



Research paper

Influence of femoral head diameter on intraoperative range of motion in total hip arthroplasty



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ABSTRACT

Purpose: To investigate the intraoperative change of range of motion (ROM) using different femoral ball head diameters in the same patient using a navigation system and to compare the postoperative ROM speculated by 3D computer simulation software and the actual intraoperative ROM.

Materials and methods: Fourteen patients (12 female and 2 male patients) who underwent one-sided primary total hip arthroplasty for hip osteoarthritis caused by developmental dysplasia of the hip from January 2016 to November 2017 were included. Dislocation was defined as the center of femoral head moved by 5 mm. After placing the cup and stem via the posterolateral approach, measurement of the ROM with 28-, 32-, and 36-mm-diameter femoral ball heads was carried out using the navigation system. Postoperative computed tomography (CT) was performed, and the ROM simulation of the same movement was measured intraoperatively using a small-sized ball head (ZedHip).

Results: The intraoperative ROM was approximately closed to the preoperative ROM, and it tended to be in the following order: preoperative < 28-mm head < 32-mm head. As the diameter of the femoral head increased, the abduction increased significantly ($p < 0.05$). None reached 80% of the ROM simulated by ZedHip, and the movements that obtained 50% or more in the simulated ROM were flexion, abduction, and the angle until the dislocation.

Conclusions: ROM expansion due to the increase in femoral ball head diameter can be obtained even in vivo, but it was suggested that there is a limitation to the effect because of the interference of bone and soft tissue.

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1. Introduction

Improvement of function aimed at the expansion of range of motion (ROM) of the hip joint and prevention of dislocation after surgery are still important challenges in total hip arthroplasty (THA), which are influenced by operative approaches, position/angle of the placed implants, existence of osteophytes, soft tissue balance, preoperative ROM, pelvic inclinations, and implant design.¹ Additionally, in the actual clinical practice, several other factors complexly affect the operative results.

Accompanying the advancement of polyethylene materials, such

as crosslink and vitamin E-containing polyethylene, and the reinforcement of the resistance to oxidation and abrasion enable the polyethylene to be thinner to maintain its mechanical strength; thus, variation of the femoral head diameters is increased, because the use of a larger diameter head makes the polyethylene liner thinner when the same cup size is used. However, in the elderly with remarkable posterior pelvic inclination, not requiring long durability, it is expected to be one of the effective methods.

A large diameter ball head increases with oscillation angle and jumping distance; thus, it is an important option for operators to achieve maximal ROM and prevent dislocation during surgery. The previous simulation studies show good results, with increased oscillation angle, head-neck ratio, and jumping distance. However, it is unknown whether the results of these studies are also applicable in vivo, involving soft tissues and anatomical bony prominences. In the clinical reports, the assessments were mostly carried

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out by determining the rate of dislocation or visual ROM; thus, the reliability of the accuracy is not high. Although the postoperative ROM is one of the most important clinical factors, its exact evaluation was often underestimated because of contraction of soft tissues and fear of dislocation from the evaluator's previous examination. Thus, to investigate the actual effect of the large ball head diameter, it is necessary to assess the difference of intraoperative ROM in the same patient.

The navigation system is a surgical assistive device that guides accurate placement of artificial implants. Additionally, this device can also measure the ROM up to the dislocation by ensuring the distance of the center of the cup and ball head is set with the registration of the pelvis and the femur. Three-dimensional (3D) computer simulation software also helps in improving the view of osteophytes in the surgical field and the projected image of the monitor as well as in improving the accuracy of preoperative planning. In addition, its performance made it possible to simulate the postoperative ROM without involving soft tissues.

The aim of this study was to investigate the intraoperative change of ROM due to the difference in femoral head diameters in the same patient using a navigation system. Moreover, we also aimed to clarify the difference between the postoperative ROM speculated by 3D computer simulation software and the actual intraoperative ROM.

2. Materials and methods

2.1. Patients and ethical statements

A total of 14 patients (12 female and 2 male patients) who underwent one-sided primary THA for hip osteoarthritis caused by developmental dysplasia of the hip (DDH) in our hospital from January 2011 to November 2012 were included. Patients' mean age during the surgery was 61.3 years (37–78 years), the mean height was 154.1 cm (141–173 cm), and the mean weight was 57.4 kg (45–81 kg). There were a total of 14 joints, with 5 right and 9 left hip joints (Supplementary Table 1). The study was approved by the Ethics Committee of XXX University (XXX, 15th September 2016) and was performed in accordance with the ethical standards of the 1964 Declaration of Helsinki and its later amendments. All patients were informed of the possible risks of surgery and provided written consent before the procedure.

2.2. Surgical procedures and devices implanted

All patients underwent a CT scan of their hip joint 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.

Prior to surgery, the objective angle was set at 40° and 15° of radiographic inclination and anteversion, respectively. Vector Vision Hip (Vector Vision Compact Hip CT version 3.5.2; Brain Lab, Munich, Germany) was used as the navigation system. After placing the antenna at the iliac crest, two fluoroscopic images with an angular difference of 20° or more, capturing the pubic symphysis and obturator foramen of the surgical side, were taken. The fluoromatch registration was conducted by pointing the anterior superior iliac spine and iliac crest of the surgical side and was compared with the preoperative CT. In the femoral side, the antenna was placed distally from the femur, two fluoroscopic images containing the femoral head, greater trochanter, and proximal femoral shaft with an angular difference of 20° or more were taken, and the fluoromatch registration was carried out in a similar

manner to the pelvic side by pointing the medial and lateral condyle. The center of rotation of the hip joint was determined by moving the femur. The divergence in all cases was within 2 mm. The preoperative ROM was measured by placing the patients in a complete lateral decubitus position. Surgery was performed under general anesthesia, and the posterior lateral approach was used, detaching the short external rotator muscles and joint capsule from the trochanteric fossa and intertrochanteric crest. On the stem side, broaching was conducted with reference to the visual lower thigh axis. AMS cup (Japan-Kyocera, Shiga, Japan), Aqala AMS polyethylene liner (Japan-Kyocera, Shiga, Japan), Wright Medical Pro-femur TL (MicroPort Orthopedics Inc, Arlington, Tennessee, USA), and BIOLOX[®] delta ball head (MicroPort Orthopedics Inc, Arlington, Tennessee, USA) were used.

2.3. Intraoperative evaluation

After placing the cup and the stem, 28- and 32-mm trial liners were set up. In a cup with a size of 52 mm or more, a 36-mm trial liner was used. All trial liners used were flat. Taking into consideration the leg length difference and the offset, the trial neck selected was either short or long. The trial heads with a neck length ± 0 of 28 mm and 32 mm were used. In this study, dislocation was defined as the movement of the femoral head center by 5 mm, which is the limit of the navigation system. The hip joint angle was recorded when the movement of 5 mm or more occurred. The measured items were hip flexion at a 90° knee joint flexion position, hip extension/abduction/inside/outside rotation at a knee joint extension position, and internal rotation at a 90° knee joint flexion position and 60° hip joint flexion position. Finally, the cups used were 48–52 mm in size, the ball head diameters were 28 mm–36 mm, and the stems were 1–5. Eight joints had short necks, whereas six joints had long necks. The capsule and short external rotator muscles were repaired in all cases.

2.4. Postoperative evaluation

After undergoing a CT scan post-surgery, the imaging data were processed using the 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), which included the implant database with computer-aided 3D design models provided by the implant manufacturer. With ZedHip, the cup inclination, cup anteversion, and stem anteversion were measured after the implants were set at the same position and angle as the postoperative CT. The actual ball head used was also elected, and we calculated the simulated ROM that was performed intraoperatively.

2.5. Statistical analysis

For the statistical analysis, preoperative ROM, intraoperative ROM of each ball head diameter, and postoperative simulated ROM were compared using the Wilcoxon-signed rank test ($p < 0.05$) using EZ-R.

3. Results

The mean cup inclination was 35.64° (range: $31\text{--}43^\circ$), the mean cup anteversion was 18.50° ($15\text{--}26^\circ$), and the mean combined anteversion was 50.21° ($43\text{--}59^\circ$) (Table 1). As shown in Table 2, the ROM was generally increased in the following order: preoperative < 28-mm diameter < 32-mm diameter. Internal rotation was remarkably increased intraoperatively compared to that

Table 1

Preoperative range of motion (ROM) and the ROM with 28-mm or 32-mm femoral ball head. Approximately close to the preoperative ROM, the ROM expands in the following order: preoperative < 28 mm < 32 mm. The internal rotation increased remarkably intraoperatively than preoperatively because of the posterolateral approach.

(Degree)	Preoperative ROM	Head size	
		Φ28 mm	Φ32 mm
Flexion	73.36 ± 17.30	74.00 ± 11.93	75.36 ± 11.41
Extension	11.71 ± 5.87	11.50 ± 7.62	13.14 ± 8.10
Abduction	24.71 ± 10.33	28.21 ± 9.62	31.21 ± 10.65
Internal rotation	18.00 ± 12.64	47.07 ± 15.89	45.21 ± 14.91
External	15.14 ± 7.23	19.64 ± 12.34	22.21 ± 14.72
Internal rotation with 60° flexion	–	54.07 ± 12.50	54.71 ± 11.30

Table 2

The comparison of the 36-mm femoral ball head with 28-mm and 32-mm femoral ball heads. Seven joints are inserted with 36-mm femoral ball heads. The flexion angle and internal rotation until dislocation with flexion of 90° increased by the use of a 36-mm femoral ball head than with the use of a 32-mm femoral ball head. However, it was equal or lower for the ROM in other directions.

(Degree)	Head size		
	Φ28 mm	Φ32 mm	Φ36 mm
Flexion	78.71 ± 8.10	79.14 ± 9.61	81.29 ± 9.62
Extension	12.57 ± 8.50	16.86 ± 5.96	13.71 ± 6.84
Abduction	31.00 ± 9.09	36.14 ± 10.47	28.71 ± 9.33
Internal rotation	39.57 ± 12.37	37.71 ± 13.20	36.14 ± 13.35
External rotation	23.14 ± 13.34	29.57 ± 14.69	20.29 ± 10.36
Internal rotation with 60° flexion	47.14 ± 12.57	49.14 ± 13.13	53.29 ± 8.36

preoperatively because of the posterolateral approach in the 28-, 32-, and 36-mm heads.

A cup with a size of 52 mm or more and a femoral head with a diameter of up to 36 mm were used in 7 joints. The 36-mm-diameter femoral head increased the internal rotation angle until dislocation at 90° hip flexion compared to the 32-mm-diameter femoral head. However, in other directions, the ROM of the 36-mm-diameter femoral head was equal or lower than that of the 32-mm-diameter femoral head (Table 2). A significant increase in the ROM ($p = 0.005$) was found due to the increase in the femoral ball head diameter at the internal rotation and abduction angle (Supplementary Table 2). There was no significant difference in the dislocation position of hip flexion and internal rotation. None reached 80% of the simulated ROM with the ZedHip, whereas the flexion and abduction reached up the 50% or more of the simulated ROM (Table 3). There was a tendency that the difference between the simulated ROM and the intraoperative ROM was small, whereas the difference between the final ROM after device implantation and the preoperative ROM was large (Fig. 1).

4. Discussion

The ROM and dislocation after THA are affected by patient's factor, surgical technique, and instrument, such as patient's age, sex, original disease, preoperative ROM, pelvic tilt, joint laxity,

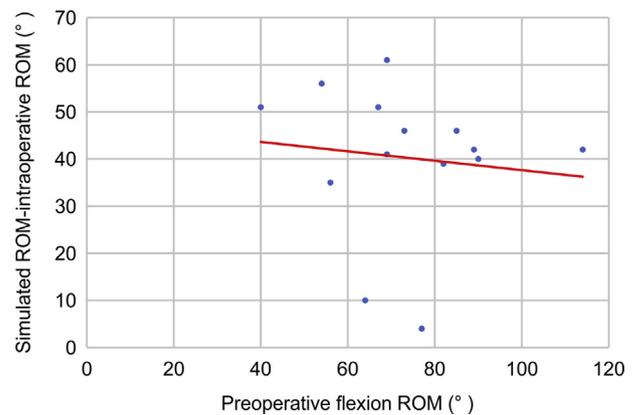


Fig. 1. The ROM simulated by ZedHip and preoperative ROM. Correlation coefficient is -0.244 . Given that the preoperative ROM is better, the difference between the simulated ROM and the ROM measured during surgery tended to decrease.

dementia, surgical approach, instrument placement position/angle, implant size, offset, osteophyte, soft tissue balance, leg length, and so on. However, perpendicular dislocation of the femoral head occurs less frequently in clinical setting in most cases; the impingement of the femur including the stem and the pelvis is expected as

Table 3

The comparison between the intraoperative ROM and the postoperative ROM simulated by ZedHip. As the soft tissue, such as short external rotator muscle, is cut off by the posterolateral approach, the flexion and internal rotation angles are closest to the simulated ROM; however, these did not reach 80%.

(14 joints)	Intraoperative ROM (°)	Simulated ROM (°)	Intraoperative ROM/simulated ROM (%)
Flexion	76.21 ± 11.47	116.50 ± 16.80	65.4
Extension	13.07 ± 6.32	58.29 ± 22.22	22.4
Abduction	29.29 ± 10.78	55.64 ± 14.97	52.6
Internal rotation	44.50 ± 14.08	93.64 ± 15.62	47.5
External rotation	18.93 ± 10.85	53.79 ± 26.37	35.2
Internal rotation with 60° flexion	52.00 ± 10.13	63.79 ± 24.52	76.7

the major cause of this dislocation. Implants, bones, and soft tissues are considered as interference factors during impingement.

The merit of using femoral heads with a large diameter is that it prevents dislocation due to the enlarged oscillation angle and jumping distance. However, it could increase friction torque and wear, has thinner liner, and may result in neck corrosion, which should be taken into consideration in clinical settings. In addition, dislocation may also occur due to the interference factors caused by bone and soft tissues; thus, its true effect should be verified before its clinical use.

Regarding the dislocation tolerance, Cuckler et al. reported no dislocation with the use of large diameter femoral heads until 3 months postoperatively, as compared with using a 28-mm ball head, with demonstrated a dislocation rate of 2.5%.² Amilie et al. also reported a lower dislocation rate when using a 32-mm than a 28-mm-diameter femoral head in patients who underwent the procedure with the posterolateral approach, regardless of gender, age, and source disease.³ Bistoli et al. also reported that the dislocation rate was 3.9% and 0.5% in 28- and 36-mm-diameter femoral heads.⁴ In other studies, there was no significant difference in the dislocation rate among the 28-mm, 32-mm, and 38-mm femoral heads; however, the dislocation rate was as low as 0.4% in patients with more than 38-mm-diameter femoral heads.^{5,6} On the other hand, Lu al. reported that the dislocation rate of 32-mm or less femoral head was similar to that of 36-mm femoral head in THA using ceramicon ceramic.⁷ However, in clinical practice, the efficacy of a large diameter head in preventing dislocation is still controversial.

The effect on the oscillation angle and the ROM due to the increase in size of the femoral head diameter was reported in a cadaveric and computer simulation study. Klingenstein showed that the large femoral head increased the oscillation angle in their three-dimensional model study.⁸ Cinotti et al. reported the effectiveness of the large diameter head, but the effect became small when 32-mm or more was used in their mathematical model study.⁹ In addition, even if the femoral head diameter increases, it is possible that osseous impingement reduces its effect. A study using a 3D computer model showed that the effect of the large diameter head on ROM was limited, because it likely caused osseous impingement.¹⁰ In a computer simulation study, stability was improved by using a large head when the cup inclination was large.¹¹ Moreover, a cadaveric study showed that implant-to-implant impingement occurred in a 22-mm-diameter femoral head, but in a 32-mm-diameter femoral head, osseous impingement between the femur and pelvis occurred.¹² These studies suggested that the ROM depends on the bony factor if the cup and the stem are placed with proper alignment, thereby the use of the large diameter head may not change the actual ROM.

In a clinical study, Matsushita et al. reported that postoperative flexion and abduction angles of 32-mm femoral heads were significantly larger than those of 26-mm-diameter femoral heads.¹³ Another study comparing the 28- and 40-mm femoral heads showed that the flexion, extension, abduction, and internal rotation were significantly larger in patients with 40-mm femoral heads.¹⁴ Lu et al. also reported that femoral heads with a diameter of 36 mm or more have increased flexion angle compared to 32-mm femoral heads in patients who underwent ceramicon-ceramic THA.⁶ On the other hand, no difference in postoperative ROM was shown between the various head diameters in a case-control study.¹⁵

In this study, the conditions, except for the diameter of the femoral ball head, are the same to accurately examine the effect of the femoral ball head diameter. Only the flexion ROM tended to expand due to the increase in femoral ball head diameter, but the difference was not significantly different. Given that there is a

wider space for flexion, which makes the patient less susceptible to the influence of bony protrusion and soft tissue intervention compared to the other movements, it seemed that the effect of increasing the oscillation angle owing to the increase in femoral ball head diameter directly reflects the intraoperative range of motion. The posterior approach was needed to detach the posterior support of the hip joint, which led to the removal of posterior strain and increase in flexion and internal rotation ROM due to the large diameter femoral ball head. Hip abduction ROM increased significantly from 28 mm to 32 mm, but a significant decrease was observed between 32-mm and 36-mm femoral ball heads. It is expected that abduction is more likely to be affected by soft tissue and osseous impingement between the tip of the great trochanter and acetabulum, because the distance of anatomical bony protrusion is short. As the preoperative ROM was better, the difference between the simulative ROM and the intraoperative ROM surgery tended to decrease. This result suggests that flexibility of the soft tissue around the hip joint before operation is important. This study showed that there is a limit to the effect on increasing the ROM by the head diameter due to influence of bone and soft tissue.

The fact that there was a difference between the simulated ROM in ZedHip using CT and the intraoperative ROM proves that existing soft tissue is an important factor in ROM. Although it seems that the surgical approach also influenced this discrepancy, the simulation test evaluating bones only may become the barometer, but it cannot predict the actual postoperative ROM correctly.

This study has several limitations. First, as the dislocation in this study was defined as the range of motion until the center of the femoral ball head moves by 5 mm from the original position, there is a possibility that the range of motion could not be contained completely until the final true dislocation. Second, given that the patients were under anesthesia during the procedure, pain, bathyesthesia, and muscle resistance are eliminated; thus, the ROM until dislocation in awake patients may not necessarily show the same results. Third, the sample size is small. If the sample size was larger, the ROM of flexion and flexion-internal rotation would be increased with a significant difference; however, clinically, it is difficult to conclude that there is a remarkable increase of the ROM that can be calculated mathematically.

5. Conclusion

The expansion of the ROM due to the increase in femoral ball head diameter can be obtained even in vivo, but it was suggested that there is a limitation on the effect because of the interference of bone and soft tissue. It is shown that the presence of soft tissue influences the discrepancy between the ROM of 3D simulation and the intraoperative ROM. It is recommended that surgeons should provide comprehensive management for patients who underwent one-sided primary THA for hip osteoarthritis to obtain a wider ROM and resistance to dislocation without relying solely on the size of the ball head, because the ROM in vivo is dependent on multiple factors, such as skeletal anatomy, interventions of bone and soft tissue, or soft tissue tension.

Author contributions

Nobuhiro Kaku was involved in Study design, concept and writing the manuscript. Hiroya Akase and Shouhei Noda were involved in data acquisition and analysis. Hiroaki Tagomori and Masashi Kataoka were involved in Interpretation. Hiroshi Tsumura was involved in supervision of research.

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Declarations of interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jajs.2019.05.001>.

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