European Journal of Orthopaedic Surgery & Traumatology (2019) 29:625–632
https://doi.org/10.1007/s00590-018-2325-5

ORIGINAL ARTICLE • HIP - ARTHROPLASTY

Effect of changing femoral head diameter on bony and prosthetic jumping angles

Takaaki Ohmori[1] · Tamon Kabata[1] · Yoshitomo Kajino[1] · Daisuke Inoue[1] · Tadashi Taga[1] · Takashi Yamamoto[1] · Tomoharu Takagi[1] · Junya Yoshitani[1] · Takuro Ueno[1] · Ken Ueoka[1] · Hiroyuki Tsuchiya[1]

Received: 9 August 2018 / Accepted: 21 October 2018 / Published online: 30 October 2018

Abstract

Background In THA, using a larger femoral head can increase the oscillation angle and jumping distance. However, there have been no reports which indicate precisely how increasing the jumping distance leads to an increase in the angle from impingement to dislocation (jumping angle). In this study, we clarified the jumping angle of various head diameters and its relationship with pelvic morphology.

Methods Using a three-dimensional templating system, virtual THA and ROM simulations were performed in 82 patients. We investigated the distance between bony and prosthetic impingement points and the head centre and calculated the jumping angle for various head diameters. We measured various pelvic shapes and length to clarify the relationship between pelvic morphology and impingement distance.

Results Jumping angles were 7.7° ± 3.2°, 12.1° ± 1.6°, 15.4° ± 2.5° and 10.0° ± 3.0° with flexion, internal rotation with 90° flexion (IR), extension and external rotation (ER), respectively, when we used a 22-mm head diameter. Bony jumping angle increased about 0.5°, 0.8°, 1.0° and 0.7° per 2-mm increase in head diameter with flexion, IR, extension and ER. On the other hand, prosthetic jumping angle remained almost stable at about 31°. Impingement distance was related to pelvic morphology in all directions. Bony jumping angles differed with ROM; the biggest was seen with extension, followed by IR, ER and flexion. On the other hand, bony jumping angle was less than prosthetic jumping angle in all cases.

Conclusion Bony jumping angles differed with ROM; the biggest was seen with extension, followed by IR, ER and flexion. Prosthetic impingement angles were stable. In addition, the bony jumping angle was less than the prosthetic jumping angle in all cases.

Keywords Total hip arthroplasty · Jumping angle · Jumping distance · Impingement distance

Introduction

Dislocation rates of between 0.5 and 10% for primary total hip arthroplasty (THA) and between 10 and 25% for revision THA have been reported [1, 2]. And dislocation is the first reason for revision surgery [3]. To prevent dislocation, various implant designs which can change stem anteversion have been developed to easily satisfy combined anteversion, and large femoral heads are often used [4, 5]. In terms of implant design, femoral head-to-neck ratio, head diameter and head offset are all related to the impingement-free angle [6, 7]. Using a larger femoral head increases the oscillation angle and jumping distance and lowers the dislocation rate. However, there are no reports which indicate precisely how an increase in jumping distance leads to an increase in the angle from impingement to dislocation (jumping angle). Jumping angle can be expected to change with impingement distance, which is the distance from the impingement point to the centre of the head. This means that the position of the fulcrum is equivalent to the impingement point. In THA, we should consider both prosthetic impingement and bony impingement [8]. Although the prosthetic impingement distance can be defined by the head diameter and neck thickness, bony impingement distance would be expected to change in each case because each impingement point would be different according to the specific pelvic morphology.

✉ Tamon Kabata
tamonkabata@yahoo.co.jp

1 Department of Orthopedic Surgery, Graduate School of Medical Science, Kanazawa University, Takaramachi 13-1, Kanazawa, Ishikawa, Japan

We do not completely understand how changing the head diameter affects the increase in jumping angle. In this study, we investigated the distance between the bony and prosthetic impingement points and the head centre, and clarified the jumping angle for various head diameters. We also investigated the relationship between bony impingement distance, pelvic morphology and length between pelvis and femur.

Materials and methods

Study design and setting

This was a prospective case series analytical study.

Participants/study subjects

This study includes data from 82 patients (82 hips; 16 men and 66 women) with normal hips from patients who had undergone primary THA or who had been diagnosed with developmental dysplasia of the hip at our hospital between 2012 and 2015. We excluded patients with bilateral osteoarthritis, insufficient data and inappropriate computed tomography (CT) images (Fig. 1). Demographic and clinical patient data are shown in Table 1.

Description of experiment, treatment or surgery

Anatomical model and reference planes: For each subject, we constructed independent three-dimensional models of the pelvis and femur from CT images (LightSpeed VCT Series/Discovery CT750; GE Healthcare, Tokyo, Japan), using a CT-based three-dimensional templating system (ZedHip™ Lexi Co., Tokyo, Japan). ZedHip can perform virtual THA, simulate impingement-free angles and calculate impingement points, including bone-to-bone, bone-to-prosthetic and prosthetic-to-prosthetic [9–11].

We used the anterior pelvic plane (APP) which consisted of both anterior superior iliac spines (ASISs) and pubic symphysis. On the APP, the X-axis was defined by a line connecting both anterior superior iliac spines and the Y-axis was defined as a line passing through the pubic symphysis on the APP and perpendicular to the X-axis. The femoral posterior condylar plane consisted of the distal posterior lateral condyle, medial condyle and proximal posterior surface. The Y-axis was defined as a projected line onto the posterior condylar plane, passing through the knee centre and trochanteric fossa, and the X-axis was defined as perpendicular to the Y-axis [8, 12, 13].

Range of motion (ROM) definition

The angle of hip flexion/extension along the sagittal plane of motion was defined as the angle between the Y-axis of the APP and the Y-axis of the posterior condylar plane. The angle of hip internal/external rotation was the angle between the X-axis of the APP and the X-axis of the posterior condylar plane [8, 12, 13].

Table 1 Data of all patients

$N = 82$ (men = 16 and women = 66)	
Hypertension $N = 22$	
Diabetes mellitus $N = 10$	
Age	59.4 ± 13.2
Height (cm)	156.1 ± 8.5
Weight (kg)	57.1 ± 10.3
BMI (kg/m^2)	23.3 ± 3.4
Femoral anteversion (°)	21.7 ± 10.1
CE angle (°)	19.6 ± 8.0

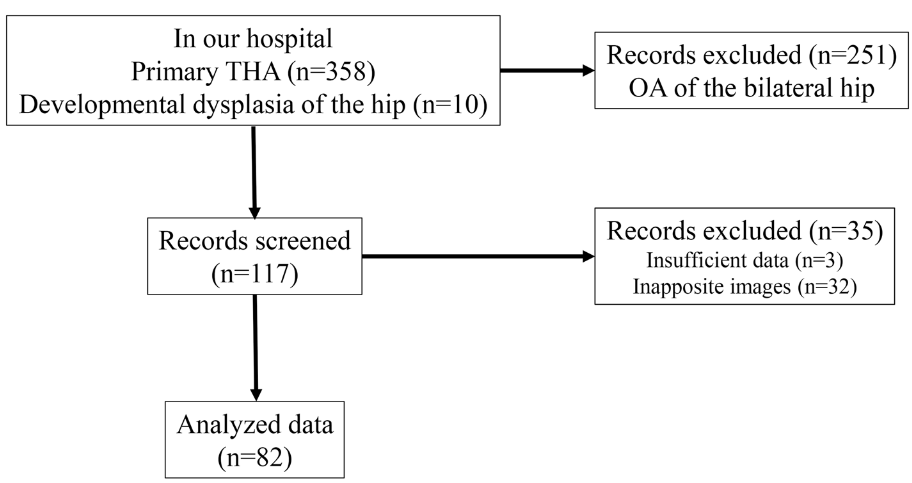

Fig. 1 Flow chart of patient selection

Implant type and positioning

We used the Stryker THA system (Stryker Orthopaedics, US NJ Mahwah) with the Trident PSL cup and Accolade II stem (neck angle 127°, V40 neck taper) in this study. To investigate bony impingement distance, we chose the optimal size of cup and stem for each case and a head with a 32-mm diameter and the 32-mm flat liner in all cases. The femoral osteotomy level was assumed as 15-mm proximal from the apex of the lesser trochanter. We placed the stem to achieve the same leg length and the same offset as in the original. Stem anteversion was fixed to satisfy the same head centre as the original. The cup was positioned at the same height as the original femoral head centre, in contact with the outer wall of the teardrop. Cup coverage was adequate in all cases. The radiographic cup inclination angle and anteversion were changed so as not to result in prosthetic impingement. To investigate the prosthetic impingement distance, we changed the head diameter from 22 to 46 mm with a 54-mm cup diameter.

In this study, our goal was to investigate jumping angles. To achieve that goal, we also had to investigate impingement distance and jumping distance. We defined those parameters as below.

Impingement distance

We defined impingement distance as the distance from the prosthetic and bony impingement points to the femoral head centre in each case (prosthetic impingement distance and bony impingement distance) based on the flexion angle, internal rotation angle with 90° flexion, extension and external rotation. Using ZedHip, we analysed the virtual motion of some ROM patterns to obtain several impingement distance. Figure 2a, b shows the situation of bony impingement and prosthetic impingement.

Jumping distance

We defined jumping distance as the distance at which the head completely left the cup. The implant used has a 2-mm head offset. Therefore, jumping distance is expressed by the following equation:

$$\text{Jumping distance} = \text{head diameter}/2 + 2\text{-mm (head offset)}$$

Figure 3 shows the relation between jumping distance, impingement distance and jumping angle. Jumping angle was obtained from the impingement distance and jumping distance, using a trigonometric function.

We also investigated the relationship between bony impingement distance, pelvic morphology and length between pelvis and femur. Based on past reports, we defined pelvic morphology measurements as below [11] (Fig. 4a).

Acetabular height (AH) Distance between the most proximal point of the pelvis and the most inferior point of the ischium.

Acetabular length (AL) Distance between the ASISs.

Ischial length (IL) Distance between both ischia.

Length between pelvis and femur Based on past reports, we defined ischio-femoral length as the shortest distance between the lesser trochanter and ischial tuberosity [11] (Fig. 4b).

We investigated the relationship between each impingement distance and AL, IL, AH, ischio-femoral length, AH/AL and IL/AL [11].

Statistical analysis, study size

All data were expressed as means ± SDs, and differences were analysed using statistical software (SPSS, version 23). Correlations were evaluated using Pearson's Chi-squared

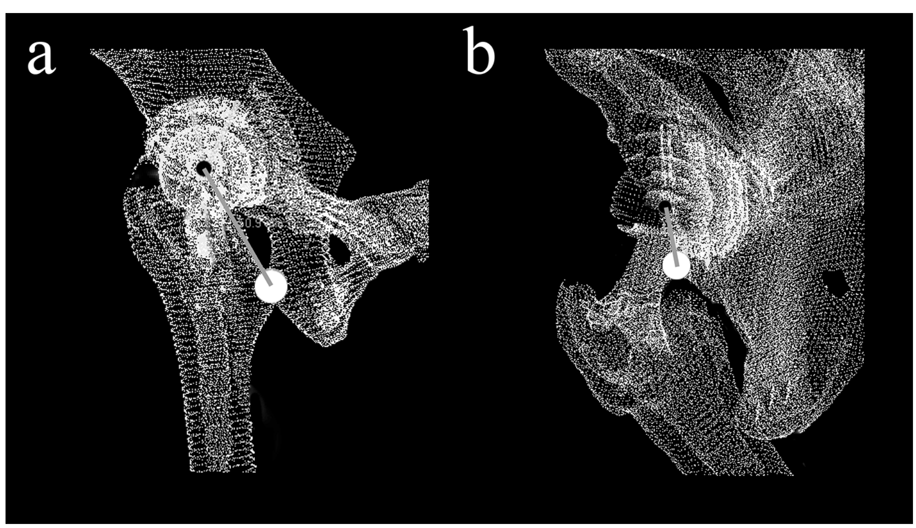

Fig. 2 ROM simulation using ZedHip. **a** Bony impingement pattern, **b** prosthetic impingement pattern

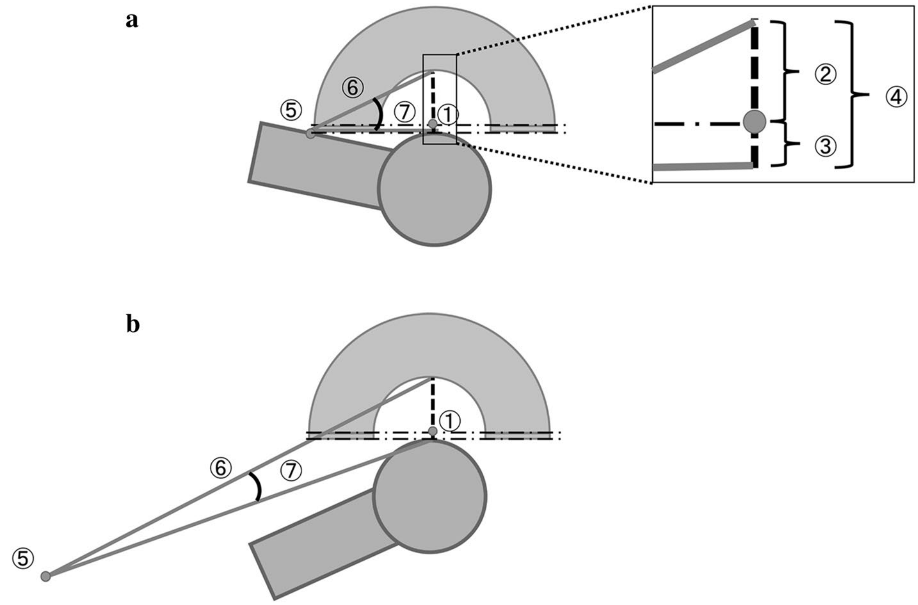

Fig. 3 Relationship between impingement distance, impingement point, jumping distance, head offset and jumping angle. **a** Prosthetic impingement pattern, **b** bony impingement pattern. ①: Head centre. ②: Head diameter/2, ③: Head offset. ④: Jumping distance. ⑤: Impingement point. ⑥: Impingement distance. ⑦: Jumping angle

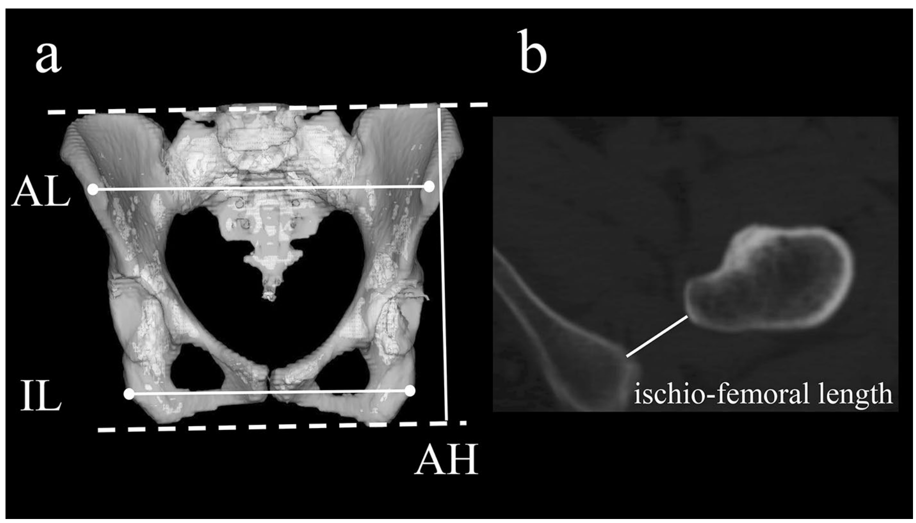

Fig. 4 **a** Pelvic morphology parameters, **b** ischio-femoral length

test. A p value of < 0.05 was considered statistically significant.

All individual participants included in the study gave informed consent, and the study was approved by the institutional review board of our university.

Results

Bony impingement distances were 64.0 ± 20.8 mm, 36.2 ± 4.6 mm, 28.8 ± 6.0 mm and 46.0 ± 10.5 mm with flexion, internal rotation with 90° flexion, extension and external rotation, respectively. Impingement regions of the pelvis are shown in Fig. 5. The impingement regions were mainly the ASIS or anterior inferior iliac spine (AIIS) with flexion, AIIS with internal rotation with 90° flexion, posterior or posterior superior aspect of the acetabulum with extension and ischial tuberosity with external rotation. Prosthetic impingement distances with head diameters are shown in Table 2. Figure 6 shows the jumping angle with each head diameter. Jumping angles were 7.7° ± 3.2°, 12.1° ± 1.6°, 15.4° ± 2.5° and 10.0° ± 3.0° when we used a 22-mm head diameter and increased about 0.5°, 0.8°, 1.0° and 0.7° with each 2-mm increase in head diameter with flexion, internal rotation with 90° flexion, extension and external rotation. Bony jumping angles differed with various ROMs due to the changing impingement point. The larger the head diameter, the more the jumping angle increased. On the other hand, prosthetic jumping angles were almost stable at about 31°. Table 3 shows the relation between each bony impingement distance and pelvic morphology and ischio-femoral distance. IL and AH were relative to flexion impingement distance.

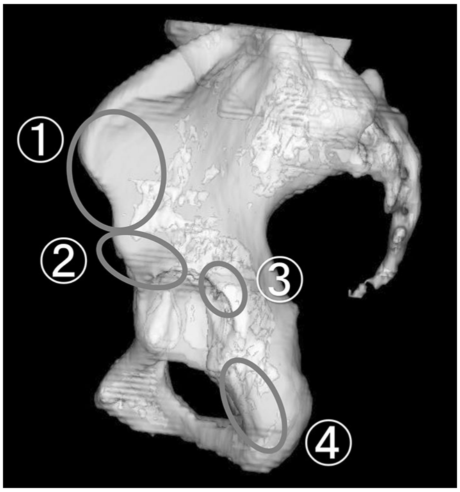

Fig. 5 Bony impingement regions of the pelvis. ① Flexion. ② Internal rotation with 90° flexion. ③ Extension. ④ External rotation

AL, AH and ischio-femoral length were relative to internal rotation with 90° flexion impingement distance. AH/AL was relative to extension impingement distance. AH/AL and IL/AL were relative to external rotation impingement distance.

Discussion

The larger the head diameter we used, the more the stability of the joint increased because the distance required for the femoral head to disengage from the acetabular component becomes longer [14, 15]. However, the larger head increased the rate of polyethylene wear when we used conventional ultra-high molecular weight polyethylene (UHMWPE) [16, 17]. Large head metal-on-metal devices, which were used widely in the early 2000s, also reduced the dislocation rate after primary THA [18]. However, they are seldom used today because of adverse reactions to metal debris (ARMD), which proved to be a serious problem [19]. In recent years, the dual mobility cup (DMC) has been widely used due to improvement in polyethylene and reduced the dislocation

Table 2 Prosthetic impingement distance of each head diameter

Head diameter (mm)	22	26	28	32	36	38	44	46
Prosthetic impingement distance (mm)	13.5	15.5	17.6	19.9	19.3	21.3	23.7	24.7

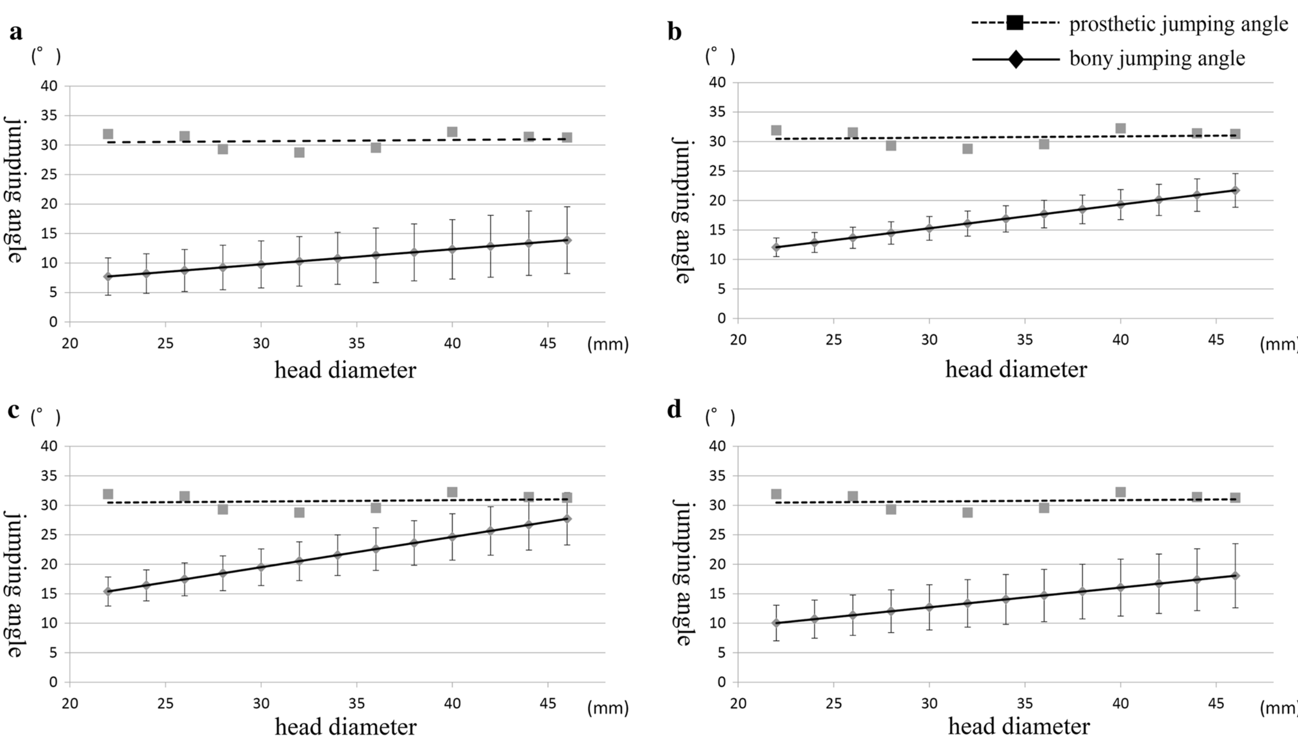

Fig. 6 Prosthetic and bony jumping angles of each femoral head diameter. **a** Flexion, **b** internal rotation with 90° flexion, **c** extension, **d** external rotation

Table 3 Relationship between each impingement distance and pelvic morphology or ischio-femoral length

	AL	IL	AH	Ischio-femoral length	AH/AL	IL/AL
Flexion						
r	0.19	0.32	0.34	0.12	0.75	0.035
p value	0.09	0.003*	0.002*	0.30	0.50	0.76
Internal rotation						
r	0.32	−0.042	0.24	0.38	−0.10	−0.27
p value	0.003*	0.71	0.033*	0.0004*	0.37	0.013*
Extension						
r	−0.19	−0.03	0.17	−0.02	0.31	0.12
p value	0.09	0.80	0.12	0.86	0.005*	0.28
External rotation						
r	−0.21	0.10	0.21	−0.16	0.365	0.23
p value	0.05	0.39	0.06	0.16	0.001*	0.039*

*$p < 0.05$

rate after primary THA [20]. Although empirically it is known that increasing jumping distance leads to resistance to dislocation, there are no reports that show how much the angle is increased by jumping distance. It is now possible to calculate the impingement point with software and investigate the impingement distance using 3D templating.

We reported that the preceding impingement types are changed by cup and stem anteversion in THA [8]. As mentioned earlier, the advantage of a large femoral head is an increase in oscillation and jumping angles. When bony impingement precedes prosthetic impingement, the increase in the oscillation angle becomes irrelevant from the standpoint of preventing dislocation, and it becomes more important to increase the jumping distance. We believe that a large femoral head or DMC reduces the dislocation rate by increasing the jumping distance [21], which is a primary factor for improved resistance to dislocation. This means that jumping angle is also an important consideration when considering dislocation resistance. Thus, it is important to understand exactly how the jumping angle increases with changing head diameter in THA. Some recent studies have investigated the risk factors for bony impingement after THA. In flexion and internal rotation, these are related to pelvic morphology [10]. In external rotation, they are said to be related to ischio-femoral length [11]. In this study, pelvic morphology was related to bony impingement distance with all directions. The jumping angle changed along with the changing impingement distance. Therefore, we see that bony jumping angles were different among several ROMs. Interestingly, prosthetic impingement angles were almost the same regardless of head diameter. Bony jumping angles were smaller than prosthetic jumping angles. On the other hand, the increase in jumping angle due to the increase in femoral head diameter was small. Therefore, we think that the decrease in dislocation rate due to the increase in the femoral head diameter may have more to do with the increased soft tissue tension than with the increase in jumping angle. Some have stated that an increase in the femoral head may be the most important reason for improved stability [22]. Others mention female gender, advanced age, neuromuscular or cognitive disorders, substance abuse, soft tissue deficits about the hip and previous hip surgery as risk factors for instability [23, 24]. The lack of soft tissue tension would lead to instability of the hip. Many reports have discussed the high rate of dislocation after revision THA [23, 25–27]. To reduce the dislocation rate, some have noted the importance of capsular repair [28–30]. Maintaining the surrounding soft tissue is important in keeping the tension. Therefore, the excessive removal of surrounding soft tissue would impair dislocation resistance.

Limitations

There were three limitations to this study. First, we could not consider soft tissue tension. Soft tissue with strong scar formation is one of the factors that increase resistance to dislocation. Second, changes in impingement point due to the position of the cup centre and offset could not be considered because we only looked at the ideal position of the implants. Third, we investigated only one type of implant. Head offset varies by implant design and this may affect results. In the future, it will be necessary to clarify dislocation resistance by the difference in soft tissue tension.

In this study, we clarified the relationship of jumping angle to bony and prosthetic impingement distances. Bony jumping angle was largest with extension, followed by internal rotation with 90° flexion, external rotation and flexion. In all cases, it is expected that the increase in dislocation resistance will be less than it is when prosthetic impingement occurs.

Conclusions

Bony jumping angles were 7.7° ± 3.2°, 12.1° ± 1.6°, 15.4° ± 2.5° and 10.0° ± 3.0° when we used a 22-mm head diameter and increased about 0.5°, 0.8°, 1.0° and 0.7° per 2-mm increase head diameter with flexion, internal rotation with 90° flexion, extension and external rotation, respectively. On the other hand, the prosthetic impingement angle was fixed at about 31°, which is larger than the bony impingement angle, regardless of femoral head diameter.

Compliance with ethical standards

Conflict of interest The authors declare no conflicts of interest as related to the study.

References

1. Alberton GM, High WA, Morrey BF (2002) Dislocation after revision total hip arthroplasty: an analysis of risk factors and treatment options. J Bone Joint Surg Am 84-A:1788–1792
2. Sariali E, Leonard P, Mamoudy P (2008) Dislocation after total hip arthroplasty using Hueter anterior approach. J Arthroplast 23:266–272. https://doi.org/10.1016/j.arth.2007.04.003
3. Bozic KJ, Kurtz SM, Lau E et al (2009) The epidemiology of revision total hip arthroplasty in the United States. J Bone Joint Surg Am 91:128–133. https://doi.org/10.2106/JBJS.H.00155
4. Dunbar MJ (2010) The proximal modular neck in THA: a bridge too far: affirms. Orthopedics 33:640. https://doi.org/10.3928/01477447-20100722-30
5. Duwelius PJ, Burkhart B, Carnahan C et al (2014) Modular versus nonmodular neck femoral implants in primary total hip arthroplasty: which is better? Clin Orthop Relat Res 472:1240–1245. https://doi.org/10.1007/s11999-013-3361-4
6. Malik A, Maheshwari A, Dorr LD (2007) Impingement with total hip replacement. J Bone Joint Surg Am 89:1832–1842. https://doi.org/10.2106/JBJS.F.01313
7. Widmer K-H (2007) Containment versus impingement: finding a compromise for cup placement in total hip arthroplasty. Int Orthop 31(Suppl 1):S29–S33. https://doi.org/10.1007/s00264-007-0429-3
8. Ohmori T, Kabata T, Kajino Y et al (2017) Differences in range of motion with the same combined anteversion after total hip arthroplasty. Int Orthop. https://doi.org/10.1007/s00264-017-3653-5
9. Shoji T, Yasunaga Y, Yamasaki T et al (2013) Bony impingement depends on the bone morphology of the hip after total hip arthroplasty. Int Orthop 37:1897–1903. https://doi.org/10.1007/s00264-013-1979-1
10. Shoji T, Yasunaga Y, Yamasaki T et al (2016) Anterior inferior iliac spine bone morphology in hip dysplasia and its effect on hip range of motion in total hip arthroplasty. J Arthroplast 31:2058–2063. https://doi.org/10.1016/j.arth.2016.02.018
11. Shoji T, Yamasaki T, Izumi S et al (2017) Factors affecting the potential for posterior bony impingement after total hip arthroplasty. Bone Joint J 99-B:1140–1146. https://doi.org/10.1302/0301-620x.99b9.bjj-2016-1078.r2
12. Ohmori T, Kabata T, Maeda T et al (2017) Increase in safe zone area of the acetabular cup using dual mobility cups in THA. Hip Int 27:361–367. https://doi.org/10.5301/hipint.5000466
13. Ohmori T, Kabata T, Maeda T et al (2017) Selection of a surgical approach for total hip arthroplasty according to the depth to the surgical site. Hip Int 27:273–280. https://doi.org/10.5301/hipint.5000463
14. Crowninshield RD, Maloney WJ, Wentz DH et al (2004) Biomechanics of large femoral heads: what they do and don't do. Clin Orthop Relat Res 429:102–107. https://doi.org/10.1097/01.blo.0000150117.42360.f9
15. Ito H, Tanino H, Yamanaka Y et al (2013) Intermediate- to long-term results after hybrid total hip arthroplasty in patients with rheumatoid arthritis. J Arthroplast 28:309–314. https://doi.org/10.1016/j.arth.2012.06.002
16. Viceconti M, Ruggeri O, Toni A, Giunti A (1996) Design-related fretting wear in modular neck hip prosthesis. J Biomed Mater Res 30:181–186. https://doi.org/10.1002/(SICI)1097-4636(199602)30:2%3c181:AID-JBM7%3e3.0.CO;2-N
17. Tarasevicius S, Robertsson O, Kesteris U et al (2008) Effect of femoral head size on polyethylene wear and synovitis after total hip arthroplasty: a sonographic and radiographic study of 39 patients. Acta Orthop 79:489–493. https://doi.org/10.1080/17453670710015472
18. Lombardi AVJ, Berend KR, Morris MJ et al (2015) Large-diameter metal-on-metal total hip arthroplasty: dislocation infrequent but survivorship poor. Clin Orthop Relat Res 473:509–520. https://doi.org/10.1007/s11999-014-3976-0
19. Bolland BJRF, Culliford DJ, Langton DJ et al (2011) High failure rates with a large-diameter hybrid metal-on-metal total hip replacement: clinical, radiological and retrieval analysis. J Bone Joint Surg Br 93:608–615. https://doi.org/10.1302/0301-620X.93B5.26309
20. Simian E, Chatellard R, Druon J et al (2015) Dual mobility cup in revision total hip arthroplasty: dislocation rate and survival after 5 years. Orthop Traumatol Surg Res 101:577–581. https://doi.org/10.1016/j.otsr.2015.05.002
21. Puch J-M, Derhi G, Descamps L et al (2017) Dual-mobility cup in total hip arthroplasty in patients less than fifty five years and over ten years of follow-up: a prospective and comparative series. Int Orthop 41:475–480. https://doi.org/10.1007/s00264-016-3325-x
22. Cooper HJ, Della Valle CJ (2014) Large diameter femoral heads: is bigger always better? Bone Joint J 96-B:23–26. https://doi.org/10.1302/0301-620x.96b11.34342
23. Werner BC, Brown TE (2012) Instability after total hip arthroplasty. World J Orthop 3:122–130. https://doi.org/10.5312/wjo.v3.i8.122
24. Komiyama K, Fukushi J-I, Motomura G et al (2018) Does high hip centre affect dislocation after total hip arthroplasty for developmental dysplasia of the hip? Int Orthop. https://doi.org/10.1007/s00264-018-4154-x
25. Hummel MT, Malkani AL, Yakkanti MR, Baker DL (2009) Decreased dislocation after revision total hip arthroplasty using larger femoral head size and posterior capsular repair. J Arthroplast 24:73–76. https://doi.org/10.1016/j.arth.2009.04.026
26. Phillips CB, Barrett JA, Losina E et al (2003) Incidence rates of dislocation, pulmonary embolism, and deep infection during the first six months after elective total hip replacement. J Bone Joint Surg Am 85-A:20–26
27. Tsikandylakis G, Karrholm J, Hailer NP et al (2018) No increase in survival for 36-mm versus 32-mm femoral heads in metal-on-polyethylene THA: a registry study. Clin Orthop Relat Res. https://doi.org/10.1097/corr.0000000000000508
28. Prietzel T, Hammer N, Schleifenbaum S et al (2014) The impact of capsular repair on the dislocation rate after primary total hip

arthroplasty: a retrospective analysis of 1972 cases. Z Orthop Unfall 152:130–143. https://doi.org/10.1055/s-0034-1368209
29. Bottner F, Pellicci PM (2006) Review: posterior soft tissue repair in primary total hip arthroplasty. HSS J 2:7–11. https://doi.org/10.1007/s11420-005-0134-y
30. Kumar V, Sharma S, James J et al (2014) Total hip replacement through a posterior approach using a 22 mm diameter femoral head: the role of the transverse acetabular ligament and capsular repair in reducing the rate of dislocation. Bone Joint J 96-B:1202–1206. https://doi.org/10.1302/0301-620x.96b9.31831