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SYMPOSIUM: FEMOROACETABULAR IMPINGEMENT: CURRENT STATUS OF DIAGNOSIS AND TREATMENT

Does Trochanteric Step Osteotomy Provide Greater Stability Than Classic Slide Osteotomy?

A Preliminary Study

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Abstract The use of a trochanteric slide osteotomy needs a partial weightbearing period to allow safe healing of the osteotomy. We compared the initial rigidity of fixation of the trochanteric slide osteotomy with that of a newly developed technique, the trochanteric step osteotomy. The slide and step osteotomies were tested on six bilateral pairs of cadaveric femora with cyclic shear load of constant amplitude for 100 cycles in both a superior direction to represent standing and 60° of hip flexion to represent a squat stance. Translational and rotational migration and cyclic amplitude were measured with an optoelectronic camera system. During superior loading, translational migration of the slide osteotomy was greater than for the step osteotomy (slide median, 1.7 mm; step median, 0.3 mm), but rotational migration was not (slide median, 1.9°; step median, 0.2°). Translational amplitude was greater for the slide osteotomy in the superior direction (median slide, 0.3 mm; median step, 0.16 mm), but not in rotational amplitude. Similar trends in migration and amplitude were observed for the squat loading configuration. The data suggest the trochanteric step osteotomy is a more stable construct than the commonly performed slide osteotomy.

Introduction

The lateral approach with the classic trochanteric osteotomy was first described by Leopold Ollier nearly 130 years ago [22]. At that time, the approach was mainly used for joint excisions and hip arthrodesis. Charnley [4] first introduced the trochanteric osteotomy for use in primary hip arthroplasty to allow better exposure. Several studies [6, 10, 19, 29] have demonstrated the incidence of trochanteric nonunion after osteotomy can be reduced by performing a trochanteric slide osteotomy instead of the classic osteotomy. Mercati et al. [19] first published the trochanteric slide osteotomy, which preserved the continuity between the greater trochanter and the muscular attachments of the vastus lateralis and hip abductor muscles, thereby providing a compressive force across the osteotomy interface to stabilize the osteotomized fragment [19, 25]. In a mathematical study, Plausinis et al. [25]

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reported the compressive force from the intact glutei and vastus lateralis bridge, together with the frictional force at the osteotomy interface, could fully counteract the shear force, which would otherwise lead to superior migration of the osteotomized fragment. In the treatment of femoroacetabular impingement, the technique of surgical hip dislocation through a trochanteric slide osteotomy is still our preferred approach [8]. Besides this indication, the use of a trochanteric osteotomy for THA is recommended to restore normal anatomy of the hip in conditions such as severe protrusio acetabuli, bony or fibrous ankylosis, congenital dysplasia, and complex revisions [30, 31]. Hamblin [12] estimated 10% to 20% of all THAs require a trochanteric osteotomy to restore normal joint anatomy.

There are two main disadvantages of the trochanteric slide osteotomy. First, a period of reduced weightbearing must follow the surgical fixation and we presume this would result in muscular atrophy. Bizzini et al. [3] reported in a case series of five professional ice hockey players treated for femoroacetabular impingement the preoperative trunk and hip strength was restored after a mean of 7.8 months (range, 5.5–12 months).

The second disadvantage is the risk of trochanteric nonunion. The nonunion rate in the treatment of femoroacetabular impingement through a surgical hip dislocation is between 0% and 2.7% [2, 8, 20]. In addition, Peters et al. [24] reported incomplete union of the greater trochanter in 26% after treatment of femoroacetabular impingement. In all these studies, a period of 6 to 8 weeks of partial weightbearing was allowed. The reported rate in the literature for nonunion of the greater trochanter in THA has ranged from 1% to 38% [1, 5, 11, 13–15, 21, 27, 28, 30, 32].

Despite the extended recovery period and associated muscular atrophy, we consider the trochanteric osteotomy the best option for surgical dislocation of the femoral head when treating femoroacetabular impingement, hip resurfacing, or THA [8]. Currently, we most commonly use a slide osteotomy (Fig. 1A–B). Due to the straight cut of the slide osteotomy, failure has occurred at the osteotomy interface in some cases (~ 2%), especially if load bearing was resumed too soon postoperatively because the cortical screws alone could not support the shear forces at the osteotomy interface [8]. Such instability at the osteotomy site has resulted in proximal and anterior migration of the greater trochanter [7, 9, 10, 16, 18, 29].

We recently proposed a step osteotomy to enhance stability since the step cut creates direct bony abutment that would counteract the shear forces along the osteotomy interface [17]. We therefore asked whether a step cut would reduce the risk of superior translational migration of the greater trochanteric fragment under superior loading compared to the slide osteotomy. We further examined translational and rotational migration and cyclic displacement under superior and squat loading configurations.

Materials and Methods

We acquired six bilateral pairs of previously frozen cadaveric femora from five Caucasian males aged 47 to 69 years (mean, 62.2 years) and one Caucasian female (aged 87 years), none of whom had been taking medication known to affect bone quality. Ethical approval was obtained from our Institutional Review Board before performing the study. Before surgery, bone mineral content was measured for all femora using dual-energy xray absorptiometry (DXA) (QDR 4500 scanner; Hologic Inc, Bedford, MA).

The slide and step osteotomies were performed on each bilateral pair of femora (slide osteotomy performed on three left and three right arbitrarily chosen femora). A priori, a power analysis was conducted to estimate the

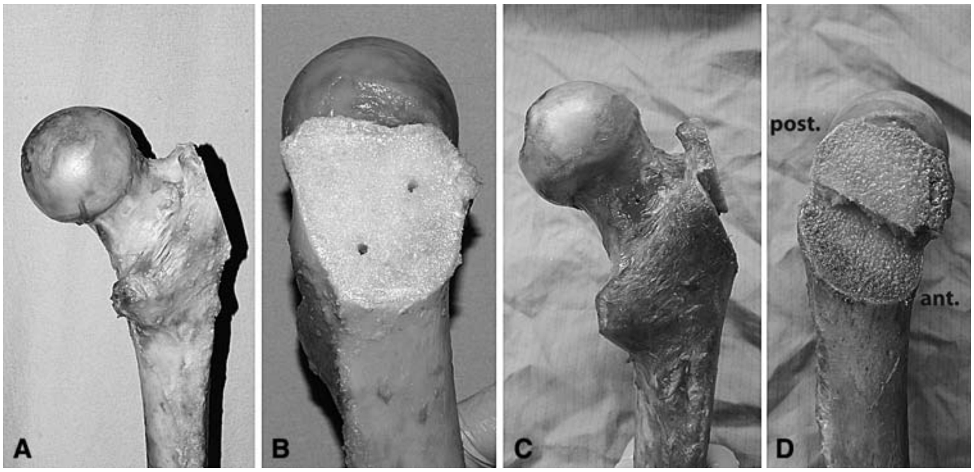

Fig. 1A–D Photographs of the posterior aspect of two right femurs with trochanteric osteotomies show (**A**) a side view of the slide osteotomy, (**B**) a view of the slide osteotomy interface, (**C**) a side view of the step osteotomy, and (**D**) a view of the step osteotomy interface.

number of specimens needed. In this analysis, we assumed a 1.5-mm difference in the translation migration under superior loading would be a clinically important difference. This would represent a 50% improvement in fixation over the levels we measured in a previous study [26]. We estimated standard deviation of the data to also be 1.5 mm, again based on previous data [26]. Assuming Type 1 and 2 errors to be 10% and 30%, respectively, a sample size of six specimens per group would be needed. We adopted somewhat larger error values than would normally be standard since this was an initial study with a limited budget for specimens. As a result, we consider this a preliminary study.

The slide osteotomy was performed just medial to the abductors and just distal to the vastus lateralis ridge, thereby producing a classic trochanteric slide osteotomy with a fragment of approximately 5 cm (height) × 4 cm (width) × 1.5 cm (depth) [29]. The superior cut of the step osteotomy was performed similarly to the slide osteotomy. The step was inclined at 20° to 30° inferiorly on the anterior side, with a 5-mm step depth (Fig. 1C). The depth of the step was chosen based on clinical experience. For the step to have maximal benefit, it must remain close to perpendicular to the direction of muscle pull throughout the range of hip flexion. A step osteotomy that is level in the anteroposterior plane would only be perpendicular to the direction of muscle pull when standing. A squat position would, theoretically, decrease the effectiveness of the step cut since it would be nearly parallel to the direction of muscle pull, rendering it ineffective at counteracting the shear forces. As a result, we chose to perform the step cut inclined upward from anterior to posterior, at an angle of approximately 20° to 30° (Fig. 1D). Due to an error during the preparation of Specimen 1, the inclination in that specimen was performed in the opposite direction. Thus, this specimen (female, 87 years old) was removed from the study. For the slide and the step cuts, the medial-lateral angle of the osteotomy was based on the soft tissue attachments, as performed surgically, and not at a specific angle. The exact medial-lateral angle of the osteotomy is presumably not critical since the loads were applied in the plane of the osteotomy interface [25]. Both the slide and step osteotomies were fixed with two 3.5-mm diameter cortical screws (superior screw offset anteriorly and inferior screw offset posteriorly), positioned parallel to each other and perpendicular to the osteotomy interface.

Before the definitive biomechanical testing of the slide and step trochanteric osteotomies, initial tests were performed on composite bones (Model 3306 third-generation Sawbones®; Pacific Research Laboratories, Inc, Vashon, WA) to confirm the relationship between the torque applied to the cortical screws used for fixation and the pressure across the osteotomy interface. Although it was known a priori the compressive force across the osteotomy interface is positively related to the screw torque, we explicitly tested the repeatability of the interface pressure (and compressive force), given a specific screw torque applied with a torque wrench. For both the slide and step osteotomies, we measured the interface pressure for a given torque in a test-retest design using an electroresistive sensor. The sensor (Model 6900 custom range; Tekscan Inc, Boston, MA) was removed and repositioned between tests. Once we established we could reproducibly obtain interface pressures for the bilateral femur pairs, we proceeded with the preparation of the cadaveric specimens for biomechanical testing.

After the osteotomy and refixation, we obtained a radiograph for each femur to confirm the positioning of the screws (Fig. 2). The insertion torque of the cortical screws was determined by the surgeon on the first specimen of the pair. The torque was measured using a torque wrench and duplicated for the screws of the second specimen of the pair. The surgeon applied the maximum torque possible without stripping the cortical bone. The surgeon determined the maximum based on his surgical experience. Since bone quality was different between pairs, the applied torque ranged between 0.3 and 1.1 Nm for the six pairs.

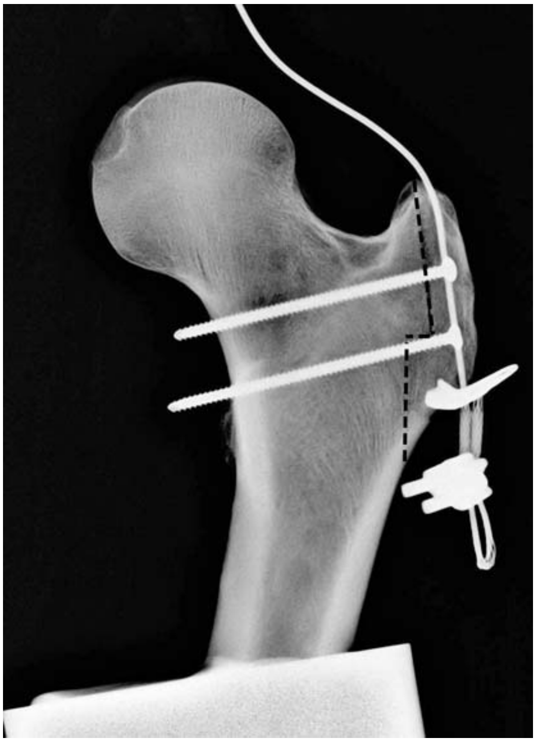

Fig. 2 Postsurgical anteroposterior radiograph of a representative step cut specimen demonstrates the cortical screws are perpendicular to the osteotomy interface and the cable is parallel to the osteotomy interface.

Based on the results of our preliminary tests with the Sawbones®, this method reliably generated equal compressive loads across the osteotomy interface for each bilateral pair.

The femoral shafts were potted in dental stone such that the osteotomy interface was exactly vertical (as measured using a laser level). Regardless of osteotomy type or loading configuration, the load was applied to the osteotomized fragment via a cable attachment. The cable passed through the fragment, parallel to the osteotomy interface (Fig. 2). For each loading configuration, 100 cycles of shear load were applied to the cable using a servohydraulic materials testing machine (Model 8874; Instron Corp, Norwood, MA). The cyclic loading was applied first in the superior configuration to represent standing (Fig. 3A). After this test, the femur was repositioned in the testing machine flexed to 60° to represent a squat stance, and the cyclic loading was applied in the anterosuperior direction (Fig. 3B). Finally, the osteotomy was loaded to failure in the squat configuration. These loading configurations were chosen based on previous findings that the trochanteric fragment tended to migrate proximally and/or anteriorly after a trochanteric osteotomy [7, 9, 10, 16, 18, 29].

The magnitude of the shear load for each femur pair was based on bone quality, as measured by DXA. The benchmark was based on a pair of femora with good bone quality and from a donor of a healthy body weight. We determined the load magnitude corresponding to 50% body weight for this individual and scaled the values for the other five pairs based on their bone mineral content values (mg) measured using DXA. Using this protocol, the peak cyclic shear loads ranged from 205 to 371 N. For each cycle, the applied shear load started at 0 N and was increased using a ramp loading profile until the specimen's predetermined peak load was reached, at which point the load was decreased to 0 N using a ramp loading profile. The load was applied under load control to generate shear forces across the osteotomy interface at a frequency of 0.25 Hz. Before applying the cyclic shear load, the compressive load across the osteotomy interface was generated by the torque applied to the cortical screws and was approximately equal for each bilateral pair.

Displacements of the trochanteric fragment were measured relative to the femur with an optoelectronic camera system with accuracy better than 0.1 mm and 0.1° (Optotrak 3020; Northern Digital Inc, Waterloo, ON, Canada). To facilitate the motion measurement, marker carriers with four infrared light-emitting diodes were attached to both the greater trochanter and the femur (Fig. 3). The amplitude and migration of the trochanteric fragment were measured over the 100 cycles of shear load. During data analysis, cyclic amplitude was defined as the difference between the peak and trough values for each cycle (excluding the initial displacement), whereas cyclic migration was defined as the mean of the peak and trough values for each cycle. Visual inspection of the raw data for all specimens revealed important translational and rotational contributions to the overall motion of the fragment (Fig. 4); therefore, we have chosen to report the translation and rotation components separately. The three-dimensional motion data are represented as a single translation and a single rotation about the helical axis of motion [23].

Nonparametric statistics were used since the variances were different between groups. We could not conclude the data were normally distributed and therefore Wilcoxon matched-pairs tests were performed to detect differences in migration and amplitude of the fragment during the last five cycles of the 100-cycle loading regimen between the trochanteric slide and step osteotomies.

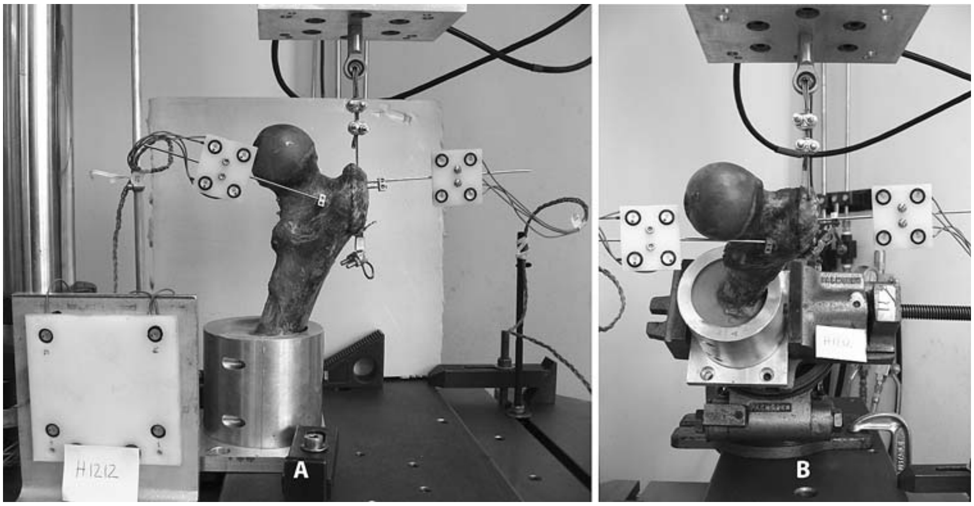

Fig. 3A–B The two testing configurations are pictured: (**A**) standing (posterior aspect of a right femur with slide osteotomy) and (**B**) squat stance (superior-posterior aspect of right femur with 60° of hip flexion).

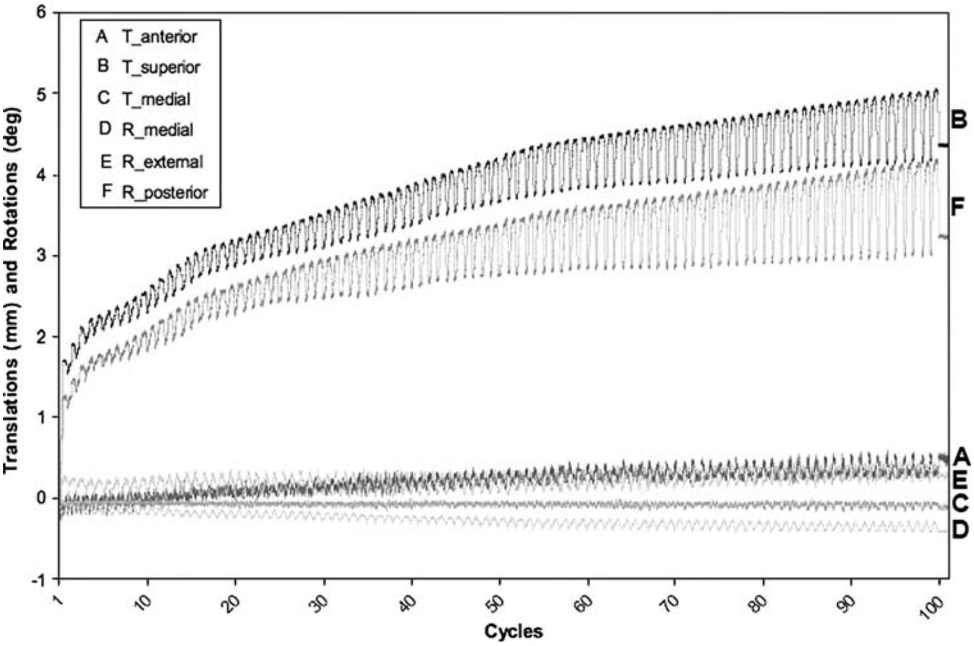

Fig. 4 Raw motion data of the osteotomized fragment are shown for a representative specimen, showing anterior translation (T anterior), superior translation (T superior), medial translation (T medial, ie, compression), medial rotation (R medial), external rotation (R external), and posterior rotation in the plane of the osteotomy (R posterior).

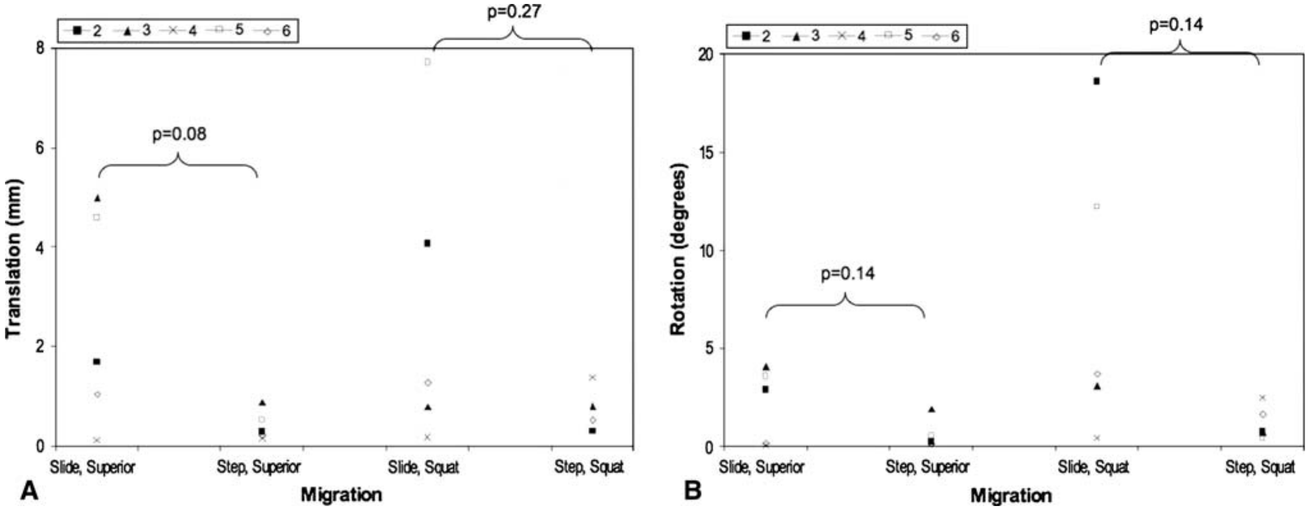

Fig. 5A–B Graphs show (**A**) translational and (**B**) rotational migration of the slide and step osteotomized fragments for the superior and squat stance loading configurations. (Each data point represents the mean value over the last five cycles of loading for a particular specimen). (**A**) Our primary outcome variable was translational migration under superior loading (left side) and we observed a greater median trochanteric migration of 1.7 mm for the slide osteotomy than the median of 0.3 mm observed for the step osteotomy. The secondary variable of translational migration under squat loading (right side) demonstrated no difference between the slide and step osteotomies. (**B**) Rotational migrations under superior loading (left side) and squat loading (right side) were not different between the two osteotomies.

Results

Under loading in the superior direction, the median trochanteric migration of 1.7 mm for the slide osteotomy was greater ($p = 0.08$) than the median of 0.3 mm observed for the step osteotomy (Fig. 5A). There was no difference ($p = 0.14$) in rotational migration between the slide and step osteotomies under superior loading (Fig. 5B). As expected, both the translation and rotation components of migration tended to increase with increasing cycles.

The cyclic amplitude of translation under superior loading was small, less than 1 mm for all specimens in both groups. Nevertheless, the median translational cyclic amplitude under superior loading of 0.3 mm was greater

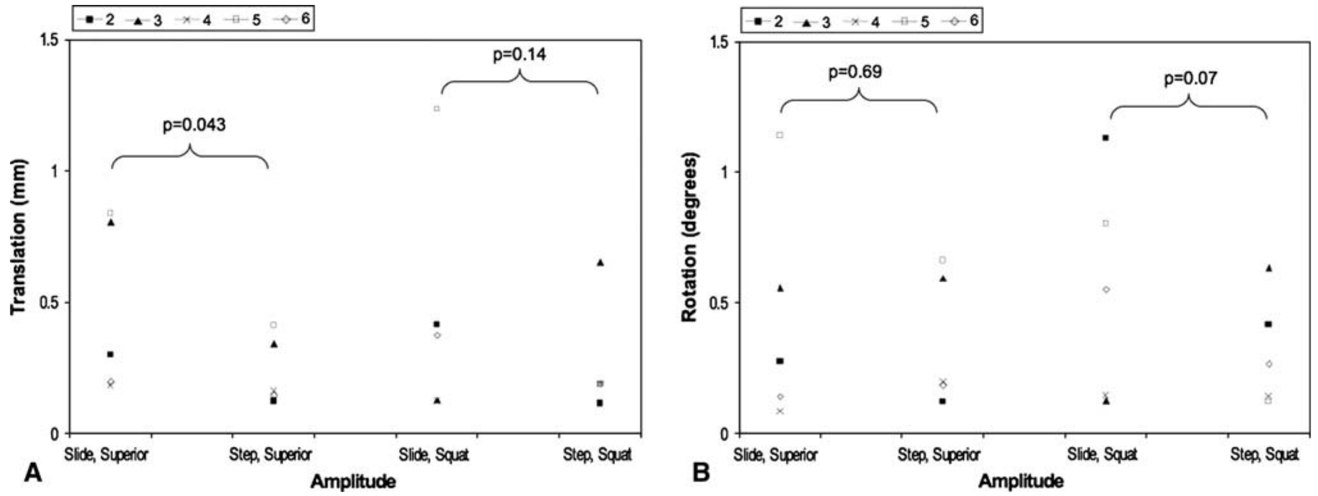

Fig. 6A–B Graphs show (**A**) translational and (**B**) rotational cyclic amplitude of the slide and step osteotomized fragments for the superior and the squat stance loading configurations. (Each data point represents the mean value over the last five cycles of loading for a particular specimen). (**A**) The secondary variable of translational amplitude under superior loading (left side) demonstrated greater motion for the slide than for the step osteotomy, while there was no difference under squat loading (right side). (**B**) Rotational amplitudes under superior (left side) were not different between the two osteotomies while the motion under squat loading was greater with the slide osteotomy than with the step osteotomy.

($p = 0.04$) for the slide osteotomy than the median of 0.16 mm for the step osteotomy (Fig. 6A). There was no difference ($p = 0.69$) in rotational cyclic amplitude between the slide and step osteotomies under superior loading (Fig. 6B).

Under loading in the squat configuration, the median trochanteric migration of 1.3 mm for the slide osteotomy was similar to ($p = 0.27$) the median of 0.4 mm observed for the step osteotomy (Fig. 5A). Further, the median rotational migration of 3.7° for the slide osteotomy was similar to ($p = 0.14$) the median of 1.2° observed for the step osteotomy (Fig. 5B).

Cyclic amplitude was less than 2 mm in translation and less than 2° in rotation for both the slide and step osteotomy fragments in the squat configuration (Fig. 6). The median cyclic translational amplitude under squat loading similar ($p = 0.14$) for the slide and step osteotomies (Fig. 6A). The median rotational cyclic amplitude in the slide osteotomy was greater ($p = 0.07$) than the step osteotomy (0.6° versus 0.2°) (Fig. 6B).

For both the superior and squat configurations, the primary contributors to the reported single translation and single rotation were superior-inferior translation and rotation in the plane of the osteotomy, respectively.

In two of the step osteotomy specimens, the cable attachment failed during cyclic testing in the squat configuration. Failure of the attachment occurred after 10 cycles in one (Specimen 2) and after five cycles in the other (Specimen 3), resulting in incomplete data. All other specimens were tested to failure in the squat configuration and the ultimate failure loads for the slide and step osteotomies ranged between 465 N and 704 N (median = 541 N) and 483 N and 690 N (median = 511 N), respectively. For the slide osteotomy, four of the six failures were deemed "clinical failures" (ie, total migration > 3 mm) while the remaining two failed at the cable attachment before reaching clinical failure. For the step osteotomy, the cable attachment failed in all cases before a clinical failure was observed. The step osteotomy of one pair (Specimen 2) was tested to failure in the superior configuration after the failure of the cable attachment in the squat stance loading configuration. In this case, the step osteotomy withstood 856 N without a clinical failure at the osteotomy interface; however, at this load, failure occurred in the form of a pertrochanteric femur fracture.

Discussion

Theoretically, a step cut resulting in direct bony abutment would better resist the applied shear forces from the hip musculature. We therefore asked whether a step cut would reduce translational and rotational migration of the greater trochanteric fragment under superior and squat loading configurations.

We acknowledge several limitations. First, for several of our secondary outcome parameters, the differences between the step osteotomy and the slide osteotomy were small. Thus, we had relatively low statistical power to detect differences. Second, our cable attachment was not ideal in the squat configuration since the direction of load caused the cable to bend and, in some cases, cut the superior aspect of the fragment. Our initial design was to apply the load to the greater trochanter via the gluteal tendon to represent the pull of the muscles; however, the gluteal tendon was too short to grip. Therefore, we mimicked the tendon using a cable that we drilled through the osteotomized fragment. Despite its limitations, we believe our attachment was an improvement over previous bolt techniques [14, 26] because the direction of loading was more physiologic and because it did not restrict fragment rotation. It is important to note the loading configurations adopted herein did not replicate hip abduction, which would lead to a certain degree of tension on the osteotomy interface and might be a worst-case scenario. Third, while we were not able to control the compressive force across the osteotomy interface, we did apply the same torque to the cortical screws in each bilateral pair. Based on our initial tests with the pressure sensor, we are confident a comparable compressive force within each pair was achieved. Fourth, variation in results between specimens in our study may result from bone quality differences between specimens. Although we did not explicitly investigate whether migration was related to bone mineral content, the wide range of bone quality between specimens, as measured by DXA, was evident to the surgeon during preparation of the specimen. The biomechanical benefit of the step depends on the resultant surface area of the step (ie, depth and width) in combination with the mechanical bone strength. Our donors had a mean age of 62.2 years, which is higher than patients who would typically qualify for joint-preserving hip procedures (18–50 years). We believe the bone strength, especially at the cancellous bone interface of the osteotomized fragment, was lower in our specimens than it would be in younger individuals. We assume better bone quality would show larger differences in migration and amplitude between the slide and step osteotomies than those measured in this study. It was not possible to obtain cadavers in the 18- to 50-year age range without them having underlying abnormalities that also affect bone quality. Finally, this study differs from our previous work [14, 26] in our current use of bone mineral content values from DXA to determine the magnitude of applied load for each specimen pair. Since all but one of our donors were obese (ie, body mass index > 33; range, 20–39), we chose not to base the load magnitude on body weight as is common in such studies [26] since our DXA results indicated the high body weight of our donors did not indicate high bone quality. In addition, the medical history data for several of our donors indicated prescription of certain medications known to cause water retention, which was likely partially responsible for the high body weight. For these reasons, we believed it more appropriate to base the load magnitude on bone mineral content.

Our model for fixation of the greater trochanter was two cortical screws across the osteotomy interface since in our clinic these are mainly used for joint-preserving procedures and hip resurfacing. For these indications, cortical screw fixation is sufficient to provide stable fixation with minimal hardware use and removal of the hardware is easy to perform. In THA, screw fixation is often not possible and therefore wire, cable, or cable grip techniques are necessary. A step osteotomy may provide additional stability and reduce the rate of wire breakage or cable fretting in THA.

We observed less translational migration for the step osteotomy compared to the slide osteotomy under superior loading, which was our primary outcome variable. Since this is the first biomechanical assessment of the step osteotomy, there are no data for comparison with respect to this loading parameter. However, our results for the slide osteotomy are consistent with those reported in a previous biomechanical study using a different geometry, in which our experimental design is most comparable to the test condition with no external compressive load in that report [26]. In the superior configuration, our data for translational motion amplitude ranged from 0 to 1 mm, compared to 0 to 1.5 mm reported by Plausinis et al. [26]. Also, in the superior configuration, our data for translational migration ranging from 0 to 5 mm for the slide osteotomy compared well to the 0 to 9 mm previously reported [26]. Comparisons between the findings from our squat configuration and those of the anterior configuration in Plausinis et al. [26] should be made with caution since the direction of shear load application was different between the two studies. Plausinis et al. [26] applied an anterior load without any rotational component, and as such, this does not fully replicate actual biomechanical conditions. Despite these differences, our results for translational motion amplitude in the squat configuration ranged from 0 to 1.5 mm, compared to 0 to 2 mm reported by Plausinis et al. [26], and our results for translational migration ranged from 0 to 8 mm, compared to 0 to 14 mm reported by Plausinis et al. [26]. We were not able to verify in our experiments the importance of the slope in the step osteotomy, especially in the squat position. No data have been previously reported for the rotational component of motion amplitude or migration in trochanteric osteotomy studies.

The data suggest the trochanteric step osteotomy is a more stable construct than the commonly performed slide osteotomy. Use of the step osteotomy could reduce the degree and length of the postoperative reduced weight-bearing period. Since performing a step osteotomy does not increase the surgical time of the procedure, allows for an anatomic reduction, and offers equal or better stability than a slide osteotomy, it appears the step osteotomy is an improvement over the classic slide osteotomy. However, the small sample size and the other limitations of this study render it a preliminary investigation rather than a definitive statement on the effectiveness of the step osteotomy.

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