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Range of Motion after CT based simulation of Intertrochanteric Corrective Osteotomy in cases of Slipped Capital Femoral Epiphysis (SCFE): Comparison of uniplanar flexion osteotomy and multi - planar flexion-, valgisation and rotational osteotomy

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Abstract

Background—Various osteotomy techniques have been developed to correct the deformity caused by SCFE and compared by their clinical outcome. Aim of the presented study was to compare an intertrochanteric uni – planar flexion osteotomy to a multi-planar osteotomy by the ability of improve postoperative range of motion as measured by simulation of CT data in patients with Slipped Capital Femoral Epiphysis (SCFE).

Methods—We analyzed 19 patients with moderate or severe SCFE classified based on their slippage angle. A computer program for simulation of movement and osteotomy developed in our laboratory served for study execution. According to 3D-reconstruction of the computer tomography data the physiological range was determined by flexion, abduction and internal rotation. The multi-planar osteotomy was compared to the uni-planar flexion-osteotomy. Both intertrochanteric

osteotomy techniques were simulated and the improvements of the movement range were assessed and compared.

Results—The average slipping and thus correction angles measured were 25° (range: 8°–46°) inferior and 54° (range: 32°–78°) posterior. After the simulation of multi-planar osteotomy the virtually measured ROM determined by bone to bone contact for flexion was 61° for abduction 57° and internal rotation of 66°. The simulation of the uni-planar flexion osteotomy achieved for flexion of 63°, an abduction of 36° and an internal rotation of 54°.

Conclusion—Apart from abduction, the improvement in the ROM by an uni-planar flexion osteotomy is comparable with that of the multi-planar osteotomy. However, the improvement in flexion for the simulation of both techniques is not satisfactory with regard to the requirements of normal everyday life, in contrast to abduction and internal rotation.

Level of Evidence—Level III: Retrospective comparative study

INTRODUCTION

The deformity caused by the posterior slippage of the epiphysis in slipped capital femoral epiphysis (SCFE) 21 can lead to decreased hip flexion and internal rotation and gait abnormalities. Additionally, the impingement caused by the metaphyseal prominence may lead to labral and articular cartilage damage in the anterior aspect of the joint as well as a contralateral lesion in the posterior aspect of the joint, leading to eventual osteoarthritis in 25–41% of hips 12,19. The goal of all correctional osteotomies for SCFE is to improve the mechanics of the hip joint, which results in improved hip function, less pain, and perhaps less osteoarthritis. Various osteotomy techniques including subcapital, base of neck, intertrochanteric and subtrochanteric osteotomies have been developed to correct the deformity caused by SCFE.

Subcapital osteotomies provide the most accurate anatomical reconstruction of the hip joint 17. However, this procedure is technically demanding and associated with a high risk of postoperative aseptic femoral head necrosis, which ranges between 14 and 28.5 %. 1,4,5. Additionally, it can be associated with a high incidence of chondrolysis between 11.8 % and 38.5 %.5,25 In intertrochanteric osteotomies, aseptic femoral head necrosis is rarely observed (6%) 9, thus it is a more commonly performed reconstructive surgical procedure 18. Two intertrochanteric osteotomy techniques are commonly used – a multi-planar osteotomy described by Southwick and Imhauser 8,9,22 and a uni-planar flexion osteotomy as described by Griffith. 7. The Imhauser or Southwick technique involves intertrochanteric flexion, valgisation and internal rotation wedge osteotomy 8,9 to reconstruct the hip joint geometry whereas the Griffith osteotomy is a purely intertrochanteric flexion osteotomy, which is unidirectional in the axis of rotation of the epiphysis, for the correction of the pathoanatomical changes in patients with SCFE. 7

The goal of our study was to simulate both osteotomy techniques using computerized tomography (CT) data of hips with SCFE. We measured the limits of hip ROM as defined by the bony anatomy alone, simulated the two osteotomy techniques, and then remeasured the hip ROM after osteotomy using computer software. Our aim was to compare these two techniques in terms of their ability to improve the range of motion of the hip.

MATERIALS AND METHODS

Patient Cohort

This is a retrospective analysis of hip computerized tomography (CT) data in patients with SCFE. The CT data was initially collected for a study looking at the association between femoral retroversion and SCFE. 3,6 Institutional review board approval was obtained for this

study. Hip CT scan data in 31 hips with SCFE in 23 patients (14 male and 9 female) were available. All CT scans were obtained prior to surgical treatment. Of these 31 hips, 19 hips with moderate (slip angle 30–50 deg) and severe (>50 deg) SCFE were analyzed.

The mean age of the patients was 13.7 years (11.4 – 16.8 years). There were 13 unilateral and 3 bilateral cases. The right hip was affected in 5 cases, the left in 14 cases. A simulated osteotomy was performed in 19 (11 male and 8 female) patients after assessment of the slippage angle: 7 moderate (30–50°) and 12 severe (>50°) slips. 12 mild slips (<30°) were excluded from this study because reorientation osteotomy are not indicated in mild SCFE. 8,9,22

Radiographic Analysis

Slip Angle—The degree of slippage and therefore the degree of correction for the osteotomy was assessed based on the method described by Southwick 22 (Figure 1). For the determination of inferior angle of slippage (α) a standard anterior-posterior radiograph were used. For the posterior slippage (β) a frog leg radiograph was used. The degree of slippage was calculated as difference between the epiphyseal plate angle of the affected (α_2 or β_2) and the unaffected side (α_1 or β_1). In bilateral cases, the mean average of the epiphyseal plate angles of the unaffected hips ($n = 15$) were used ($\alpha_3=142.5$, $\beta_3=14.3$). A slippage angle less then 30° was classified mild, a slippage angle between 30° and 50° as moderate and a slippage angle more then 50° was classified severe.

CT Analysis

CT scans of the hips were initially obtained for evaluation of association between femoral retroversion and SCFE 3,6 and were analyzed retrospectively for this study. The patients were examined supine with 2–5 mm contiguous, axial slices through the hip joint and the femoral condyles. Semi-automated segmentations of the femoral condyles, the proximal femur, the femoral epiphysis, the femoral head and the pelvic bone were reconstructed into 3D Models using marching cube, an algorithm implemented in “The Visualization Toolkit” (Kitware, Inc.; Clifton Park; NY 12065; USA).

Range of Motion analysis—For simulation of the Range of Motion we used a program developed in our laboratory, which enables us to move the single three-dimensional structures independently based on a coordinate grid in the x, y and z direction. 16,17 The coordinate grid was positioned at the centre of the femoral head which was assumed to be equal to the centre of rotation. The femoral segment was then manipulated until direct (i.e. bone on bone) contact with the bony acetabulum and the maximal hip ROM was measured. Our computer model did not include the ability to account for any limitation of motion due to soft tissue constraints; therefore, the measurements provided are a theoretical maximum hip ROM as defined by the bony anatomy alone.

Frequently, the affected hips were observed to be in external rotation at rest at time of the CT examination. In order to have a standard frame of reference for comparison across hips with differing severity of SCFE, it was necessary to internally rotate the hip back to neutral position prior to range of motion analysis. Tangent to the dorsal curves of the femoral condyles of both sides defined the reference axis. The tangent lines were set to parallel orientations by rotation about the center of the femoral head prior to determination of the ROM (Fig. 2).

Validation of the Range of Motion Simulation—The accuracy of range of motion measurements was evaluated using a phantom constructed out of wood. The model consisted of four opposing blocks of wood of different heights providing the limits of rotational movement. A cylinder containing a third of an overlaying bowl represented the ball and socket joint and was located at the center of the model. A stick, perpendicular to the base of the

cylinder, was affixed to the bowl to simulate movement. Two opposing blocks of wood acted as references for measurement of flexion/extension or abduction/adduction. The horizontal movement of the stick between two blocks was defined as rotation.

The range of motion in each direction was then measured manually and by computer simulation. In 12 measurements for each direction (36 measurements total) the average error between manual and computational measurement was 1.92° .

Simulation of Osteotomy—Two different reorientations using an intertrochanteric osteotomy were simulated by a software tool developed in our laboratory for planning and simulation of osteotomy in maxillofacial surgery.²⁴ This allows a virtual cutting of the femoral bone in two fragments and a reorientation of the proximal bone fragment according to the center of rotation in the three directions of the coordinate grid. For the multiplanar osteotomy, the flexion and abduction correction was prescribed by the alpha (inferior) and beta (posterior) slip angles. For the uniplanar osteotomy, flexion correction was prescribed by the beta (posterior) slip angle. The maximum correction recommended in a multi-planar intertrochanteric osteotomy are flexion up to 60° (angle β), abduction up to 45° (angle α) and internal rotation up to 30° (neutral position)^{8,9,22} In an uni-planar intertrochanteric osteotomy the maximum recommended flexion is 70° according to Griffith⁷.

Statistical Analysis

Three independent investigators (XX, YY, ZZ) performed hip ROM simulation before and after osteotomy. The mean average of the ROM obtained by the three investigators were used for the analysis. For comparison of the two different osteotomy techniques we used Wilcoxon Test. Interobserver variability in range of motion measurement were assessed using interclass correlation. The statistical analysis was done using SPSS 12.0[®] (SPSS Inc., Chicago, IL).

RESULTS

For all measurements of ROM in the validation study using the phantom the interclass correlation was 0.967 for analysis of flexion, internal rotation and abduction. For the measurements of Range of motion before and after simulation of osteotomy Interobserver variance was 0.913.

In 12 cases the entire femur was externally rotated during the CT scan; therefore, the femur was internally rotated to align the distal femur with the pelvis. The amount of external rotation during the scan was 28.6° on average ($9.0^{\circ} - 34.3^{\circ}$ sd. 11.9°). Complete compensation was not possible in 7 cases, 2 of them moderate and 5 with severe SCFE, due to a non-physiological bone-bone contact before the neutral position was achieved. In these patients the lower limb was still externally rotated by 11.4° ($6.8^{\circ} - 18.9^{\circ}$ sd. 4.9°). Table 1 is the range of motion before osteotomy.

The mean value of the inferior slip angle was 25.4° degrees ($7.5^{\circ} - 46.0^{\circ}$, sd. 11.3°) and the posterior slip angle was 54.3° degrees ($31.5^{\circ} - 78.0^{\circ}$, sd. 12.8°), in the 19 cases of moderate and severe slips analyzed for this study. The angle of correction for flexion of both osteotomies were 42.1° degrees (sd. 6.5°) for the moderate cases and 57.3° degrees (sd. 4.1°) for the severe cases. For the simulation of the multi-planar osteotomy the angle of correction for abduction was 20.3° (sd. 7.8°) in moderate, 25.3° (sd. 4.8°) in severe and for internal rotation 24.8° (sd. 6.0°) in moderate, and 7.4° (sd. 4.0°) in severe cases.

The resultant ROM after simulation of the multi-planar intertrochanteric osteotomy are flexion 61° (sd. 18°), abduction 57° (sd. 16°), and internal rotation 66° (sd. 30°). When the uni-planar

osteotomy was simulated the resultant ROM were flexion 63° (sd. 9°), abduction 36° (sd. 15°), and internal rotation 54° (sd. 20°). The results are shown in table 2.

The improvement in hip flexion, abduction, and internal rotation after Griffith and Imhauser/Southwick osteotomy simulation were calculated and compared using the Wilcoxon sign rank test. Between the two osteotomy techniques, only the improvement in abduction were significantly different ($p = 0.004$). Improvement in internal rotation ($p = 0.14$) and flexion ($p = 0.45$) were not significantly different.

DISCUSSION

The present study is unique as a comparison of different techniques of intertrochanteric osteotomy by assessment of range of motion before and after computer-simulated surgical treatment in patients with SCFE.

When ROM was simulated before osteotomy, some hips were noted to rest in external rotation. When the femoral reference frame is brought back to neutral, some hips were seen to be impinging even in extension and certainly in flexion. This finding may not be clinically apparent due to the fact that with some external rotation of the hip, the impingement can be relieved and the hip will flex.

When the range of motion after osteotomy was compared, both procedures improved hip flexion and internal rotation to a similar extent. Only hip abduction was improved to a larger extent by the technically challenging multi-planar osteotomy. However, the abduction obtained by the uni-planar osteotomy was 36.4 degree, which appeared to be within physiological range.

Although, hip flexion did improve with both types of osteotomies, neither provide physiological hip flexion after simulation. This is due to underestimation of the impingement from the metaphyseal prominence when slip angles alone are used in preoperative planning. Several authors have observed that SCFE is also associated with other proximal femoral deformities such as proximal femoral varus, decreased head-neck offset, and femoral retroversion 11,23, that would not be taken into account in the slip angle measurement. Additionally, the orientation of the acetabulum will influence the hip range of motion 23, which again would not be taken into account when planning the osteotomy using the slip angle alone. Although we regard the computer simulation as a valuable tool for pre-operative planning, its major benefit is in aiding our understanding of other factors such as head-neck prominence and femoral retroversion that have an equally important role in determining the final range of motion after osteotomy. Also, in practice, most surgeons make adjustments from their pre-operative plan based on their intraoperative assessment of range of motion after provisional fixation of the osteotomy and therefore clinical results after osteotomy will likely serve as better predictors of surgical outcome than our computer simulation. However, the value of this type of simulation is found in uncovering alternative strategies for improving range of motion such as resection of the metaphyseal prominence or derotation through the osteotomy.

Therefore, the entire deformity will need to be assessed and taken into account when planning a reconstructive procedure for SCFE. Pre-operative simulation of the osteotomy using CT data combined with direct intra-operative visualization of the joint to estimate the limits of flexion may be necessary to truly achieve sufficient range of motion.

One limitation of this study is the fact that effect of soft tissue restraints on ROM was not taken into account. Therefore, the results provided here reflect the theoretical maximum hip ROM as determined by the bony anatomy alone. Additionally, our software model was unable to account for possible improvement in ROM due to remodeling of the metaphyseal 13,15,20

Additionally, the software allows preoperative planning of intertrochanteric osteotomies in patients with SCFE taking into account the degree of the slippage, the geometry of the proximal femur, the orientation of the acetabulum and the deformity of the femoral neck. Kamegaya et al 10 described the use of CT data in planning of intertrochanteric osteotomy for more precise anatomical alignment and could show improvement of clinical results, which add to the value of using CT data for planning of the osteotomy.

This study demonstrates that the postoperative improvement in the range of flexion and internal rotation of the technically easier intertrochanteric uni-planar flexion osteotomy is comparable to that of the multi-planar osteotomy. The improvement of abduction is not as good, but the achieved value of 36.4° is still acceptable.

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Figure 1.

Assessment of the degree of slippage (Southwick). A. Standard anteroposterior pelvis for the assessment of inferior slippage (α). B. Frog Leg View for the assessment of posterior slippage (β).

Figure 2.
Compensation of the external rotation (right side) with simulation of an internal rotation of the femur towards an alignment of the knee condyles axis (left side)

Figure 3.
Assessment of center of rotation (right side) Limitation of Range of Motion by bone bone
contact (left side)

Figure 4. Simulation of Osteotomy: A. Positioning of the intertrochanteric plane B. Simulation of Osteotomy C. Flexion D. Valgisation

Table 1

Simulated range of motion before osteotomy

	Flexion	Abduction	Internal Rotation
moderate	14°(± 24°)	18°(± 16°)	22°(± 30°)
severe	4°(± 13°)	6°(± 20°)	8°(± 23°)

Table 2

Improvement of Range of Motion in moderate and severe cases after simulation of the two different osteotomy techniques (Southwick Osteotomy = SO, Griffith Osteotomy = GO)

	Improvement Flexion	Improvement Abduction	Improvement Internal Rotation
moderate			
SO	56° (± 21°)	28° (±13°)	39° (± 26°)
GO	51° (± 18°)	15° (±5°)	34° (± 16°)
severe			
SO	50° (± 19°)	58° (±19°)	61° (± 30°)
GO	57° (± 11°)	33° (±22°)	52° (± 17°)