obtained from donors with no history of hip

Authors' Disclosure Statement: Funding for this study was provided through an educational grant from Stryker Trauma.

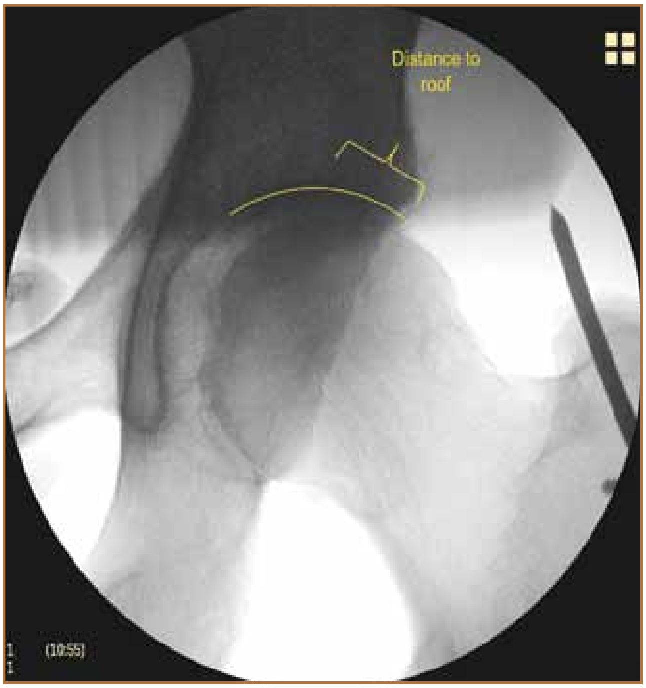

Figure 1. Method for measuring distance from roof to fracture line on plain radiograph.

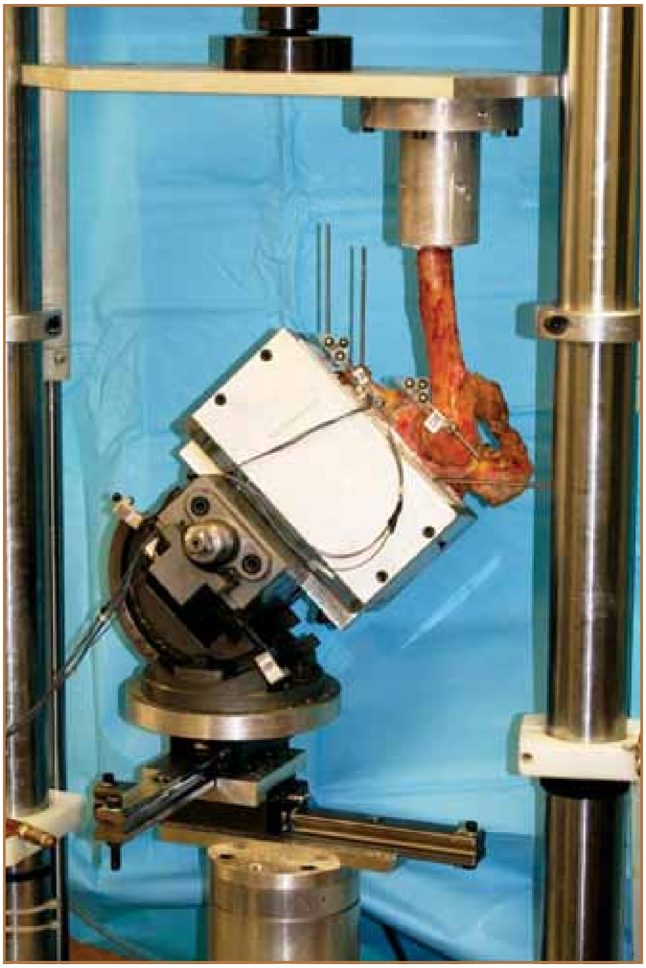

Figure 2. Testing apparatus in sit-to-stand position.

arthritis or other pathology. Mean (SD) age at time of death was 58 (12) years. Total hip dual-energy x-ray absorptiometry (DXA) scans were performed, and specimens with T-scores of less than -3.5 were excluded as being severely osteoporotic. Mean DXA scan T-score was -1.5. The soft-tissues were dissected from the pelvic girdle, with care taken not to damage the articular surface or labrum. The pelves were then disarticulated from the sacrum, and the pubic symphysis was divided. The dissection allowed for full visualization of the right and left innominate bones. A Kirschner wire was then placed from the anterior superior iliac spine to the posterior superior iliac spine to allow for correct orientation of the pelvis after it was potted. The ilium was then potted in a custom container using a 2-part epoxy (Smooth-Cast 300; Smooth-On Inc, Easton, Pennsylvania). Specimens were potted with the pubic symphysis parallel to one side of the container while leaving the acetabulum exposed and accessible for fracture generation. The shaft of the femur was potted to a depth of at least 75 mm with 2-part epoxy. For each anatomical donor, one randomly chosen side (right or left) was assigned to receive a PW acetabular fracture in this study.

A fellowship-trained orthopedic trauma surgeon osteotomized the PW with a surgical reciprocating saw (System 6; Stryker Orthopaedics, Mahwah, New Jersey) in 5-mm increments to replicate a PW acetabular fracture. The articular surface was reduced until the specimens displayed instability in the STS and SLS orientations. The shortest distance from the cotyloid fossa to the fracture line was measured on the specimen to assess the remaining PW/PW fragment size, and the DFD to the superior portion of the osteotomy was measured on radiograph (**Figure 1**).

Hip stability was assessed by placing each specimen in a servohydraulic testing machine (MTS Model 858 Mini-Bionix; MTS Systems Corp, Eden Prairie, Minnesota) in the SLS and STS orientations. The femur was mounted to the actuator head of the testing machine while the pelvis was fixed to a frictionless X-Y table atop a load cell (MC5-6-500; Advanced Mechanical Technology Inc, Watertown, Massachusetts) rigidly attached to the hydraulic test frame. The X-Y table allowed for hip dislocation with medial–lateral and anterior–posterior motion relative to the hip joint. The hip was placed in 15° of abduction and 0° of flexion for the SLS orientation. For the STS orientation, the hip was placed in 15° of abduction and 95° of flexion (**Figure 2**). These positions were chosen because they represent the direction of the maximum load during the SLS portion of the gait cycle or during transition from sitting to standing.[13,17] Specimens were loaded up to a maximum force of 1200 N, representing 190% of average body weight. If the hips did not dislocate at this force level, they were determined to be stable. If a hip dislocated before 1200 N, it was deemed unstable

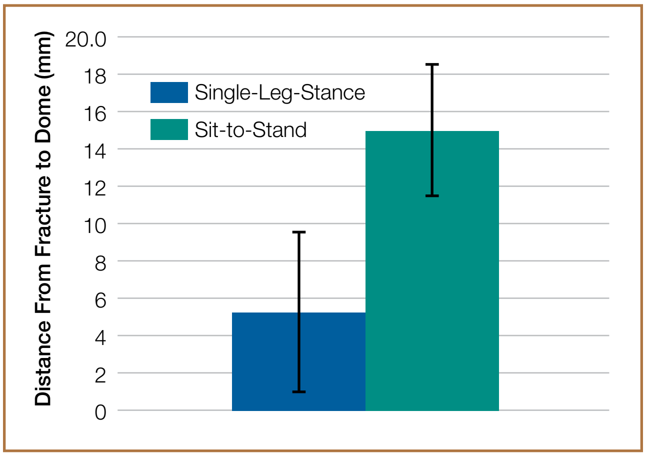

Figure 3. Distance from proximal extension of posterior wall fracture line to dome of acetabulum as measured on plain radiographs. Mean distance at time of dislocation is shown for sit-to-stand and single-leg-stance loading cycles.

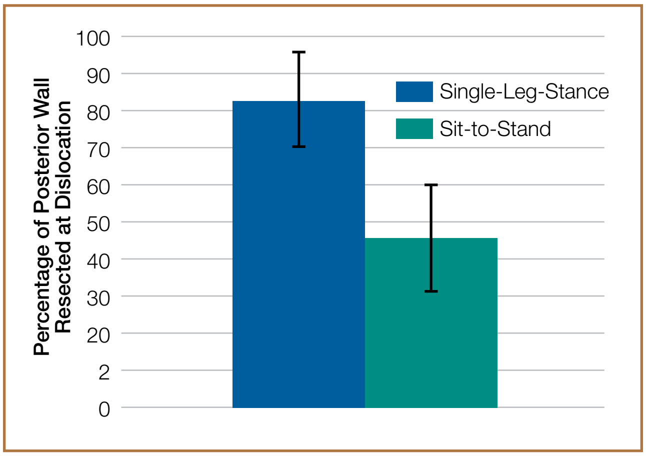

Figure 4. Percentage of posterior wall resected measured on specimens using shortest distance from cotyloid fossa to fracture line after posterior wall osteotomy relative to distance in intact specimen. Mean percentage at time of dislocation is shown for sit-to-stand and single-leg-stance loading cycles.

and was no longer tested in that orientation and fracture size. Specimens were kept hydrated with a saline solution during testing and fracture generation.

The parameters measured on the acetabulum at the point of instability were DFD of the acetabulum to the osteotomy (measured on radiograph) and the remaining longest distance on the articular surface from the cotyloid fossa to the osteotomy (corresponds to the size of the intact PW). The stability of the hip joint and the reduction in the articular surface in the STS position relative to the SLS position were evaluated with paired t-tests. Commercial statistics software (JMP version 5.0; SAS Institute Inc, Chicago, Illinois) was used for all analyses. The significance level was set at $P<.05$.

Results

One of the 7 specimens fractured during testing and was excluded from the final results. Mean (SD) diameter of the femoral head was 50.4 (3.6) mm. Mean (SD) size of the articular surface of the PW from the cotyloid fossa to the labrum was 27.7 (2.5) mm.

Simulated PW fractures rendered the hip joint significantly more unstable in STS loading than in SLS loading. All hip joints eventually dislocated posteriorly through the area of the osteotomy site. None of the specimens dislocated after the first osteotomy. Mean (SD) maximum load during the nonfractured position and before dislocation was 1211.1 (3) N for the SLS position and 1210 (2) N for the STS position. Hip dislocation occurred with much less resection of the PW in STS loading than in SLS loading (**Figures 3, 4**). There was a significant ($P<.001$) difference in mean distance from the cotyloid fossa to the remaining osteotomized articular surface before the hip joint dislocated in the SLS position (4.2 mm; SD, 3.7 mm) compared with the STS position (16.3 mm; SD, 2.1 mm). There was also a significant ($P<.001$) difference in the percentage of PW resected at time of hip joint dislocation in the SLS position (85%; SD, 13%; range, 81%-100%) compared with the STS position (40%; SD, 7%; range, 33%-52%). In addition, mean DFD to fracture line was larger ($P = .04$) at time of dislocation for the STS position (15.0 mm; SD, 3.5 mm) compared with the SLS position (5.3 mm; SD, 4.3 mm).

Discussion

Our study results demonstrated that hip instability after fracture of the PW of the acetabulum is more likely to occur during STS than SLS activities. Furthermore, propensity for dislocation was related both to DFD of the acetabulum to the superior aspect of the fracture line on radiograph and to size of the fractured fragment.

These findings agree with those of other studies focused on predicting hip instability from CT measurements of the PW fragment.[7] One CT cadaveric study assessed PW stability and found that all hips with an osteotomized fragment larger than 40% were unstable, and all hips with a fragment of 20% or smaller were stable.[10] A clinically based CT study of 26 patients with PW acetabular fracture-dislocations suggested there was instability when the PW fragment was larger than 66%, and stability when the fragment was smaller than 45%.[9] In concert with these studies, our investigation found that instability occurred when mean fragment size was 42% (SD, 6%; range, 33%-72%). These results are similar to those from another biomechanical study, which found instability in all specimens with fragments larger than 50% and in none of the specimens with fragments smaller than 25%.[8] The difference in fragment size percentages between the different studies can be attributed to differences in hip diameter, loading parameters, and number of subjects tested.

Other studies have found that CT-based predictions of hip instability can be unreliable. For example, in some cases where CT predicted stable hips, there were clinically unstable hips, and in other cases the converse was true.[5,7-9] This led some authors to recommend routine evaluation of hip stability under anesthesia—stressing the hip in the posterior lateral direction to mimic the forces created during STS motion.[5,7] Our results support this practice by demonstrating the significantly increased instability created when the hip is loaded by an STS force vector compared with an SLS vector.

A new, unique finding of this study is that the DFD to the fracture line on a radiograph is an important parameter that may predict hip instability in the setting of acetabular PW fractures. The subchondral arc, measured on CT as the DFD of the acetabulum to the fracture line crossing the articular surface, has been suggested as an instability index equivalent to the roof arc angle measured on radiograph.[11] The recommended DFD to the fracture line as a cutoff for a stable hip and nonoperative treatment was 10 mm or less when applied to a columnar acetabular fracture.[11] Our study results showed that with isolated PW fractures, mean DFD to the fracture line at time of dislocation was 15 mm (range, 9-20 mm). These results imply that, in the setting of acetabular PW fractures, maintenance of hip stability may necessitate 20 mm of DFD to where the fracture superiorly enters the joint.

Our study did have some limitations. One limitation was that absolute values of articular surface size and percentage of remaining acetabular PW can only grossly be interpreted as accurate for the clinical situation. Moreover, even though we tried to mimic the PW fracture pattern in accord with our experience, clinical fracture patterns may differ from the simulated PW osteotomies. Specifically, PW fractures can have several described patterns—with or without marginal articular surface impaction.[18,19] Another limitation of this study was loading the acetabulum in a static rather than a dynamic manner. Although other studies have used the same static loading parameters, ours would have been more clinically accurate using a dynamic loading pattern that mimics actual movement patterns. Lastly, resection of the hip capsule before loading rendered the hips more unstable than they would be in a clinical situation[8]; however, it is difficult to clinically determine the integrity of a hip capsule before surgery. Thus, the parameters suggested in this study for hip instability represent a worst-case scenario in which the hip capsule is torn. To prove otherwise would require a clinical evaluation under anesthesia.

Our study has 2 clinical implications. First, it supports the clinical method of examining hip stability under anesthesia in the presence of PW fractures. Specifically, an evaluation should include flexing and adducting the hip to simulate STS loading. Second, this study expands the indications for evaluating PW fractures under anesthesia. In addition to arriving at the common indication of having a PW fragment size of 20% to 40%, this investigation suggests that a DFD to the fracture line of less than 20 mm on radiograph may predict instability and therefore warrants further evaluation.

Dr. Marmor is Orthopaedic Trauma Attending Surgeon, and Mr. McDonald is Mechanical Engineer, Biomechanical Testing Facility, Orthopaedic Trauma Institute, University of California San Francisco and San Francisco General Hospital, California. Dr. Buckley is Director of Taylor Collaboration and Research Director of San Francisco Orthopaedic Residency Program, St. Mary's Hospital, San Francisco, California; and Founder and Co-Director of Perry Initiative. Dr. Matityahu is Director, Pelvis and Acetabular Trauma, Orthopaedic Trauma Institute, University of California San Francisco and San Francisco General Hospital, California.

Acknowledgment: The authors thank Virginia Klausmaier, MS, for her logistical assistance on this project.

Address correspondence to: Meir Marmor, MD, Orthopaedic Trauma Institute, University of California San Francisco and San Francisco General Hospital, 2550 23rd St, Building 9, Floor 2, San Francisco, CA 94110 (tel, 415-206-8812; fax, 415-206-8244; e-mail, marmorm@orthosurg.ucsf.edu).

Am J Orthop. 2013;42(9):412-415.

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