Effect of Decreasing the Anterior Pelvic Tilt on Range of Motion in Femoroacetabular Impingement

A Computer-Simulation Study

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Background: The influence of pelvic tilt mobility, which can be reproduced in computer-simulation models, is an important subject to be addressed in the understanding of femoroacetabular impingement (FAI) pathophysiology.

Purpose: To use computer-simulation models of FAI cases to evaluate the optimum improvement in hip range of motion (ROM) achieved by decreasing the anterior pelvic tilt and compare the results with the improvement in ROM achieved after cam resection surgery.

Study Design: Controlled laboratory study.

Methods: The pre- and postoperative computed tomography (CT) images from 28 patients with FAI treated with arthroscopic cam resection were evaluated. Using a dynamic computer-simulation program, 3-dimensional models with a 5° and a 10° decrease in anterior pelvic tilt from the supine functional pelvic plane (baseline) were created from the preoperative CT scans. Similar models were constructed for hips before (at baseline) and after cam resection. Improvements from baseline in maximum internal rotation at 45°, 70°, and 90° of flexion were assessed for the 5° change in pelvic tilt, 10° change in pelvic tilt, and cam resection models, and the results were compared for all conditions.

Results: The combination of a 10° change in pelvic tilt and cam resection showed the largest ROM improvement from baseline ($P < .001$). Improvement in internal rotation in the cam resection model was significantly higher compared with the 5° pelvic tilt change model ($P < .001$), while there was no significant difference between the cam resection model and the 10° pelvic tilt change model.

Conclusion: Decreasing anterior pelvic tilt by 10° in the preoperative computer simulation model resulted in an equivalent effect to cam resection, while a 5° change in pelvic tilt was inferior to cam resection in terms of ROM improvement.

Clinical Relevance: Enough of a decrease in anterior pelvic tilt may contribute to ROM improvement that is as effective as that of cam resection surgery.

Keywords: femoroacetabular impingement (FAI); pelvic tilt; computer simulation; cam resection

Femoroacetabular impingement (FAI) is widely recognized as an important pathophysiological cause of hip pain, particularly in young, active patients. Bony impingement between the acetabular and femoral parts of the hip is the principal cause of FAI[9]; however, the actual location of impingement may be difficult to visualize on conventional imaging modalities. Therefore, several studies have used computer-simulation analyses based on computed tomography (CT) models to try to reproduce the mechanical impingement.[5,6,13,24] An advantage of such computer simulation analysis of FAI is that the impingement point can be visualized in different limb positions (with flexion and internal rotation being the typical anterior impingement position),[13] thereby providing the possibility to evaluate improvements in range of motion (ROM) by virtual cam resection,[14] and ultimately providing planning for computer navigation–assisted cam resection.[3,12,26] Thus, computer-assisted methodologies

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can form powerful tools for both clinical and research aspects of FAI treatment.

In terms of the dynamics of the hip joint, the alignment and mobility of the pelvis and spine are important factors.[8,19] With or without cam morphology, hip ROM has been demonstrated to be influenced by pelvic tilt,[23] and pelvic tilt can be influenced by certain kinds of exercise, such as abdominal drawing in[17]; thus, in some cases, it may be possible to improve ROM and possibly activity-related pain through physical therapy. In fact, deliberate physical therapy with consideration for trunk-stabilization exercise was proven to have significant improvement in hip ROM.[2] Clinical questions that arise are as follows: How is the ROM causing impingement influenced by decreasing anterior pelvic tilt in FAI? and Is decreasing anterior pelvic tilt as effective as cam resection in improving ROM in FAI?

The purposes of this study were to evaluate the improvement in ROM achievable by decreasing anterior pelvic tilt in FAI cases using computer-simulation models and to compare the degree of improvement achievable between actual cam resections performed in surgical cases and virtual pelvic tilt change in the same cases. Our hypothesis was that a decrease in anterior pelvic tilt by a given amount may have an equivalent effect to cam resection regarding ROM improvement.

METHODS

In this institutional review board–approved study, 91 consecutive cases of hip arthroscopic surgery performed between April 2014 and September 2018 were retrospectively reviewed. Excluded were patients with no available CT imaging, patients with a history of surgery on the same joint, and non-FAI cases. A total of 63 hips were excluded: 8 had no available pre- or post-CT data, 10 had a history of surgery on the same joint (ie, total hip arthroplasty, osteotomy, or primary arthroscopic surgery), and 45 did not meet any of the diagnostic criteria for FAI on radiograph (ie, borderline dysplasia, synovial osteochondromatosis, labrum tear after trauma, osteonecrosis, or osteoarthritis), leaving 28 hips with evaluations before and after surgery.

The 28 study hips were from 22 male and 6 female patients, with a mean age at surgery of 39.8 years (range, 14-60 years); 26 hips had cam-type FAI and 2 had combined-type FAI. Table 1 shows the characteristics of the study patients. In all cases, a preoperative CT was performed within the 4 months prior to surgery, and postoperative CT was performed within the 2 weeks after surgery.

TABLE 1
Patient Characteristics (N = 28)[a]

Parameter	Value
Age at operation, y, mean (range)	39.8 (14-60)
Male/female, No.	22/6
Body mass index, kg/m^2	23.1 ± 4.3
Preoperative alpha angle, deg	63.9 ± 5.5
Postoperative alpha angle, deg	44.2 ± 11.9
Lateral center-edge angle, deg	32.4 ± 4.7
Baseline FPP tilt (anterior tilt), deg	15.2 ± 5.7

[a]Data are reported as mean ± SD unless otherwise indicated. FPP, functional pelvic plane.

Surgical Procedure

All patients underwent hip arthroscopic surgery performed by a single experienced surgeon (N.K.). All arthroscopic procedures were performed with the patients in a supine and tractioned position. Instruments were inserted via 2 (anterolateral and midanterior portals) or 3 (an additional proximal midanterior portal) portals. Cam resection was performed for all cases, based on virtual cam resections performed using Zed Hip simulation software (LEXI).[12] Briefly, the optimal resection area was determined as the area needed to achieve an improvement in ROM of at least 10° on the virtual cam resection model. In all cases, labral tears were repaired using suture anchors. Pincer resection was added in 2 combined FAI cases.

Radiographic Evaluation

The following radiographic definitions of FAI were used. Cam-type FAI was defined as an alpha angle >55° on the cross-table lateral view or 45° on the flexion Dunn view,[7,27] and a lateral center-edge angle ≥25° on the anteroposterior (AP) pelvic view.[17] This was to exclude the cases with borderline developmental dysplasia of the hip. Pincer-type FAI was defined as a lateral center-edge angle >40° on the AP pelvic view.[15] Combined-type FAI was defined as the presence of both cam and pincer deformities.

CT Imaging

All patients had undergone a CT examination of the pelvis and both femurs in the supine position both preoperatively and postoperatively. The CT images were acquired on a Sensation 16 scanner (Siemens) using a tube voltage of 140 kV, current of 300 mA, and slice thickness of 1.5 mm. The mean duration between preoperative CT and surgery

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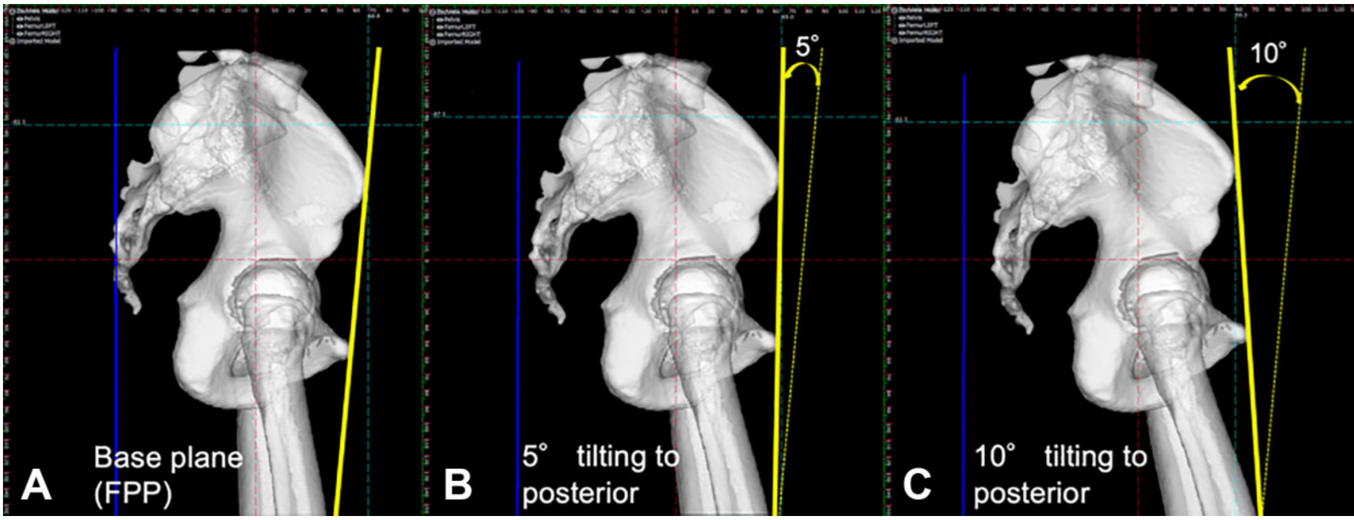

Figure 1. Representative images of the virtual posterior pelvic tilt model. (A) The functional pelvic plane (FPP) in the supine position was used as the baseline pelvic plane, with reference points of the anterior inferior iliac spine and pubic joint. (B) Then, 5° tilting to posterior (decreasing anterior tilt) and (C) 10° tilting to posterior were defined relative to the baseline plane. The yellow lines represent the pelvic tilt.

was 76 days (range, 14-123 days), and the duration between surgery and postoperative CT was 7 days (range, 6-15 days).

3-Dimensional Dynamic Simulation

The 3-dimensional (3D), dynamic-simulation analysis was performed following a previously described method.[13] Briefly, Zed Hip software was used to reconstruct and segment 3D bone models of the pelvis and femur from the CT data in Digital Imaging and Communications in Medicine format. In this study, the functional pelvic plane (FPP) in the tabletop supine position was used as the baseline pelvic plane, with this model being reconstructed from the reference point of the anterior inferior iliac spine and pubic joint (anterior pelvic plane [APP]). For the femoral plane, reference points around the femoral head on the axial and sagittal planes were used to define the femoral head center. Also identified were points on the medial/lateral epicondyles and posterior condyles, knee center, greater trochanter tip, and lesser trochanter. Next, coordinate systems in which the pelvis was tilted posteriorly (decreasing anterior pelvic tilt) by 5° or 10° from the baseline FPP were reconstructed (Figure 1).

Using a 3D dynamic simulation created on Zed Hip, we identified the impingement points between the acetabular rim and femoral head-neck junction during internal rotation at 45°, 70°, and 90° of flexion with 0° of adduction, and we evaluated the maximum internal rotation causing impingement on the femoral head-neck junction (Figure 2). The same simulation was conducted for a cam resection model based on the postoperative CT data. In each case, the tilt angle of the baseline reference plane in the FPP was completely adjusted to the preoperative CT data. The change in maximum internal rotation from pre- (baseline) to postoperatively was measured at 45°, 70°, and 90° of flexion.

Statistical Analysis

Using the Wilcoxon signed-rank test and Bonferroni test for multiple comparisons, we compared the difference in maximum internal rotation between baseline and each pelvic tilt change model, the cam resection model, and combination models with pelvic tilt change (5° and 10°) and cam resection in each condition (45°, 70°, and 90° of flexion). The improvement from baseline in maximum internal rotation in each condition was compared between each pelvic tilt change model and the cam resection model using the Wilcoxon signed-rank test. Statistical analyses were performed using R Version 3.0.2 software (R Foundation for Statistical Computing). $P < .05$ defined a significant difference.

RESULTS

The mean anterior tilt of baseline FPP in the supine position was 15.2° when an APP of 0° was used as a reference. The mean alpha angle significantly decreased from 63.9° preoperatively to 44.2° postoperatively ($P < .001$). Compared with the baseline FPP, maximum internal rotation improved significantly ($P < .001$) at each flexion angle in both the posterior pelvic tilt model and the cam resection model (Figure 3). Among all the conditions tested, the combination of a 10° change in pelvic tilt and cam resection showed the largest improvement in ROM.

The improvement from baseline in maximum internal rotation was compared between the cam resection model and both the 5° pelvic tilt change model (Figure 4) and the 10° pelvic tile change model (Figure 5). After a 5° change in

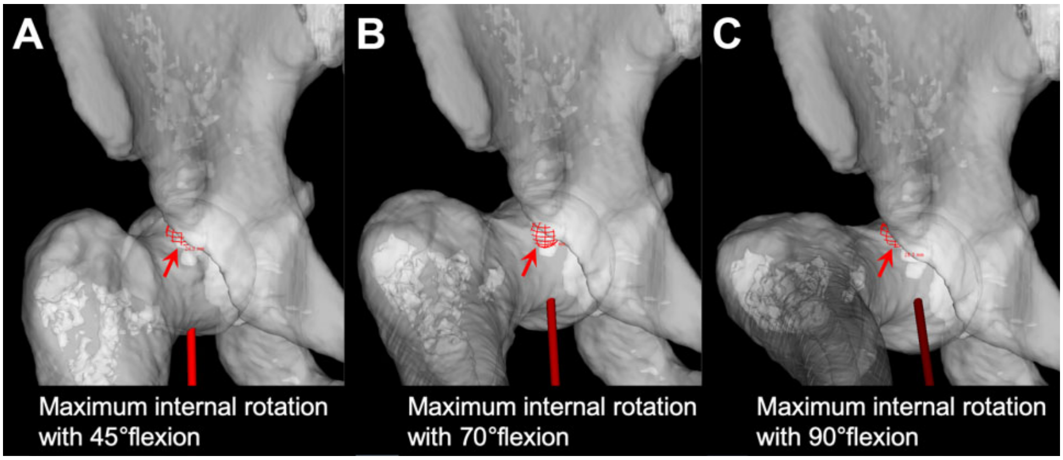

Figure 2. Representative images of the 3-dimensional dynamic simulations of a right hip at each flexion condition: (A) 45°, (B) 70°, and (C) 90°. The red arrows indicate impingement points on the femoral head-neck junction. The red bars indicate the femoral alignment in each condition.

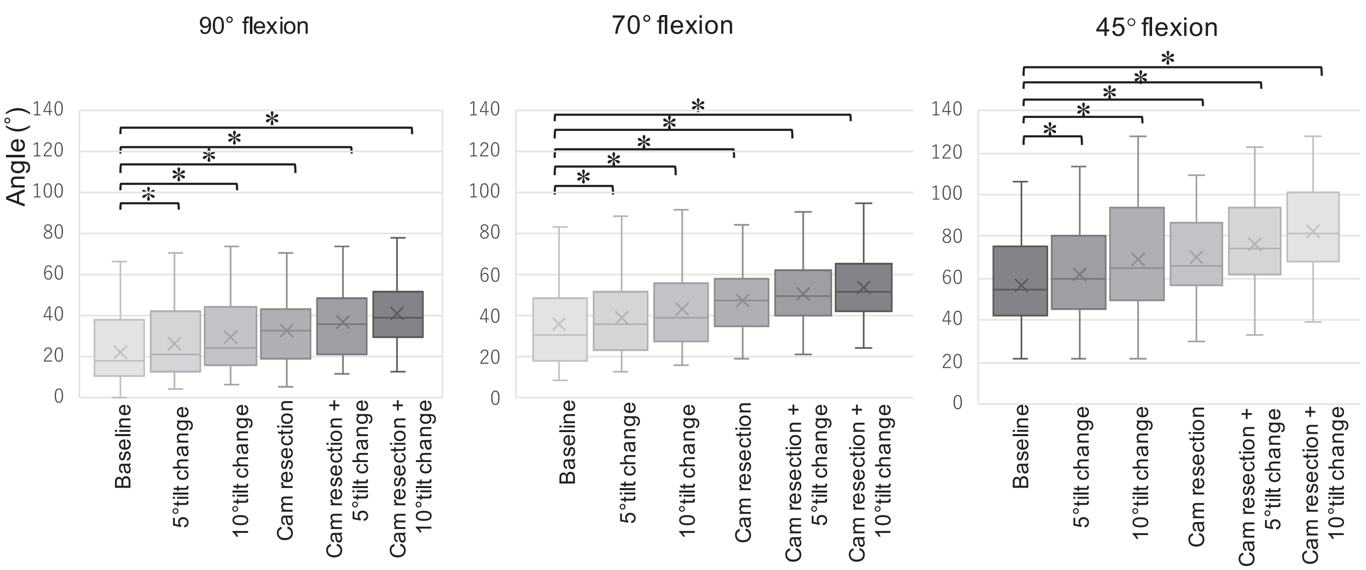

Figure 3. Maximum internal rotation at 45°, 70°, and 90° of flexion for the pelvic tilt change, cam resection, and combined models. In all 3 flexion conditions, the combination of a cam resection with a 10° pelvic tilt change showed the largest internal rotation. The shadow boxes indicate the interquartile range, the middle line indicates the median, the X indicates the mean, and the whiskers indicate the range. *$P < .001$ compared with baseline.

pelvic tilt, the mean internal rotation improvement over baseline was 3.3° at 90° of flexion, 3.6° at 70° of flexion, and 4.8° at 45° of flexion. After a 10° change in pelvic tilt, the mean improvement in internal rotation was 6.5° at 90° of flexion, 7.7° at 70° of flexion, and 11.5° at 45° of flexion. By comparison, the mean improvement in internal rotation after cam resection was 10.2° at 90° of flexion, 11.5° at 70° of flexion, and 12.8° at 45° of flexion. The improvement in the internal rotation of the cam resection model was significantly higher than that of the 5° pelvic tilt change model ($P < .001$) (Figure 4), while there was no significant difference between the cam resection model and the 10° pelvic tilt change model (Figure 5).

DISCUSSION

The most clinically relevant finding of this simulation study is that decreasing anterior pelvic tilt by 10° is as effective for improving ROM as actual cam resection by hip arthroscopy. Although decreasing anterior pelvic tilt by 5° did improve hip ROM, it was not as effective as cam resection. The most desirable result was achieved when both conditions were applied: that is, when enough pelvic tilt change was applied after cam resection. A strength of our simulation study is that we analyzed both pre- and postoperative bone models reconstructed from actual surgically treated cases. This setting enabled us to compare the effect of pelvic

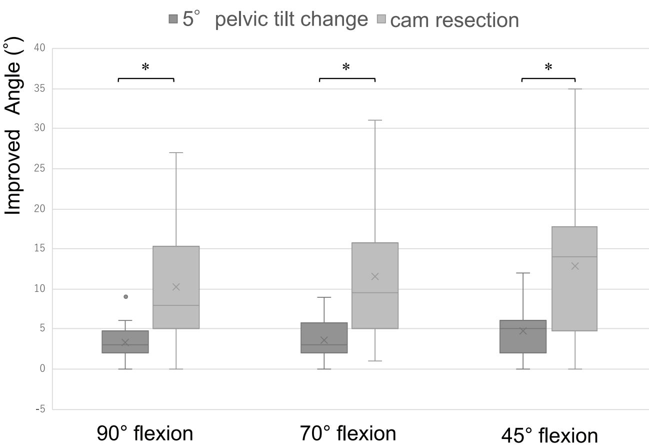

Figure 4. Improvement in maximum internal rotation at 45°, 70°, and 90° of flexion between the 5° pelvic tilt change model and the cam resection model. For each flexion angle, the cam resection group showed significantly higher improvement than the 5° pelvic tilt change group. The shadow boxes indicate the interquartile range, the middle line indicates the median, the X indicates the mean, and the whiskers indicate the range. The dot indicates an outlier. *Statistically significant difference ($P < .001$).

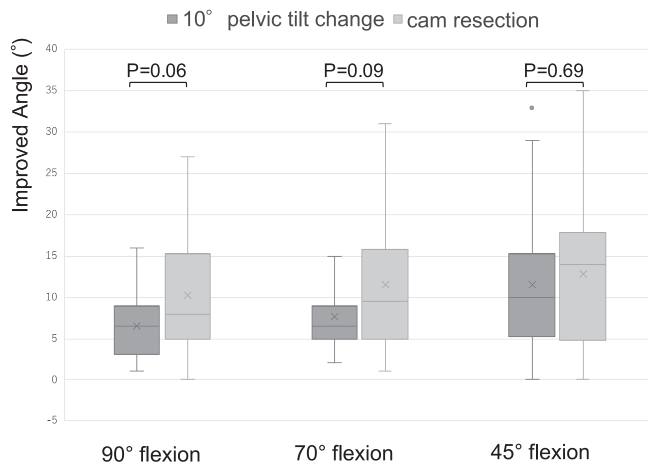

Figure 5. Improvement in maximum internal rotation at 45°, 70°, and 90° of flexion between the 10° pelvic tilt change model and the cam resection model. There were no significant differences between the groups at any flexion angle. The shadow boxes indicate the interquartile range, the middle line indicates the median, the X indicates the mean, and the whiskers indicate the range. The dot indicates an outlier.

tilt change and actual cam resection in each individual. Although these findings were obtained in a computer simulation, they will nevertheless contribute to an understanding of both conservative and operative treatment for FAI.

Pelvic mobility and biomechanics have been recognized as important factors in the FAI pathomechanism.[4,11,19] In fact, functional acetabular alignment varies depending on the patient's position, such as supine or standing, which directly affects the ROM.[22] Furthermore, active pelvic tilt, which is the anterior-to-posterior arc of motion, is reduced in athletes with groin injuries in comparison with the noninjured side and healthy controls.[25] Our current results in an FAI population showed that the baseline pelvic tilt was inclined approximately 15° anteriorly in the supine position, resulting in less ROM to anterior impingement compared with the anatomic flat zero position in the APP. This suggests that FAI cases are susceptible to anterior impingement in terms of pelvic alignment in the supine position. In addition, anterior pelvic tilt is known to be associated with a greater risk of cam morphology.[16] Thus, to understand the condition of FAI, it is important to consider pelvic alignment, which was the first motivation behind our current study. It must be noted that ROM improvement is not a true target of FAI treatment and does not directly link to the resolution of FAI conditions, because the substantial mechanism of FAI is shear stress at cartilage during engagements of acetabulum and cam morphology.[1] Nevertheless, ROM until occurring bony impingement is an approachable parameter of the FAI condition.

One of the easiest-to-comprehend methods for reproducing the bony impingement situation is a computer-simulation analysis based on CT imaging. Bedi et al[6] reported that the location of impingement was unique in each of their examined cases and was not predictable on the basis of radiographic measures alone. Similarly, the distribution of impingement points shows wide variation in FAI cases.[13] Dynamic computer-assisted evaluations have been used not only for preoperative evaluations but also for postoperative evaluations, including examination of residual deformities.[20] Such computer-simulation studies are valuable in terms of visualizing the actual impingement point, which is difficult using only conventional radiographic modalities. However, a serious limitation of these previous studies is that the variation in pelvic tilt and its mobility are not well-considered. In addition, CT imaging does not account for the labrum, so the actual impingement may occur sooner than where the bony impingement is confirmed on CT modeling.

Ross et al[21] conducted a simulation study to evaluate how dynamic change in pelvic tilt affected the ROM to impingement in FAI cases. They demonstrated that anterior pelvic tilt induced earlier occurrence of anterior impingement, while posterior pelvic tilt resulted in later occurrence of impingement by computer-simulation analysis. The fact that relatively small changes in pelvic tilt had a significant influence on the FAI condition was an important finding. In the current study, we focused on a comparison between impingement with pelvic tilt change without cam resection (preoperatively) and impingement after cam resection (postoperatively) without pelvic tilt change. This comparison was intended to represent the clinical treatment methods of physical therapy–based improvement of pelvic mobility and cam resection by surgery.

Decreasing anterior pelvic tilt with 10° of pelvic tilt resulted in an effect on impingement equivalent to that of actual cam resection. However, it should be noted that this is the result from the computer-simulation mode; therefore, we need careful interpretation in a clinical setting. A previous randomized controlled trial revealed that hip arthroscopy still led to a greater improvement than conservative care for the treatment of FAI.[10] It is difficult to determine the degree of pelvic tilt change that can be brought about by physical therapy. In this regard, Oh et al[17] reported that an abdominal drawing-in maneuver during a prone hip extension exercise could significantly decrease anterior pelvic tilt from $10^\circ \pm 2^\circ$ to $3^\circ \pm 1^\circ$. This indicates that appropriate exercise could realistically induce pelvic mobility around 7°. Similarly, Park et al[18] reported that an active prone knee flexion exercise improved an anterior pelvic tilt by around 4°. Thus, we assume that a change in pelvic tilt of between 5° and 10° after effective physical therapy is realistic in a clinical situation. Nevertheless, the actual improvement in pelvic mobility by physical therapy is still unclear. Further clinical studies are needed to clarify the actual change in pelvic tilt after rehabilitation or cam resection and to investigate whether the improvements in pelvic tilt with physical therapy can be maintained over time. In addition, we should consider the possibility of some negative effect, such as posterior impingement or lumbar spine problems, due to decreasing anterior pelvic tilt.

There are several limitations in this study. First, again, our simulation study did not enhance the actual pelvic mobility in each individual. This is needed to reveal the actual change of pelvic tilt by physical therapy. Second, although the pre- and postoperative CT models for each case were obtained from the same individual, they were from independently acquired CT data at different time points. Furthermore, the difference in pelvic tilt between the supine and standing positions[22] is not considered in our study. Standing pelvic tilt results in posterior pelvic tilt and later occurrence of FAI in the arc of motion.[22] However, we unified the simulation settings as far as possible, including the baseline pelvic position at a functional supine position in each individual. Finally, our dynamic simulation did not consider the influence of soft tissue, including the labrum or joint capsule. This is a fundamental limitation in the study based on CT-based, computer-simulation study.

CONCLUSION

We conducted a computer-simulation study to evaluate the effect of decreasing anterior pelvic tilt by comparing it between pre- and postoperative FAI cases. A decreasing anterior pelvic tilt change of 10° in the preoperative model resulted in an equivalent effect to that of cam resection in the postoperative model, while a pelvic tilt change of 5° was inferior to cam resection, at least in terms of ROM improvement based on computer simulation.

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