Introduction
Periacetabular osteotomies are performed for improvement of femoral head coverage in a variety of clinical scenarios. A number of osteotomies are in clinical use today, and they differ in surgical technique, amount of coverage attainable, and biomechanical strength. The use of the triple innominate osteotomy in North America was popularized by Steel. In Tonnis’ modification of the osteotomy, the level of the ischial cut is above the level of the sacropinous attachment to the ischium. Tonnis believes that freeing the acetabular fragment from its attachments to the pelvic floor ligaments allows increased mobility of the osteotomized fragment. The Bernese periacetabular osteotomy has also been well described in the literature and enjoys widespread clinical use. This procedure, first described by Ganz, allows rotation of the acetabular fragment free from its attachment to the pelvic floor ligaments and preserves a portion of the posterior column. It is theorized that this allows minimal intraoperative fixation and early postoperative weightbearing. This osteotomy violates the triradiate cartilage, however, and cannot be performed in skeletally immature individuals, making the triple innominate osteotomy a necessary surgical alternative. We believe that there is little difference in the biomechanical stability between these two osteotomies.

Materials and Methods
Eight fresh-frozen male cadavers (mean age 39 years ± 4.3 years) were dissected to expose the regions from L1 to the mid-shaft of each femur. All muscle tissue was removed while maintaining an intact hip joint capsule and both sacropinous and sacroteruterous ligaments.

Performance of osteotomy: Each specimen underwent both the Bernese and Tonnis’ modification of triple osteotomy, with random assignment to either the right or left side. Typical surgical osteotomies were used to perform each surgical procedure. The Bernese periacetabular osteotomy was performed as described in Ganz’ original publication. The triple osteotomy was performed as described in Tonnis’ original publication. The acetabular fragments were fixed with AO 4.5 mm cortical screws. Each osteotomy was fixed with three different screw constructs (figure 1). In addition, the Tonnis osteotomies were fixed with wire across the pubic osteotomy.

Development of coordinate system: Anatomical landmarks were chosen on the pelvis and areas of acetabular osteotomy to establish local coordinate systems. A triad of 4 mm retro-reflective markers were placed on each sacrum at the center sacral line to establish a pelvic coordinate system. Additional marker triads were placed on each acetabular osteotomy fragment and femur. The x, y, and z axes correspond to the anterior-posterior, medial-lateral, and superior-inferior directions, respectively. The local coordinate system for each fragment was matched to the pelvic coordinate system, establishing a baseline orientation for each fragment relative to the pelvic coordinate system.

Biomechanical testing: Each specimen was placed into the testing rig, which was coupled to a MTS 858 Mini-Bionix servohydraulic bi-axial testing machine. The specimens were mounted into the apparatus with femurs pointing cephalad and iliac wings pointing caudal. The rig base held each specimen in 8 degrees of anterior pelvic tilt. Loads were applied directly to the superior iliac wings. Each specimen was cyclically loaded in axial compression from 0 to 450 Newtons for 10 cycles for each screw construct. The loading profile was that of full weight bearing for a 50kg 12 year old boy, approximating partial weight bearing in an adult. Each specimen underwent loading with the 2, 2W, 3, 3A, 3AW, 3B, and 3BW screw constructs. The order of trials was randomized to prevent bias from increased osteotomy fragment motion in the later trials. This system is capable of detecting >0.1 mm of displacement and >0.5 mm of angular motion between fragments. The data was transferred into a 3 dimensional imaging program (Bodybuilder 3.0, Oxford Metrics, UK), which allowed calculation of fragment displacement and angular rotation. 10 trials were collected for each screw construct for each cadaver. The maximum and minimum displacements and angular rotations were collected from the 6th through 9th loading cycles and then averaged. Four 2 (Ganz vs. Tonnis) X 6 (2, 2W, 3, 3A, 3AW, 3B, 3BW) ANOVA’s using SPSS statistical analysis software were performed to compare mean displacements and angular rotations among osteotomy type and screw constructs. Post hoc analyses included one independent samples t-test to examine a trend within a particular screw construct and one ANOVA to examine a trend across screw constructs within the Tonnis osteotomy. The Bonferroni corrected significance level was set at p = 0.008.

Results
No statistically significant difference in displacement could be found between the Ganz and Tonnis osteotomies (p = 0.37). Very little displacement was encountered during loading for all screw constructs, with a range of 0.6 to 1.3 mm on average. Post hoc analysis of the 2W trial (2 screws in Ganz osteotomy vs. 2 screws in Tonnis with pubic wire) using independent samples t-test approaches statistical significance, with the Tonnis osteotomy showing less displacement in this construct (p = 0.05). For 3 screw constructs, the addition of a pubic wire makes the displacement very similar for both osteotomies.

Angular motion about the x-axis (flexion/extension) was quite small (range: 3.16-4.09 degrees). No statistically significant difference in flexion/extension could be found between the Ganz and Tonnis osteotomies (p = 0.98). A trend towards increasing stability about the x axis was noted for the Tonnis osteotomies, but post hoc analysis of screw constructs within the Tonnis osteotomies only revealed that this was not statistically significant (p = 0.65). Motion about the Y axis (abduction/adduction) was also noted to be small (range: 1.33-2.56 degrees). The effect of the wire on increasing stability for the Tonnis osteotomies was clearly noted. No statistically significant difference was encountered between the two osteotomies (p = 0.19). Rotation about the Z axis (internal/external rotation) was similar to x-axis motion. Once again, no statistically different difference was encountered (p = 0.32). The influence of the pubic wire on Tonnis osteotomy stability was best seen in motion about this axis.

Discussion
Overall, very small amounts of displacement and angular rotation were noted when comparing the two osteotomies across fixation methods. The Tonnis osteotomy appears to benefit when a pubic wire is used, and its displacement vector actually decreases below that of the Ganz osteotomy when moving from the 2 screw to 3 screw constructs.

In summary, the two osteotomies performed quite similarly, especially in the 3 screw constructs. Use of a pubic wire or some other type of pubic fixation in the Tonnis (and possibly all triple innominate osteotomies) is essential to give them fixation strength parallelizing that of the Ganz osteotomy with a three screw construct. The question of how much displacement and angulation of osteotomy fragment is permissible to obviate post-operative immobilization remains unanswered.

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