Orthopaedics & Traumatology: Surgery & Research 105 (2019) 23–28

Contents lists available at ScienceDirect

Orthopaedics & Traumatology: Surgery & Research

journal homepage: www.elsevier.com

Original article

Influence of hip center position, anterior inferior iliac spine morphology, and ball head diameter on range of motion in total hip arthroplasty

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ARTICLE INFO

Article history:
Received 14 April 2018
Accepted 13 September 2018

Keywords:
Total hip arthroplasty
Computer tomography
Range of motion
Bony impingement

ABSTRACT

Background: Acetabular component orientation, such as high placement and femoral head diameter influence joint stability in total hip arthroplasty (THA), wherein anterior inferior iliac spine (AIIS) shape could cause femoro-acetabular impingement. Little is known regarding the combined influence of these parameters, particularly in the context of developmental dysplasia of the hip. Therefore we conducted a computer simulation study based on computed tomography (CT) data to determine whether: (1) AIIS shape, (2) high placement of acetabular cups, and (3) ball head diameter influence the range of motion (ROM) after THA.

Hypothesis: The decrease in ROM depends on AIIS shape and the ROM decreases even if the femoral head diameter is increased when high placement of acetabular cups.

Patients and methods: CT data from 14 hips of 14 patients were evaluated. Hips were categorized by Hetsroni classification type I ($n = 6$), type II ($n = 6$), and type III ($n = 2$) depending on AIIS shape. ROM was evaluated using CT-based software. Cups were placed at and 5 and 10 mm above the normal hip position. The femoral heads used were 28 (standard simulation), 32, and 36 mm in diameter. ROM at impingement was measured under flexion (Flex), internal rotation (IR) at 90° flexion (IR at 90Flex), IR at 45° flexion with a 20° adduction (IR at 45Flex20Add), and external rotation at 10° extension (ER at 10Ext).

Results: The mean ROM standard simulation for Flex, IR at 90Flex, IR at 45Flex20Add and ER at 10Ext were: 119.8 ± 5.4°, 31.0 ± 11.3°, 70.0 ± 11.9°, and 33.0 ± 9.7° for type I; 118.5 ± 5.5°, 31.5 ± 2.9°, 71.3 ± 2.2°, and 33.3 ± 3.3° for type II; and 105.5 ± 13.4°, 21.0 ± 15.6°, 61.0 ± 11.3°, and 34.5 ± 2.1° for type III, respectively. There were no significant differences in the ROMs of each type (Flex, $p = 0.252$; IR at 90Flex, $p = 0.461$; IR at 45Flex20Add, $p = 0.261$; and ER at 10Ext, $p = 0.655$). For the high placement of acetabular cups, ROM increase was restricted despite the femoral head diameter increase.

Discussion: Larger femoral head diameters increased ROM, with a lower increase in type III because of bony impingement. ROM decreased with higher cup placement. Expansion effects were minimal, even with larger ball head diameters, and were further decreased in types II and III. Attention should be paid to AIIS shape because bony impingements occur early with higher acetabular cup placement.

Level of evidence: VI Simulation study.

1. Introduction

Total hip arthroplasty (THA) has various complications, with postoperative dislocation being one of the most important and frequent. There are reports that postoperative dislocation is the most common complication requiring revision surgery [1]. Dislocation is related to various factors, including surgical approach, implant design, soft tissue condition, patient age, and diagnosis. Of these factors, it has been reported that nearly 30% of dislocations were caused by implant malposition [2,3]. Therefore, accurate placement of the implant is important for providing maximum range of motion (ROM) and resistance to dislocation. Reina et al. defined the optimal positioning windows of the safe zone for cup position as a 40–50° inclination and 15–30° anteversion [4].

It has already been reported that the implantation of the cup in the normal anatomical hip center is advantageous with respect to increasing ROM and decreasing stress on the load-bearing surface [5]. Watts et al. reported the placement of acetabular components

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https://doi.org/10.1016/j.otsr.2018.09.021

in an anatomic position to promote long-term durability after THA [6]. There are several reports that superior positioning of the acetabular component, even without lateral displacement, leads to increased rates of the femoral and acetabular component loosening [7]. On the other hand, a long-term result of THA could be the expected proximal positioning of the acetabular component without lateral displacement [8,9].

The high placement of the acetabular cup, causes a difference in the bony anatomy surrounding it. In particular, the anterior inferior iliac spine (AIIS) becomes a bony protuberance adjacent to the cup, similar to a residual osteophyte. Because the AIIS is located along the front upper side of the acetabular cup, it may cause dislocation due to impingement during flexion and internal rotation. However, as the rectus femoris muscle is attached to the AIIS, it cannot be excised easily because it is the source of the force for flexion of the hip joint. The AIIS has been found to have several different shapes. Hetsroni et al. classified the morphology of the AIIS into three groups [10]. To the best of our knowledge, there are no reports considering both the variations in AIIS shape and high placement of the acetabular cup.

Increasing the diameter of the ball head expands the oscillation angle and jumping distance, and has the potential to achieve maximum ROM and resist dislocation after THA [11,12]. The tendency to use a larger ball head diameter (32 mm or 36 mm) is seen worldwide [13]. However, to our knowledge, there are no experimental reports on the effect of ball head diameter, assuming high placement of the acetabular cup particularly in the context of developmental dysplasia of the hip. Therefore we conducted a computer simulation study based on computed tomography (CT) data to determine whether:

- AIIS shape;
- high placement of acetabular cups and;
- ball head diameter influence the range of motion (ROM) after THA.

We hypothesized the decrease in ROM depends on AIIS shape and the ROM decreases even if the femoral head diameter is increased when high placement of acetabular cups.

2. Patients and methods

2.1. Patients

This study included 14 patients with disordered hip joints that were affected by rheumatoid arthritis, idiopathic osteonecrosis of femoral head, and osteoarthritis with fewer morphological abnormalities. Patient demographic data are presented in Table 1. All patients completed CT scans of their hip joints, from the iliac crest to the knee joint and through the distal femoral condyles using a 320-row multi-detector helical CT scanner (Aquilion ONE; Toshiba Medical Healthcare, Tochigi, Japan) (detector configuration 80 × 0.5, beam collimation 40 mm) with reconstructed slice widths of 1 mm and slice intervals of 1 mm. The imaging data were in Digital Imaging and Communications in Medicine format (DICOM; National Electrical Manufacturers Association, Rosslyn, VA, USA) and were transferred into CT-based simulation software (ZedHip Lexi Co., Ltd., Tokyo, Japan). This software included the implant database with computer-aided 3D design models provided by the implant manufacturer. This software allowed for preoperative THA planning and ROM simulation until impingement occurred between the implants and bones.

Table 1
Patient demographics.

Total number of hips	14
Age (y)	62.4 ± 11.7 (40–80)
Sex (female/male)	2/12
Diagnosis (RA/ION/OA)	3/2/9
Height (cm)	163.8 ± 8.0 (152–178)
Weight (kg)	67.6 ± 6.7 (55–80)
BMI (kg/m^2)	25.2 ± 1.8 (21.8–27.9)

Data are presented as numbers or mean ± standard deviation (range). RA: rheumatoid arthritis; ION: idiopathic osteonecrosis of femoral head; OA: osteoarthritis; BMI: body mass index.

2.2. Methods

The simulated implant was the Accolade II TMZF and a Trident acetabular hemispherical cup (Stryker Orthopedic, Mahwah, NJ, USA) with a polyethylene insert, without marginal lips, in all cases. The acetabular component size was maximized, but did not exceed the acetabular anterior-posterior diameter. Anteversion was determined such that the center of the normal hip joint did not change, and the anterior edge of the component did not protrude from the anterior edge of the acetabulum. The cup was placed at the same location as the original hip joint center. The femoral implant size was selected to maximize both fit and fill in the femoral metaphysic, and the femoral shaft axis was placed in the center of the original femoral diaphysis so that the leg length, the offset, and the anteversion did not change in all cases. Both the acetabular component and the femoral implant were taken under consideration when selecting the implant size used in the operation. The 28 mm femoral head diameter was used as the standard for simulation. The center of the femoral head was located through fitting a sphere to the articular surface of the femoral head. The pelvis was fixed in space, whereas the femur was free to rotate in all directions while being constrained to rotate around the rotational center of the hip. The computer software was capable of detecting bone-to-bone, bone-to-implant, and implant impingements, which allowed maximum ROM to be defined as the degree of movement before the impingement of either the bone or implant occurred. The location of this impingement on both the femoral and acetabular sides, and the position of the femur in space relative to the fixed pelvis, could also be determined in the model. We also measured the ROM at impingement under flexion (Flex), internal rotation at 90° flexion (IR at 90Flex), IR at 45° flexion with 20° adduction (IR at 45Flex20Add), and external rotation at 10° extension (ER at 10Ext); these are all required ROMs for activities of daily living.

2.3. Evaluation design

We identified different AIIS morphologies according to the classification of Hetsroni et al. [10] (Fig. 1). We evaluated the changes in ROM associated with changing ball head diameter (32 mm and 36 mm) and acetabular cup placement position (5 mm and 10 mm above the anatomic hip center). When simulating the 36-mm ball head in an upward acetabular component setting, we completed the simulation with and without correcting for leg length. Then, we compared the difference between each experimental ROM and the ROM of the standard simulation.

2.4. Statistics analysis

Descriptive statistics were first conducted on the patient background data. Next, comparisons of the ROM by classification type of AIIS were conducted using the Kruskal wallis test. Finally, for each type classification of AIIS, comparisons of the ROM under each simulation condition were performed using the Friedman test. $p < 0.05$ indicates statistical significance. All analyses were performed using IBM SPSS Statistics 22 (IBM, Tokyo, Japan).

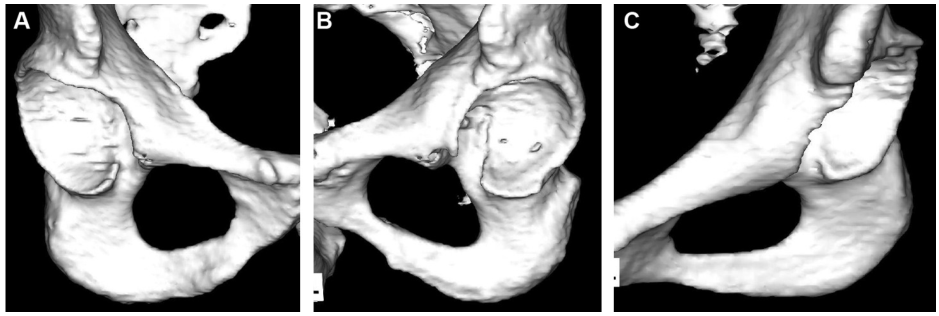

Fig. 1. A–C. AIIS morphological variant types depicted in a “head-on AIIS view” of hips. A. Type I AIIS variant in a right hip. There is a smooth ilium wall between the caudal level of the AIIS and the acetabular rim. B. Type II AIIS variant in a left hip. Bony prominences are seen on the ilium wall extending from the caudal area of the AIIS to the acetabular rim. C. Type III AIIS variant in a left hip. The AIIS extends distally to the anterosuperior acetabular rim.

3. Results

The patient’s hips were identified according to Hetsroni et al. [10] classification as type I ($n = 6$), type II ($n = 6$), and type III ($n = 2$). For type I hips with standard simulation, the ROM under Flex was 119.8 ± 5.4° (111–127°), IR at 90Flex was 31.0 ± 11.3° (19–52°), IR at 45Flex20Add was 70.0 ± 11.9° (57–92°), and ER at 10Ext was 33.0 ± 9.7° (15–43°) (Table 2). For type II hips with standard simulation, the ROM under Flex was 118.5 ± 5.5° (111–123°), IR at 90Flex was 31.5 ± 2.9° (27–35°), IR at 45Flex20Add was 71.3 ± 2.2° (68–74°), and ER at 10Ext was 33.3 ± 3.3° (30–39°) (Table 3). For type III hips with standard simulation, the ROM under Flex was 105.5 ± 13.4° (96–115°), IR at 90Flex was 21.0 ± 15.6° (10–32°), IR at 45Flex20Add was 61.0 ± 11.3° (53–69°), and ER at 10Ext was 34.5 ± 2.1° (33–36°) (Table 4). There were no significant differences in the ROMs between each type (Flex, $p = 0.252$; IR at 90Flex, $p = 0.461$; IR at 45Flex20Add, $p = 0.261$; and ER at 10Ext, $p = 0.655$).

For high placement of the acetabular cup (at 5 mm and 10 mm) simulations, the ROMs, with the exception of IR at 90Flex for type III, all decreased significantly compared with the standard simulation (Tables 2–4). ROM in flexion significantly decreased by −4.5 ± 4.6° at 5 mm and by −7.3 ± 7.8° at 10 mm for type I hips, by −3.8 ± 3.2° at 5 mm and by −9.2 ± 5.6° at 10 mm for type II hips, and by −8.5 ± 0.7° at 5 mm and by −17.0 ± 2.8° at 10 mm for type III hips (Fig. 2). Although the ROM decreased with IR at 90 Flex for type III, the difference was not significant ($p = 0.061$).

With a 32-mm ball head, type I and II hips had increased ROMs in the standard hip position (Tables 2 and 3). In flexion, the ROMs increased by 2.5 ± 2.6° for type I hips and by 1.3 ± 1.0° for type II hips. For type III hips, there were no changes in the ROM with Flex and IR at 45Flex20Add, but the ROM increased by 1.5 ± 2.1° with IR at 90Flex.

With a 36-mm ball head, type I and II hips had increased ROMs in the standard hip position (Tables 2 and 3). In flexion, the ROMs increased by 3.8 ± 3.1° for type I hips and by 2.2 ± 1.9° for type II hips. For type III hips, there were no changes in the ROM with Flex and IR at 45Flex20Add, but the ROM increased by 2.0 ± 2.8° with IR at 90Flex.

With a 5-mm high cup position, the Flex ROM decreased due to bony impingements with all ball head diameters, including the 36-mm ball head with leg length correction (36LLC), up to −17.5 ± 5.4° for type I and II hips. For type III hips, this decrease was even larger, with 36LLC resulting in a ROM decrease up to −24.5 ± 0.7°. Moreover, the ROM expansion also decreased with IR at 90Flex and IR at 45Flex20Add (Table 4).

Regarding the 10-mm high cup placement, greater decreases in ROM were observed due to early bony impingements. Even if the ball head diameter was increased, the expansion effect of ROM was minimal and further decreased in type II and III hips. For the 36LLC simulations, ROM limitations were at their greatest for each hip classification type (Tables 2–4).

4. Discussion

The study hypothesis was substantiated, even though there were no significant differences, the ROM tended to decrease depending on the shape of AIIS, in agreement with Hetsroni et al. [10], which simulated the femoro-acetabular impingement model and Shoji et al. [14]. Even if the femoral head diameter is increased

Table 2
Difference between ROM (°) of standard simulation and ROM of each simulation in Hetsroni type I hips [10].

Position\ball head diameter (mm)	Normal			5 mm high				10 mm high				*p*-values
	28[a]	32	36	28	32	36	36LLC	28	32	36	36LLC	
Flex	119.8 ± 5.4 (111–127)	+2.5 ± 2.6 (0–7)	+3.8 ± 3.1[a] (0–7)	−4.5 ± 4.6 (−10 to 0)	−3.8 ± 5.5 (−10 to 3)	−3.3 ± 6.3 (−10 to 6)	−4.8 ± 6.7 (−12 to 6)	−7.3 ± 7.8 (−17 to 0)	−6.8 ± 8.5 (−17 to 3)	−6.8 ± 8.5 (−17 to 3)	−12.5 ± 10.8[b] (−25 to 2)	<0.01[b]
IR at 90Flex	31.0 ± 11.3 (19–52)	+3.5 ± 1.8 (2–7)	+6.7 ± 0.5 (6–7)	−0.7 ± 1.2 (−3 to 0)	+2.3 ± 4.1 (−3 to 9)	+3.2 ± 4.3 (−3 to 7)	+2.5 ± 4.4 (−5 to 7)	−1.2 ± 10.3 (−12 to 17)	+0.2 ± 11.2 (−12 to 19)	+0.7 ± 11.4 (−12 to 19)	−4.2 ± 14.4 (−22 to 17)	<0.01[b]
IR at 45Flex20Add	70.0 ± 11.9 (57–92)	+3.8 ± 2.0 (3–8)	+7.3 ± 0.5 (7–8)	−0.5 ± 1.2 (−3 to 0)	+1.8 ± 2.4 (−3 to 3)	+4.5 ± 4.2 (−3 to 7)	+5.7 ± 4.3 (−3 to 8)	+2.5 ± 8.8 (−5 to 20)	+5.0 ± 9.0 (−5 to 22)	+6.8 ± 8.8 (−5 to 22)	+8.8 ± 6.6 (4–22)	<0.01[b]
ER at 10Ext	33.0 ± 9.7 (15–43)	+3.8 ± 1.6 (3–7)	+8.2 ± 1.5 (7–11)	+0.7 ± 1.6 (0–4)	+3.3 ± 2.0 (1–7)	+7.8 ± 0.8 (7–9)	+8.2 ± 1.5 (7–11)	−2.3 ± 7.8 (−18–4)	+0.7 ± 7.8 (−15 to 6)	+2.2 ± 6.6 (−11 to 7)	+4.2 ± 7.3 (−10 to 10)	<0.01[b]

Data are presented as mean ± standard deviation (range). ROM: range of motion; 36LLC: 36-mm ball head with leg length correction; Flex: flexion; IR at 90Flex: internal rotation at 90° flexion; IR at 45Flex20Add: internal rotation at 45° flexion and 20° adduction; ER at 10Ext: external rotation at 10° extension.

[a] ROM of the standard simulation at normal hip center placement using a 28-mm ball head.

[b] Analysis of variances were performed using the Friedman test. Pairwise comparisons were performed using the Tukey procedure or Games-Howell procedure; a versus b: $p = 0.026$. There were no significant differences in other pairs

Table 3
Difference between ROM (°) of standard simulation and ROM of each simulation in Hetsroni type II hips [10].

Position\ball head diameter (mm)	Normal			5 mm high				10 mm high				*p*-values
	28[a]	32	36	28	32	36	36LLC	28	32	36	36LLC	
Flex	118.5 ± 5.5 (111–123)	+1.3 ± 1.0[a] (0–2)	+2.2 ± 1.9[b] (0–5)	−3.8 ± 3.2 (−7 to 0)	−3.2 ± 3.7 (−7 to 2)	−2.8 ± 3.9 (−7 to 3)	−6.0 ± 3.8 (−11 to 1)	−9.2 ± 5.6 (−16 to 2)	−9.2 ± 5.6 (−16 to 2)	−9.0 ± 5.5 (−16 to 2)	−17.5 ± 5.4[c] (−23 to 9)	<0.01[b]
IR at 90Flex	31.5 ± 2.9 (27–35)	+2.0 ± 1.5 (0–3)	+4.7 ± 3.6 (0–7)	−4.5 ± 4.8 (−11 to 0)	−1.5 ± 6.3 (−11 to 3)	+0.2 ± 7.8 (−11 to 7)	−1.8 ± 9.4 (−17 to 6)	−7.0 ± 10.2 (−22 to 0)	−6.3 ± 10.7 (−22 to 2)	−6.2 ± 10.9 (−22 to 3)	−13.3 ± 13.3 (−31 to 3)	<0.01[b]
IR at 45Flex20Add	71.3 ± 2.2 (68–74)	+2.8 ± 1.5 (0–4)	+4.7 ± 2.9[d] (0–7)	−2.8 ± 3.3[e] (−7 to 0)	+0.2 ± 4.5 (−7 to 3)	+2.2 ± 6.2 (−7 to 7)	+4.3 ± 3.6 (−2 to 7)	−3.8 ± 5.7 (−13 to 0)	−2.8 ± 6.6 (−13 to 3)	−1.5 ± 8.2 (−13 to 7)	+1.3 ± 5.4 (−31 to 3)	<0.01[b]
ER at 10Ext	33.3 ± 3.3[f] (30–39)	+3.5 ± 0.5 (3–4)	+8.0 ± 0.6[g] (7–9)	−1.0 ± 3.0[h] (−7 to 1)	+3.5 ± 0.5 (3–4)	+8.0 ± 0.6[i] (7–9)	+8.0 ± 0.6[j] (7–9)	0.0 ± 0.0[k] (0–0)	+3.2 ± 0.8 (2–4)	+7.0 ± 2.5[l] (2–9)	+6.3 ± 2.5[m] (2–9)	<0.01[b]

Data are presented as mean ± standard deviation (range). ROM: range of motion; 36LLC: 36-mm ball head with leg length correction; Flex: flexion; IR at 90Flex: internal rotation at 90° flexion; IR at 45Flex20Add: internal rotation at 45° flexion and 20° adduction; ER at 10Ext: external rotation at 10° extension.

[a] ROMs of the standard simulation at normal hip center placement using a 28-mm ball head.

[b] Analysis of variances were performed using the Friedman test. Pairwise comparisons were performed using the Tukey procedure or Games-Howell procedure; a versus c: $p = 0.042$; b versus c: $p = 0.027$; d versus e: $p = 0.039$; f versus g: $p = 0.033$; f versus j: $p = 0.033$; f versus j: $p = 0.033$; g versus h: $p = 0.009$; g versus k: $p = 0.033$; h versus j: $p = 0.009$; h versus j: $p = 0.009$; h versus l: $p = 0.033$; h versus m: $p = 0.033$; j versus k: $p = 0.033$; j versus k: $p = 0.033$. There were no significant differences in other pairs.

Table 4
Difference between ROM (°) of standard simulation and ROM of each simulation in Hetsroni type III hips [10].

Position\ball head diameter (mm)	Normal			5 mm high				10 mm high				*p*-values
	28[a]	32	36	28	32	36	36LLC	28	32	36	36LLC	
Flex	105.5 ± 13.4 (96–115)	0.0 ± 0.0 0	0.0 ± 0.0 0	−8.5 ± 0.7 (−9 to 8)	−8.5 ± 0.7 (−9 to 8)	−8.5 ± 0.7 (−9 to 8)	−12.5 ± 0.7 (−13 to 12)	−17.0 ± 2.8 (−19 to 15)	−17.0 ± 2.8 (−19 to 15)	−17.0 ± 2.8 (−19 to 15)	−24.5 ± 0.7 (−25 to 24)	0.029[b]
IR at 90Flex	21.0 ± 15.6 (10–32)	+1.5 ± 2.1 (0–3)	+2.0 ± 2.8 (0–4)	−7.5 ± 3.5 (−10 to 5)	−7.5 ± 3.5 (−10 to 5)	−7.5 ± 3.5 (−10 to 5)	−9.5 ± 0.7 (−10 to 9)	−12.5 ± 3.5 (−15 to 10)	−12.5 ± 3.5 (−15 to 10)	−12.5 ± 3.5 (−15 to 10)	−19.5 ± 13.4 (−29 to 10)	0.061[b]
IR at 45Flex20Add	61.0 ± 11.3 (53–69)	0.0 ± 0.0 0	0.0 ± 0.0 0	−8.5 ± 2.1 (−10 to 7)	−8.5 ± 2.1 (−7 to 10)	−8.5 ± 2.1 (−10 to 7)	−9.0 ± 0.0 (−9)	−16.5 ± 3.5 (−19 to 14)	−16.5 ± 3.5 (−19 to 14)	−16.5 ± 3.5 (−19 to 14)	−17.0 ± 0.0 (−17)	0.042[b]
ER at 10Ext	34.5 ± 2.1[a] (33–36)	+4.0 ± 0.0 −4	+7.5 ± 0.7[b] (7–8)	0.0 ± 0.0[c] 0	+4.0 ± 0.0 −4	+7.5 ± 0.7[d] (7–8)	+7.5 ± 0.7[e] (7–8)	0.0 ± 0.0[f] 0	+4.0 ± 0.0 −4	+7.5 ± 0.7[g] (7–8)	+7.5 ± 0.7[h] (7–8)	0.029[b]

Data are presented as mean ± standard deviation (range). ROM: range of motion; 36LLC: 36-mm ball head with leg length correction; Flex: flexion; IR at 90Flex: internal rotation at 90° flexion; IR at 45Flex20Add: internal rotation at 45° flexion and 20° adduction; ER at 10Ext: external rotation at 10° extension.

[a] ROMs of the standard simulation at normal hip center placement using a 28-mm ball head.

[b] Analysis of variances were performed using the Friedman test. Pairwise comparisons were performed using the Tukey procedure or Games-Howell procedure; a versus b: $p = 0.041$; a versus d: $p = 0.041$; a versus e: $p = 0.041$; a versus g: $p = 0.041$; a versus h: $p = 0.041$; b versus c: $p = 0.l041$; b versus f: $p = 0.041$; c versus d: $p = 0.041$; c versus e: $p = 0.041$; c versus g: $p = 0.041$; c versus h: $p = 0.041$; d versus f: $p = 0.041$; e versus f: $p = 0.041$; f versus g: $p = 0.041$; f versus h: $p = 0.041$. There were no significant differences in other pairs.

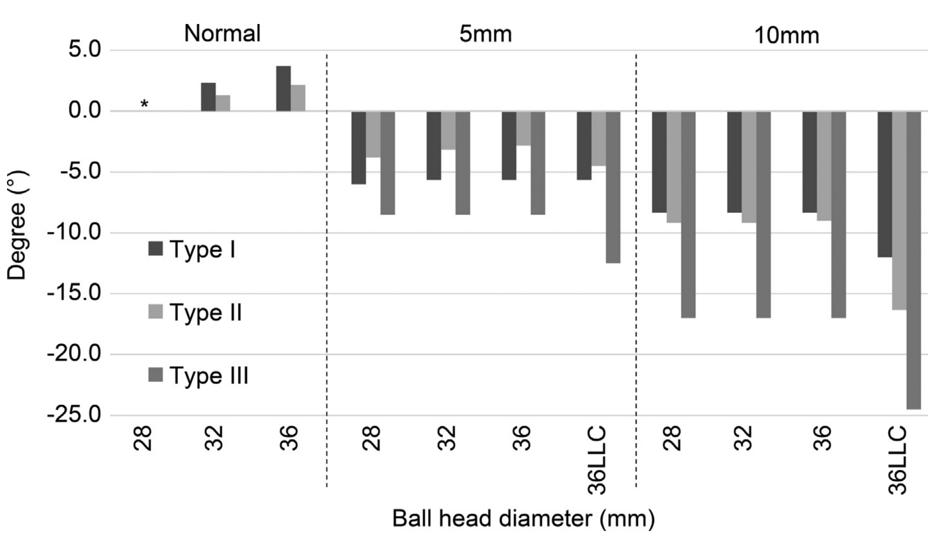

Fig. 2. Difference of the Flexion ROM associated with changing the ball head diameter and the acetabular cup placement position in each type of AIIS. *ROM of the standard simulation at normal hip center placement using a 28-mm ball head. ROM: range of motion; 36LLC: 36-mm ball head with leg length correction.

with the higher placement of the acetabular cups, the ROM still decreases in a manner dependent on the shape of AIIS.

There have been reports of the comparison of the ball head diameter [12,15] and the high placement of acetabular cups [5] by both ROM simulation and clinical results. However, there have been no reports accounting for the shape of the AIIS. Morphological characteristics, such as the size and position of the AIIS, are particularly important for the ROM of the hip joint. Hetsroni et al. [10] reported that the shape of the AIIS can cause femoral acetabular impingement. Shoji et al. [14] reported that the AIIS influences the ROM after THA, especially when it is wide, the ROM decreases laterally. As the AIIS has individual anatomical differences, it is clinically important to perform a detailed examination that includes assessing the effects of the AIIS shape.

It appears that installing a cementless acetabular cup above the hip center is preferable to a cemented acetabular cup. According to reports of mid or long-term clinical results, treatments involving high-center hip surgery may have both positive and negative outcomes [16,17]. In contrast, with regard to the position of the cup, it has also been reported that the load on weight-bearing surfaces increases the load on the hip joint when the center of the femoral head is placed more superiorly and laterally compared to normal positioning in a basic study with mathematical modeling [18,19]. There are few basic reports on cup implantation in superior positions and its effect on ROM. In simulation tests, Komiyama et al. [5] showed that ROM decreases with the high placement of the acetabular cup.

The effect of increasing ball head diameter on the expansion of ROM and the resistance to dislocation has been reported both experimentally and clinically. Kessler et al. and Klingenstein et al. used 3D computer models to measure the oscillation angle between implants [12,15]. They reported that the larger the ball head, the larger the oscillation angle, but this also facilitated the occurrence of bony impingements; therefore, there is a limit to its effect on ROM. However, realistically, impingement between native bones is rare, and there are no actual clinical coping methods. Khatod et al. reported that the clinical dislocation rate was significantly lower for ball head diameters greater than 32 mm [20]. However, to our knowledge, there are no experimental reports investigating the influence of different ball head diameters on ROM, for hip centers at higher placements.

In this study, implantation simulations showed that cups that were implanted at higher positions (up to 10 mm above the normal hip position) had decreased ROM. However, most of these implantations were also affected by impingement with the AIIS. Therefore, the anatomical shapes of the AIIS are very important, as illustrated by our finding that the ROM was most reduced in Hetsroni classification type III hips. When comparing type I and type II hips, type II had less ROM up to the point of impingement. In hips with a larger AIIS, decreased ROM and high dislocation rates are concerns associated with the high placement of the acetabular cup. Regarding the high implantation positions of the acetabular cup, increased ROM due to larger ball head diameters was less likely to result in bony impingement compared to normal positioning of the acetabular cup. In THAs performed for hip arthritis with acetabular dysplasia, the higher the cup placement, the smaller the anterior-posterior diameter of the ilium, resulting in a cup size that tends to be smaller. In the case of a high hip center, the concurrent use of a large ball head has a potential effect on jumping distance and/or dislocation; however, an increase in ROM is not expected, since the thickness of the polyethylene liner becomes thinner, and its use must be sufficiently considered.

The limitations of this study include the lack of consideration of soft tissue impingement, soft tissue balance, neck offset, liner offset, cup position angle, position depth, and differences in anterior-posterior position. Further, only the Accolade II TMZF and Trident acetabular hemisphere cups were simulated, and we have not studied other implants. Additionally, the number of simulated samples was small. To evaluate the influence of bony impingement for range of motion without soft tissue impingement or imbalance, it becomes clear to exclude soft tissues and unite parameters, other than, for example, the ball head diameter and hip center position, as much as possible. Moreover, it is unlikely that different results will be obtained with this study method even if the number of samples is increased. Even if simulation tests will be able to be performed under conditions closer to clinical reality by adding such as soft tissues, the result from it will be likely to correlate with ones of this study with the end point of bony impingement, which is one of the clinical main factors of restricting the range of motion. Therefore, the findings of the study are valid to express the influence of a true bony impingement and are unaffected by these limitations.

5. Conclusions

In conclusion, AIIS shape, higher placement of acetabular cups, and ball head diameter all influenced the hip ROM after THA. Whereas larger ball head diameters increased the ROM, the shape of the AIIS influenced the early occurrence of bony impingements, impeding ROM. Higher acetabular cup placement resulted in a decrease in the ROM in an AIIS shape-dependent manner, even with an increase in the ball head diameter. Therefore, the shape of the AIIS should be taken into consideration when considering THA procedures because of its effects on the occurrence of bony impingements.

Disclosure of interest

The authors declare that they have no competing interest.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Contribution

T. Tabata, N. Kaku, and H. Tsumura conceived and designed the study.

T. Tabata and H. Tagomori completed the experiments.

T. Tabata and N. Kaku analyzed the data.

T. Tabata and N. Kaku wrote the paper.

All authors have approved the final manuscript.

Acknowledgements

We thank Editage (www.editage.com) for English language editing and Publication Support.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version at: https://doi.org/10.1016/j.otsr.2018.09.021.

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