The association between femoroacetabular impingement and sitting positions: A three-dimensional simulation study

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The association between femoroacetabular impingement and sitting positions: A three-dimensional simulation study

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Abstract: *To investigate the relationship between femoroacetabular impingement (FAI) and different sitting positions. We retrospectively reviewed 24 patients with FAI. Femoral and pelvic parameters were measured, and 3D simulation software was used to create and analyze a 3D model of the hip. The data were divided into impingement and non-impingement groups according to whether impingement occurred in the normal or cross-legged sitting positions. The parameters were compared between these groups, and the effect of each parameter on impingement volume was estimated. Femoral anteversion and the difference in sacral slope (SS) between standing and sitting positions (ΔSS) were significantly lower in the impingement group than in the non-impingement group (both $p<0.05$). Alpha angle, sacral slope in the sitting position (sitting-SS), and femoral flexion angle (FFA) were significantly higher in the impingement group than in the non-impingement group ($p<0.05$, $p<0.01$, and $p<0.05$, respectively). Femoral neck shaft angle (FNSA) correlated with impingement volume in the normal sitting position ($r=0.602$ $p<0.01$). FNSA, SS, and FFA correlated with the impingement volume in the cross-legged sitting position ($r=0.409$, $p<0.05$; $r=-0.438$, $p<0.05$; $r=0.420$, $p<0.05$, respectively).Our simulation study demonstrated that, during normal and cross-legged sitting positions, FAI patients with increased sitting-SS, alpha angle, and FFA as well as decreased ΔSS and femoral anteversion were more likely to have impingement. These findings suggest that FAI patients with increased alpha angle and sitting-SS as well as decreased ΔSS and femoral anteversion should avoid excessive femoral flexion during sitting and cross-legged sitting positions.*

Keywords: *femoroacetabular impingement, 3-D computer simulation, hip, acetabulum, morphology, sitting position*

1. Introduction

Femoroacetabular impingement (FAI) is a motion-related clinical disorder of the hip characterized by an abnormal contact between the bones of the hip joint that may lead to articular damage and hip pain in non-dysplastic hips [1]. It is one of the primary causes of early hip osteoarthritis in young and active adults aged 15-50 years [1-4]. It is also most commonly diagnosed in active adults who have sustained repetitive collisions during hip motions. Based on its bony morphological changes, FAI is subdivided into the following three classifications: the cam-type, which is caused by proximal femur deformity; the pincer-type, which is caused by acetabular overcoverage; and the mixed-type, in which both cam-type and pincer-type are seen in the same hip [2,5].

With deeper understanding of the morphological alterations in the hip joint, it has become clear that the dynamic impingement between the proximal femur and the acetabulum may lead to cartilage and labral damage [6]. Such a dynamic impingement depends not only on the anatomic variations of the proximal femur and acetabulum but also on the motion of the hip joint. In particular, excessive flexion and internal rotation of the hip may be responsible for FAI development and has been associated with its clinical symptoms [7]. While patients often experience acute pain during a sporting activity, hip pain is most commonly experienced in the sitting position [8]. In daily life, as more jobs become desk-based, a growing number of people are spending long periods in the sitting position. It has been found that adults spend at least 8 hours per day in the sitting position [9]. In combination with the time sitting at home or elsewhere, the time spent in the sitting position will be even greater. Although the normal and

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cross-legged sitting positions (crossing one leg over the other) are the most common sitting positions, both positions involve hip joint flexion, especially the cross-legged sitting position, which requires excessive flexion and internal rotation of the hip joint, increasing the risk of the development of labral and cartilage lesions in patients with FAI. Therefore, performing a computer simulation and analysis of the relationship between different sitting positions and FAI could help clarify the causes of hip pain and its prevention.

To the best of our knowledge, previous reports on FAI studies are mainly focused on abnormal morphologies [10-13], but few reports on the relationship between different sitting positions and FAI have been published. To improve the understanding of FAI, three-dimensional (3D) simulation methods have been developed for evaluating the association between FAI and sitting positions. The purposes of this study were as follows: (1) to investigate the relationship between the different sitting positions and risk factors of FAI; and (2) to investigate the relationship between impingement volume and related factors during normal and cross-legged sitting positions using computer-assisted 3D simulation software.

2. Methods

2.1 Participants

The Hamamatsu University School of Medicine Hospital Institutional Review Board approved this study (the approval number: No. 19-335). The requirement for obtaining informed consent from the patients was waived due to the retrospective nature of the study. Clinical data were retrospectively retrieved from a database-maintained institutional inpatient registry of consecutive patients who had undergone hip arthroscopy for the treatment of FAI between April 2015 and March 2018. The inclusion criteria were limited to patients with unilateral symptomatic FAI in the absence of significant chondral degeneration. The exclusion criteria included prior hip arthroscopy or surgery, hip dysplasia, hip osteoarthritis (Tönnis grade >1), spine deformity (e.g., scoliosis, kyphosis, lordosis, spondylolisthesis, degenerative disc disease), musculoskeletal abnormality, and major lower limb and spinal injuries. A total of 24 consecutive patients (mean age, 26.04 years; range, 13-68 years) met the inclusion criteria. Patients' demographics, including age, sex, weight, height, and body mass index (BMI), were collected and reviewed.

2.2 Imaging measurements

Radiographic views included a lateral pelvis-hip view in the standing and sitting positions. Sacral slope (SS), pelvic incidence (PI), and pelvic tilt (PT) were obtained from the lateral pelvis-hip radiographs in the standing positions. Sacral slope in the sitting position (sitting-SS) and femoral flexion angle (FFA) were obtained from the lateral pelvis-hip radiographs in the sitting position, and the difference between the standing and sitting-SS (ΔSS) was used as a measure of pelvic motion. Computed tomography (CT) imaging was performed with a standard helical scanner in all cases. CT examination of the pelvis and the proximal and distal femur was performed. The alpha angle, lateral center-edge angle (LCEA), acetabular version (AV), femoral anteversion, femoral neck shaft angle (FNSA), and SS in the supine position (supine-SS) were measured on the CT images (shown in Figure 1).

2.3 3D simulation

The CT imaging data were reconstructed with software (Mimics 20.0; Materialise) to create 3D computer models of each hip. The 3D model of each hip was loaded in software (3-Matic 12.0; Materialise) to construct the femur and pelvis. Once the femur and pelvis were established, the 3D models were placed in the supine and simulated normal and cross-legged sitting positions, and the impingement between the proximal femur and acetabulum was assessed (shown in Figure 2). When we simulated the impingement, the difference between the sitting and supine positions was also considered. The pelvis was fixed in the predefined position, and the femur was free to move to simulate the following two activities: (1) normal sitting position (the hip in 90° flexion plus the FFA and the difference in SS between the sitting and supine positions), and (2) cross-legged sitting position (the hip in 90° flexion plus 20°, the FFA, the difference in SS between the sitting and supine positions, and 30° adduction). According to the result of the analysis, all data were divided into the following two groups: impingement and non-impingement groups. The bone-to-bone overlapping volume of the impingement

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was also calculated.

2.4 Statistical analysis

Descriptive statistics summarizing patient demographics were presented as means, standard deviations, ranges, and percentages where appropriate. Categorical variables were analyzed with the Fisher's exact test, data normality with the Kolmogorov-Smirnov test, and unequal variances with the Levene's test. Differences in patient demographics between the two groups were analyzed with independent samples t-tests and those in morphological parameters between the two groups with the Mann-Whitney U test, with $p<0.05$ indicating statistical significance. A correlation analysis was performed to examine the relationship between morphological parameters and impingement volume, using the Pearson's linear correlation coefficient. All analyses were conducted using SPSS software (version 25.0; IBM).

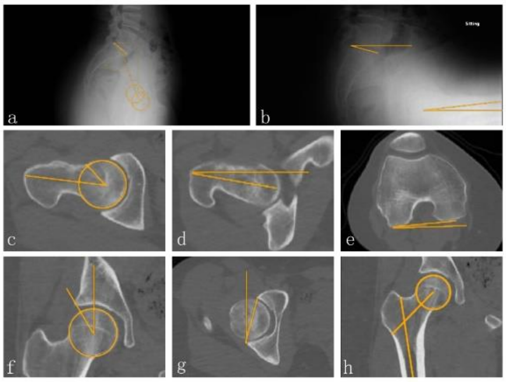

Figure 1. a–h. X-ray and computed tomography (CT) parameters including sacral slope (SS), pelvic incidence (PI), and pelvic tilt (PT) in the standing position (a); sacral slope in the sitting position (sitting-SS) and femur flexion angle (FFA) (b); alpha angle (c); and neck (NH) (d) and condyle horizontals (CH) (e) for femoral anteversion; lateral center-edge angle (LCEA) (f) acetabular version (AV) (g); femoral neck shaft angle (FNSA) (h).

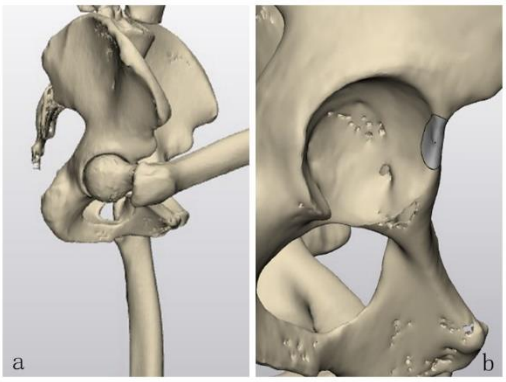

Figure 2. The 3D model in the sitting position (a) and impingement volume (gray segment) (b).

Table 1. Demographic data of patients in the impingement and non-impingement groups

	Group 1	Group 2	p
Age (years)	41.85±13.48	28.91±14.68	0.021*
Height (cm)	167.93±9.38	156.22±10.39	0.008*
Weight (kg)	64.14±12.58	52.26±10.57	0.035*
BMI (kg/m^2)	21.53±3.37	21.31±3.13	0.873
Male/female	5/8	7/4	0.414
Group 1: impingement group (N=13) Group 2: non-impingement group (N=11)			

Abbreviations: BMI, body mass index

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Table 2. Parameters in the impingement and non-impingement groups

Parameter	Group 1	Group 2	p
Alpha angle	55.21±3.03	50.80±5.38	0.015*
LCEA	32.41±5.86	35.32±6.22	0.277
AV	20.30±7.74	19.07±6.85	0.569
Femoral anteversion	-9.65±12.08	3.49±12.44	0.018*
FNSA	130.87±9.53	127.08±7.76	0.569
PI	52.31±5.93	47.93±8.83	0.228
PT	12.13±4.81	10.57±5.31	0.494
SS	40.13±6.02	37.43±5.76	0.207
ΔSS	22.93±10.10	35.67±14.72	0.03*
Sitting-SS	17.20±9.705	1.76±15.08	0.009**
FFA	3.57±3.98	-1.72±4.76	0.015*
Group 1: impingement group (N=13) Group 2: non-impingement group (N=11)			

Abbreviations: LCEA, lateral center-edge angle; AV, acetabular version; FNSA, femoral neck shaft angle; PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope; ΔSS, difference between the standing and sitting sacral slopes; sitting-SS, sacral slope in the sitting position; FFA, femoral flexion angle.

Table 3. Coefficients of the correlation between the morphological parameters and impingement volume (N=24)

Parameters	Impingement volume Normal sitting position		Impingement volume Cross-legged sitting position	
	r	p-value	r	p-value
Alpha angle	0.031	0.886	0.207	0.331
LCEA	-0.188	0.379	-0.262	0.217
AV	0.170	0.427	-0.114	0.597
Femoral anteversion	-0.204	0.338	-0.189	0.376
PI	-0.276	0.192	-0.081	0.707
ΔSS	-0.170	0.427	-0.438	0.033*
Sitting-SS	0.097	0.654	0.318	0.129
FNSA	0.602	0.002**	0.409	0.047*
SS	-0.158	0.460	-0.237	0.264
PT	-0.230	0.280	0.154	0.472
FFA	0.320	0.127	0.420	0.041*

Abbreviations: LCEA, lateral center-edge angle; AV, acetabular version; FNSA, femoral neck shaft angle; PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope; ΔSS, difference between the standing and sitting sacral slopes; sitting-SS, sacral slope in the sitting position; FFA, femoral flexion angle

3. Results

This study retrospectively reviewed the collected data of 24 patients with FAI (12 men, 12 women; mean age of 36.04 years (range, 13 to 68 years)). There were 13 and 11 patients in the impingement and non-impingement groups, respectively. The demographic characteristics of both groups are summarized in Table 1. BMI and sex were not statistically significantly different between the two

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groups. The patients in the impingement group were significantly older and taller and had greater weight than those in the non-impingement group. The values of the morphological parameters are shown in Table 2. The LCEA, femoral anteversion, AV, FNSA, PI, PT, and SS were not significantly different between the two groups. The femoral anteversion and ΔSS were significantly smaller in the impingement group than in the non-impingement group ($p<0.05$ and $p<0.05$, respectively). The alpha angle, sitting-SS, and FFA were significantly larger in the impingement group than in the non-impingement group ($p<0.05$, $p<0.01$, and $p<0.05$, respectively). The relationships between the morphological parameters and impingement volume are shown in Table 3. The FNSA correlated with the impingement volume in the normal sitting position. The FNSA, ΔSS, and FFA correlated with the impingement volume in the cross-legged sitting position.

4. Discussion

In the current study, we demonstrated the relationship between the different sitting positions and FAI. BMI and sex were not statistically and significantly different between the two groups. Age, weight, and height in the impingement group were significantly higher than those in the non-impingement group. This may indicate that, although the age, weight, and height differed between the non-impingement and impingement groups, their BMI did not vary, and the 3D simulation was therefore not affected. The results demonstrate that in the normal and cross-legged sitting positions, increased alpha angle, SS-sitting, and FFA, as well as decreased ΔSS and femoral anteversion, were the main predictors of impingement. By performing a 3D impingement simulation, we found that the FNSA was correlated with the impingement volume in the normal sitting position. The FNSA, ΔSS, and FFA were correlated with the impingement volume in the cross-legged sitting position.

In this study, one of the most important findings was that the abnormalities of femoral anteversion significantly affect the FAI during different sitting positions, even in the absence of a cam- or a pincer-type morphology. Although femoral anteversion affecting FAI is not a new concept [14,15], both increased and decreased femoral anteversion are shown to be closely related to osteoarthritis of the hip [16,17]. Recently, femoral anteversion is becoming more recognized as a contributing factor to FAI development. However, the contribution of femoral anteversion in patients with FAI remains controversial. Lall et al. reported in their study, with a minimum 5-year follow-up, that the clinical outcomes of patients with decreased femoral anteversion was not different from those of patients with normal femoral anteversion after hip arthroscopy for FAI [18]. Ferro et al. also reported a similar result [19]. In contrast, Lerch et al. reported that decreased femoral anteversion may be one of the factors causing FAI [20]. Although many articles reported that femoral anteversion affected FAI, including that of Satpathy et al., who conducted a biomechanical study [21], there are few 3D simulation studies that have been published. Moreover, whether decreased femoral anteversion is correlated with FAI in the sitting position is less reported. Therefore, we evaluated the hips in the different sitting positions by performing a 3D simulation and investigated the relationship between the different sitting positions and FAI. Most importantly, it is shown from the results of the simulation analysis of normal and cross-legged sitting positions that decreased femoral anteversion was the main determinant for predicting impingement.

From the result, we also noticed that the increased alpha angle was the other main determinant for predicting the differences in the sitting position. The alpha angle was one of the most important parameters of FAI, and it is commonly used to describe the cam-type morphology. However, there were few related studies about the relationship between the alpha angle and sitting position. Urquhart et al. reported in their meta-analysis that the alpha angle was restored to less than 55° in cam-type FAI by surgery, resulting in improved patient outcomes [22]. Our study shows that the increased alpha angles may result in increased impingement risk in the different sitting positions.

In this study, ΔSS, sitting-SS, and FFA were the other main determinants for predicting the differences in sitting position during the impingement simulation. Previous studies have examined the combined effects of different hip morphological features on impingement. However, little attention has been paid to the relationship between SS and FAI in different sitting positions. PT and SS have all been used to quantify sagittal balance [23]. The FFA is reflective of the hip joint flexion degree in the sitting position. During the transition from standing to the sitting position, SS decreased to as low as 0° or even to negative values, depending on the individual’s morphology [24,25]. In this study, compared to the non-impingement group, the impingement group had a significantly higher sitting-SS and FFA and a lower ΔSS in the normal and cross-legged sitting positions. It is clear that the increased sitting-SS resulted in decreased ΔSS, resulting in anterior PT, which led to the increased femoral head coverage

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and increased FFA that exacerbated the relative anterior pelvic tilt, and subsequently led to an increased risk for developing FAI. The result contributes to furthering our understanding of the mechanisms of FAI during different sitting positions, in particular, the knowledge that increased sitting-SS protects the hip joint from impingement and decreased sitting-SS accelerates the development of impingement, which could be applied to the management of FAI patients.

By performing the 3D impingement simulation, not only did we find the correlation of FNSA with the impingement volume in the sitting position, but also did observe the correlation of FNSA, ΔSS, and FFA with the impingement volume in the cross-legged sitting position. In the impingement simulation, we noticed that the impingement volume was correlated with FNSA. However, whether the increase or decrease in the FNSA was correlated with the impingement remains controversial. Ng et al. reported that patients with decreased FNSA are at a risk of symptomatic FAI [26]. Conversely, Vallon et al. reported that FAI occurs in both increased or decreased FNSA [27]. In this study, we found that FNSA was correlated with the impingement volume during normal and cross-legged sitting positions. These results show that the FNSA deformity might be a mechanical factor that could contribute to the impingement volume. We also found that the ΔSS and FFA are reflective of the impingement volume. Regarding ΔSS, it is necessary to understand that ΔSS corresponds to the lumbar-sacral-pelvic joint range of motion, which might reflect the function of the hip joint [28]. Our results suggest that FAI patients with increased sitting-SS may have decreased ΔSS, which could result in femoral head overcoverage. The increased FFA exacerbated the situation in the normal and cross-legged sitting positions, which might cause FAI. Conversely, FAI patients with decreased sitting-SS have an increased ΔSS and a large pelvic motion, which could be considered as a compensatory mechanism against FAI, especially in the cross-legged sitting position. This is consistent with the results of other studies [7,29].

Despite the encouraging findings, this study had some limitations. First, the patients reviewed were from only one university hospital, the number of subjects was relatively small, and all subjects were ethnically homogeneous. Second, we performed a 3D simulation in this study; therefore, our study does not consider the soft tissue or cartilaginous components of the junction in the sitting positions, which is an inescapable fact when CT scans are used. Third, the alpha angle was assessed in only one position, and the femoral head deformity was not evaluated sufficiently. Fourth, cam- and pincer-type morphologies were not investigated in this study. These morphological classifications could be considered in future studies. Finally, the actual clinical findings of the patients were not considered. Despite these limitations, we believe that these results could contribute not only to understand FAI in the different sitting positions but also to determine the relationship between the impingement volume and related factors during normal and cross-legged sitting positions.

5. Conclusion

Our simulation study demonstrated that, during normal and cross-legged sitting positions, FAI patients with increased sitting-SS, alpha angle, and FFA as well as decreased ΔSS and femoral anteversion were more likely have impingement. In the normal sitting position, the impingement volume may be correlated with FNSA, whereas in the cross-legged sitting position, the impingement volume may be correlated with the FNSA, ΔSS and FFA. These findings suggest that FAI patients with increased alpha angle and sitting-SS as well as decreased ΔSS and femoral anteversion should avoid excessive femoral flexion during sitting and cross-legged sitting positions.

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