Pelvic Osteotomy Techniques and Comparative Effects on Biomechanics of the Hip: A Kinematic Study

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abstract

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Dysplasia of the hip is characterized by malpositioning of the proximal femur in a shallow acetabulum, providing deficient femoral head coverage. This abnormal relationship leads to altered biomechanics of the hip joint, as predicted by measurement of kinematic parameters such as increased load over reduced acetabular weight-bearing area, leading to increased joint contact stresses, which subsequently results in secondary osteoarthrosis, pain, and disability. To prevent these sequelae, particularly in children and younger adults, various osteotomies have been performed with varying degrees of success. The goal of this study was to devise a simple and reproducible laboratory method to perform a kinematic analysis of the individual and comparative effects of 5 commonly performed pelvic osteotomy techniques: Chiari pelvic osteotomy, Salter innominate bone wedge osteotomy, Steel triple pelvic osteotomy, Tönnis triple pelvic osteotomy, and Ganz periacetabular pelvic osteotomy. The aim was to determine which of the osteotomy techniques caused greater correction in most of the kinematic parameters used to estimate changes in the biomechanics of the hip joint. Our hypothesis was that pelvic osteotomies such as Chiari and Salter produced favorable changes and were relatively easily reproducible, but that more biomechanical correction in all planes would be achieved by the relatively more complex triple innominate bone and Ganz osteotomy.

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Figure: The Sawbones model (Smith & Nephew, Memphis, Tennessee) of the femur and hemipelvis with the clamp system.
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**Chiari Pelvic Osteotomy**

The Chiari pelvic osteotomy is considered a salvage, rather than a reconstructive, procedure for dysplastic hips. It was first performed by Professor Karl Chiari in 1950 in Austria, with results published in 1953 and a long-term follow-up study comprising approximately 600 patients (at least 400 followed up for >2 years) published in 1974. The Chiari pelvic osteotomy is a capsular interposition arthroplasty that should be considered when other reconstructive procedures cannot be performed.

**Salter Innominate Bone Wedge Osteotomy**

Salter described his innominate bone wedge osteotomy in 1961 (after a series of 96 procedures, the first of which was performed in 1957) when a problem with instability of the hip joint after reduction was found in children older than 18 months due to abnormal direction of the entire acetabulum. It is generally recommended in children aged 18 months to 6 years with congruous and concentric hip reduction. This osteotomy results in a shift of the acetabular roof anteriorly and laterally. The wedge of the osteotomy is held anterolaterally by a wedge of bone graft, and the symphysis pubis acts as a hinge.

**Steel Triple Pelvic Osteotomy**

Steel described his triple osteotomy of innominate bone in 1973 with a 2- to 10-year follow-up of 52 patients, with successful results in 40. It is performed initially in older children where other reconstructive procedures can be performed but are limited in different ways, such as the mobility of the symphysis pubis in Salter’s procedure and triradiate cartilage restriction in Pemberton’s procedure. The ischium, superior pubic ramus, and ilium superior to the acetabulum are divided, and the acetabulum is repositioned and stabilized in a more effective anatomical position.

**Tönnis Triple Pelvic Osteotomy**

Tönnis described the results of his modification of the triple pelvic osteotomy in young adults in 1990. With continuous improvement in measurement and analysis techniques, it was found that the Tönnis method could result in better acetabular coverage of the femoral head and particularly the translation movement in the 3 planes. Tönnis triple pelvic osteotomy is performed more commonly in adolescents and young adults. The procedure differs from other triple innominate bone techniques mainly in the ischial osteotomy; the cut is closer to the acetabulum.

**Ganz Periacetabular Pelvic Osteotomy**

Ganz developed a periacetabular osteotomy for hip dysplasia in adolescents and adults. It was first performed in 1984, and first results were published in 1988 in a series of 75 procedures. Although this osteotomy is triplanar, requires careful 3-D planning, and is technically more difficult, large corrections can be achieved in all directions. The posterior column of the hemipelvis remains mechanically intact, and thus stability can be easily achieved with minimal internal fixation. Partial weight bearing has been advocated early in clinical studies. The shape of the true pelvis is unaltered in the Ganz osteotomy.

**Materials and Methods**

Our kinematic analysis of biomechanical parameters of the hip was performed on similar normal adult Sawbones hemipelvis and femur models provided by Smith & Nephew (Memphis, Tennessee). Seventeen hemipelvis model were used. Two (1 hemipelvis and 1 femur) were control models from which the original set of values were obtained, and 5 different pelvic osteotomies were performed, 3 times each, on the other 15 experimental models (Figure 1).

The hemipelvis had an extension rod over the posterosuperior part of ilium with a provision to fit on a specially designed clamp system to hold the model firmly in the same position while the cuts were made (Figures 2-6).

Various points of reference on the pelvis and femur were carefully chosen and marked on the control models and the experimental models at similar points, with the help of the PiGalileo Hip Navigation System (Plus Orthopaedics AG, Aarau, Switzerland).

The Fastrak digitizing system (Polhemus, Colchester, Vermont), an electromagnetic motion tracking system that computes position and orientation through space, was used. The stylus was touched to the reference points on the...
control models, and a set of raw data with reference to the coordinate system of the electromagnetic plate was obtained. The same method was used to obtain data from the experimental models.

The osteotomies were performed in the same fashion as described by the creators of the original techniques. A handheld battery-operated oscillating saw was used to perform the osteotomy cuts. All necessary precautions were taken to prevent any interference in the electromagnetic fields. No metalwork was used to fix or stabilize the cuts; glue was used instead.

The following 9 parameters were considered:

- The center-edge angle of Wiberg;
- Sharp’s angle (acetabular index);
- Femoral head coverage (percentage acetabular head index);
- Displacement in the mediolateral, anteroposterior, and vertical (superoinferior) planes (translation in 3 planes from a central point of reference); and
- Rotation of the acetabulum in 3 planes: internal/external, flexion/extension, and varus/valgus.

RESULTS

Each technique was performed 3 times. Mean values with standard deviation were calculated and used for further analysis (Table 1).

The aforementioned values are not directly comparable with the biomechanical parameters of the hip joint or radiographic findings as shown in various published clinical studies. This study was performed on normal adult models, and electromagnetic fields with reference marker systems were used instead of radiographs. Measurement of the shift differences from the preosteotomy values is the basis of our data analysis.

Confidence interval (CI) values were calculated assuming the alpha value to be 0.05 (95% CI) and taking the mean of the differences, the standard deviation, and the n value of 3. The standard formula used to calculate the CI values was CI = mean ± 1.96 × SD/√n. Because the size of this study was small, performing further statistical analysis to obtain a statistical significance was not considered relevant (Table 2).

DISCUSSION

Rab13 performed a biomechanical analysis of the Salter osteotomy based on mathematical calculations using osteotomy simulated on a male adult pelvis on a cadaver trunk mounted in a plywood box. Küßwetter and Magers14 compared changes in the pelvis after Chiari and Salter osteotomies performed using a macerated, normally developed female pelvis. Joint simulators have been used.
Plain radiographs have been widely and successfully used for measurement of biomechanical parameters in 2 dimensions, but computer programs have been devised that calculate 3-D coverage of the femoral head. Computed tomography (CT) scans and reconstructions have been used, as well as computer-assisted surgery. Three-dimensional finite element analysis and roentgen stereophotogrammetric analysis studies have been performed. Mathematical models, like the hip stress, have been devised to calculate and analyze the biomechanics of the hip joint.

Chiari osteotomy is effective at correcting the deformity and reducing pain, but up to 70% of these patients have a limp due to weak abductor strength. Delp et al devised 2 computer simulations of Chiari osteotomy to measure the geometric parameters, namely the angulation of the osteotomy, the distance of the medial displacement, and the angle of internal rotation. They proved that the loss of gluteus medius abductor torque strength up to 65% can be prevented by reducing the angle of osteotomy to a 0° to 10° range and reducing the medial displacement of the distal fragment can preserve the abductor length and thus the abductor torque and strength.

In our study, an osteotomy angle of approximately 20°, medial displacement of the distal fragment approximately 50% of the width of the ilium, and the level of osteotomy was followed as described originally by Chiari. A standard deviation range of 0.15 to 4.81 suggests that the Chiari osteotomy is easily reproducible compared with other techniques. Some improvement in most of the parameters with this technique has been observed, particularly the femoral head cover, up to 106.6% from an original 81.1% (mean, 102.1%) and the mean difference (improvement) of 21% from the original. The center-edge angle of Wiberg improved by a moderate 7.4° in this study.

In the single innominate bone osteotomy, femoral rotation was also noticed, slightly increased variability in values was found when this technique was performed and reproduced each time (SD range, 0.12-8.94).

The ischial cut in the triple osteotomy described by Steel is far from the joint, and this was modified by Tönnis. The ischial osteotomy being closer to the acetabulum achieves similar correction, and normal tension in the sacroiliac ligaments is maintained; thus, desirable anteversion (15°-20° as recommended by Tönnis) can be achieved. In the Tönnis triple osteotomy, average improvement in center-edge angle is 19° and in acetabular index is 12°.

In our study, after the Tönnis technique, a mean 28.4° improvement, 29.4° correction in Sharp’s angle, and 27.4% improvement in femoral head cover were found. Significantly greater correction in the acetabular rotation was also found.

Ganz et al developed a periacetabular osteotomy for hip dysplasia in adolescents and adults. It was performed first in 1984, and results were published in 1988 in a series of 75 procedures. Siebenrock et al performed their study using radiographic evaluations based on a standard anteroposterior pelvic radiograph, and a false-profile radiograph measured the lateral center-edge angle of Wiberg, the anterior center-edge angle, and the acetabular index. The results showed marked improvement in the lateral center-edge angle of Wiberg (up to 34° from a preoperative average of 6°) and the anterior center-edge angle (up to 28° from a preoperative average of 4°). Lateralization of the femoral head was significantly improved, and Shenton’s line was restored in 62% patients.

In our study, after the Ganz technique, a mean 31° improvement in center-edge angle of Wiberg and 37° improvement in Sharp’s angle were found. Femoral head

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**Table 1**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Original Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center-edge angle</td>
<td>27.5°</td>
</tr>
<tr>
<td>Sharp’s acetabular angle</td>
<td>55.5°</td>
</tr>
<tr>
<td>Femoral head cover</td>
<td>81.1%</td>
</tr>
<tr>
<td>Mediolateral translation</td>
<td>8.8 mm</td>
</tr>
<tr>
<td>Anteroposterior translation</td>
<td>0.3 mm</td>
</tr>
<tr>
<td>Vertical translation</td>
<td>−1.3 mm</td>
</tr>
<tr>
<td>Acetabular internal/external rotation</td>
<td>−68.3°</td>
</tr>
<tr>
<td>Acetabular flexion/extension</td>
<td>38.1°</td>
</tr>
<tr>
<td>Acetabular varus/valgus</td>
<td>−26.9°</td>
</tr>
</tbody>
</table>

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In our study, there was a mean improvement of 9.6° in center-edge angle and only a minimal improvement in femoral head cover and acetabular index. Although vertical translation (lengthening) achieved was greater than in other techniques, the acetabulum is more extended. High consistency was achieved when these values were obtained from the Salter osteotomy models (SD range, 0.31–2.97).

The results of our study show that a somewhat better correction can be achieved for parameters such as Sharp’s acetabular angle (mean improvement, 10.8°), center-edge angle (mean improvement, 16.9°), and femoral head coverage (mean improvement, 15.8%) with the Steel triple osteotomy. Although a significant change in parameters of acetabular rotation was also noticed, slightly increased variability in values was found when this technique was performed and reproduced each time (SD range, 0.12-8.94).

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coverage (mean increase, 24.1%) and changes in the acetabular rotation were also found.

With the Ganz and Tönnis osteotomies, overcorrection and secondary impingement can occur. Therefore, intraoperative radiographs and measurement of center-edge angle and vertical-center anterior angle using a goniometer is helpful. Assessment of the crossover sign on intraoperative pelvic radiographs can reveal retroversion. This kinematic analysis helps show the mobility of the acetabulum after various osteotomies and makes the operative surgeon aware of the direction and magnitude of acetabulum movement after these various osteotomies.

Our study was limited to a kinematic analysis and was performed on normal adult Sawbones models, so it cannot be directly translated clinically where each procedure is done for different indications. Also, the number of times each technique was performed may not attract a statistically significant conclusion; however, based on the experimental results achieved and the methodology used for this study, a larger study can be designed to compare the effects of different pelvic osteotomy techniques. Further study could include estimation of pressure distribution and the kinetic effects of these techniques on the biomechanics of the hip joint.

**CONCLUSION**

Chiari and Salter osteotomies can be relatively easily reproduced and can bring about moderate improvement in most of the kinematic parameters of the hip joint, including a 21.03% increase in femoral head coverage with the Chiari osteotomy. The 3-D spatial movement of the acetabulum achieved with these 2 techniques is significantly smaller as compared to the triple pelvic osteotomies and Ganz periacetabular osteotomy, where the free acetabulum can be rotated to a greater extent. The triple innominate bone osteotomies and Ganz osteotomy also achieve a greater change in the center-edge angle (up to 31°) and Sharp's acetabular angle.

**REFERENCES**


