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Current Concepts of Using Large Femoral Heads in Total Hip Arthroplasty

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Instability and dislocation after total hip arthroplasty are the most common causes of revisions and major complications for failure of inserted prostheses, leading to a reduction in quality of life. Because the use of artificial femoral head sizes smaller than patient's own size is the important cause for dislocation, the use of large femoral head have increased. Femoral head sizes greater than 32 mm offer multiple advantages in physical function and activity levels of patients by improving hip stability, decreasing dislocation rate and increasing range of motion. However, various concerns are encountered including wear debris generation at the trunnion-bore interface and increases in frictional torque and stress over the component-bone interface when using larger head sizes. So, the use of femoral head sizes less than 40 mm is recommended.

Key Words: Large femoral head, Instability, Dislocation, Total hip arthroplasty

INTRODUCTION

Recent advances in prosthetic materials, shapes, and articulating surfaces of total hip arthroplasty (THA) have helped, to some degree, overcome wear, one of the most chronic complications. However, instability and dislocation are the most common causes of THA revisions and major complications for failure of inserted prostheses, leading to a reduction in quality of life. Although the use of femoral head sizes smaller than patient's own femoral heads is a critical cause for dislocation, the use of larger femoral heads has been limited by increased volumetric wear at bearing surfaces. Great efforts have been made to reduce wear rates, and the materials of articulating surfaces have advanced a great deal leading to the more extensive use of larger femoral head articulations in an effort to overcome postoperative instability when performing THA. In particular, larger femoral head sizes have been frequently used in cases with instability risk factors including female gender, advanced age, neurovascular or cognitive disorders, substance abuse, soft tissue deficits of the hip, previous hip surgery, and others. The use of large femoral head sizes are common in THA in the United States, rising from 1% in 2001 to 58% in 2009. This aim of this paper is to review the literature and issues on the use of larger femoral heads in hip replacement as bearing surfaces.

BACKGROUND

When McKee-Farrar et al. performed hip arthroplasties using large femoral heads in the 1950s, dislocation was

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not an important issue at the time[1-3]. Major concerns were destruction at the prosthesis-bone interface and component loosening due to instable prosthesis design and higher frictional torque increased by the larger head size[4]. Charnley[5] used a 41.5 mm diameter femoral head in primary THA, but experienced early failure due to massive wear-through of the acetabular component. Subsequently, he used a smaller diameter head (22.25 mm) to hip arthroplasty in order to reduce high frictional torque resulting from a large head size and used a thicker polyethylene liner by assuming that wear-through originated from the use of a thin polyethylene component[6]. Charnley's concept has been practiced predominantly over the past 50 years due to limitations of polyethylene quality. To prevent instability and dislocation caused by the use of small head sizes, Charnley used a 22 mm diameter femoral head in hip arthroplasty for stability of the femoral head and polyethylene liner, and achieved a dislocation rate of less than 1% through additional deepening of the acetabulum by 2 mm, preservation of the superior capsule, anteversion of the acetabular cup, and distal advancement of the greater trochanter by 1 cm after trochanteric osteotomy[7].

A large number of surgeons including Fender et al.[8] applied the same surgical technique of THA advised by Charnley, but they were unable to achieve the same low dislocation rate and expereined dislocation rates of more than 5%. Because higher linear wear rates resulted from the use of a 22 mm diameter head, head sizes gradually increased from 22 mm to 26 mm, 28 mm, and 32 mm. However, head sizes less than 32 mm diameter were chiefly used due to high volumetric wear increases associated with larger femoral heads. Nevertheless, dislocation remains a major concern after total hip replacement. Though various sizes of femoral heads have been used in THA, previous studies on component instability and wear according to femoral head sizes have revealed a higher volumetric wear rates in 32 mm diameter heads compared to those 22 mm or 28 mm in diameter. The volumetric wear rate has negligible influence, while stability has improved substantially[9,10]. With recent advances in articulation materials such as polyethylene, metal, ceramic and others, progress has been made on wear, one of the most common chronic complications after THA. As a result, femoral heads larger than 36 mm in diameter are more widely used for hip stability after hip replacement.

WEAR

Wear is an important factor in the survival of hip prostheses, and is the most common cause for revision THA. The two major wear mechanisms are abrasive and adhesive wear[11]. Abrasive wear occurs between surfaces during frictional contact, while adhesive wear occurs when bonding of microcontacts exceeds the inherent strength of a material. Wear debris is inevitable followed by sliding between two materials due to the worn surfaces in contact, and the diameter of a femoral head is a crucial factor in production of wear debris.

1. Basic Mechanism

Contact surface and sliding distance are critical aspects in the production of wear particles. When two surfaces slide against each other, the softer material usually wears more. After THA using a 28 mm diameter head, each walking step produces an excursion of about 2 cm between the femoral head and polyethylene liner. Presuming that annual walking steps are one million, the surface area of sliding bearing surfaces is equivalent to approximately 2,463 m^2, the size of six basketball courts[12]. Since the contact area of articulating surfaces and sliding distance increase with the diameter of a femoral head, the degree of volumetric wear differs by articulation material. The formation of volumetric wear debris increases with $\upsilon=\pi\gamma 2w$ (υ, volume of debris from wear; γ, radius of the femoral head; w, linear migration distance of the femoral head). Frictional torqueis proportional to the diameter of the femoral head, and this torque is an important factor leading to the destruction of the contact area, between the component and the bone, and component loosening[4]. Increased friction associated with the use of larger diameter heads is an insignificant issue with respect to failure of prosthetic components developed by instability, as long as wear amount produced by increasing head size is insignificant and stable fixation can be achieved between the prosthesis and the bone[13]. Jasty et al.[9] reported that abrasion and adhesion are principal mechanisms of wear between the femoral head and acetabular cup after THA, and sliding distance and the number of sliding contacts are more important factors than weight load imposed on the joint. In addition, they addressed that wear rate increased from 7.5% to 10% in metal-on-polyethylene bearings with an increase of 1 mm in femoral head diameter. Therefore, wear-resistant bearings need to be chosen as a prerequisite when head sizes larger than 36 mm are used.

DISLOCATION

Dislocation following THA is the most common reason for revision surgery. Even though dislocation rates seem to decrease with advancements in implant design and surgical techniques, the frequency of dislocation after THA still ranges between 1.0% to 4.9% after primary THA, and 4.8% to 20% after revison[14-17]. The primary causes of dislocation may be patient-related, operative-related and/or implant-related factors. Patient-related factors include dislocation rates that are twice as high in females than males, ages older than 70 years, smaller muscle mass, underlying diseases requiring surgery, neuromuscular status and patient compliance. Operative-related factors include posterior approach in posterior dislocation, anterior approach in anterior dislocations of tissue imbalance, component mal-positioning and others. Implant-related factors include femoral head size, head-to-neck ratio, head-to-metal shell size, types of the inner liner and others. The most common cause for dislocation is mal-positioning of the acetabular cup and femoral stem which requires early revision surgery[1]. The three main mechanisms of dislocation are component-to-component impingement, bone-to-bone impingement and spontaneous dislocation. Component-to-component impingement occurs as the femoral head escapes from the acetabular cup when the prosthetic femoral neck impinges on the liner at extremes of motion. A decreased head-to-neck ratio may increase dislocation risks[18]. The Charnley implant with a head-to-neck ratio of 1.74 in the acetabular cup with an anterior angle of 20° impinged on the liner at a hip flexion of 80°. On the contrary, the T28 prosthesis with a head-to-neck ratio of 2.01 to 3.24 had no impingement until a hip flexion angle of 114°[7]. Bone-to-bone impingement typically occurs between the trochanteric area of the femur and the pelvic ring. Spontaneous dislocation results from inverse high Newtonian joint force applied posterolaterally with movement of the hip into adduction and flexion.

1. Basic Mechanism

The advantages of using large femoral heads are as follows: (1) increased range of motion in all directions (Fig. 1); (2) no component-to-component impingement and increased joint range of motion after removal of the bone at the site of impingement in cases of delayed bone-to-bone impingement; and (3) no need of a skirt for improved stability of the trunnion and femoral head socket areas when using a long neck (increase of the relative head-neck ratio). Since larger diameter heads require a longer distance of displacement for dislocation, they are more stable than smaller diameter heads[1,19] (Fig. 2). A 32 mm diameter head has a greater rotation, flexion and extension angles by approximately 10° to 20° compared to a 22 mm diameter head[20,21]. Scifert et al.[22] have reported that range of motion increases 0.84° ±0.43° in all movement directions with each 1mm increase in the head size, and the peak moment resisting dislocation increased 3.6%. The 38 mm and 42 mm heads result in range of motion increases by 6° and 16°, respectively, compared to a 32 mm head before dislocation[21]. In another previous study on the range of

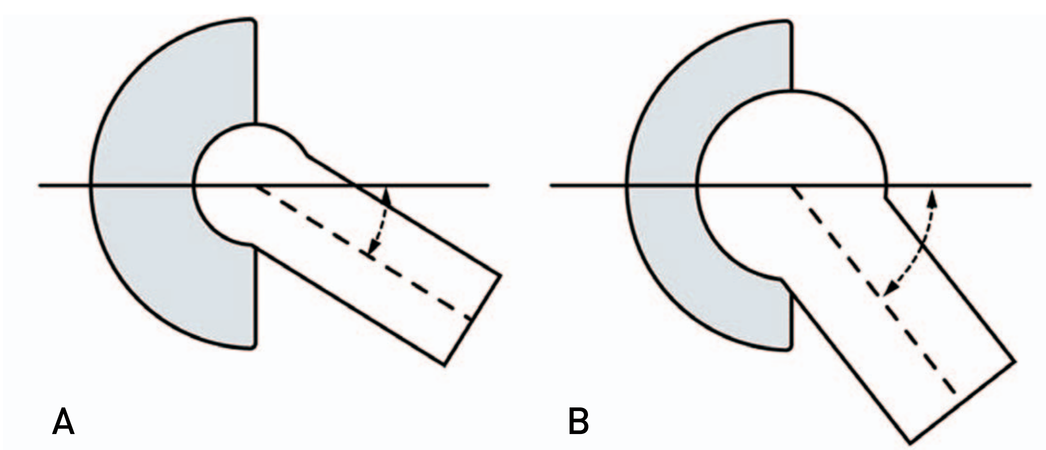

Fig. 1. A larger diameter head (B) has the greater range of motion than smaller one (A) by delaying neck socket impingement.

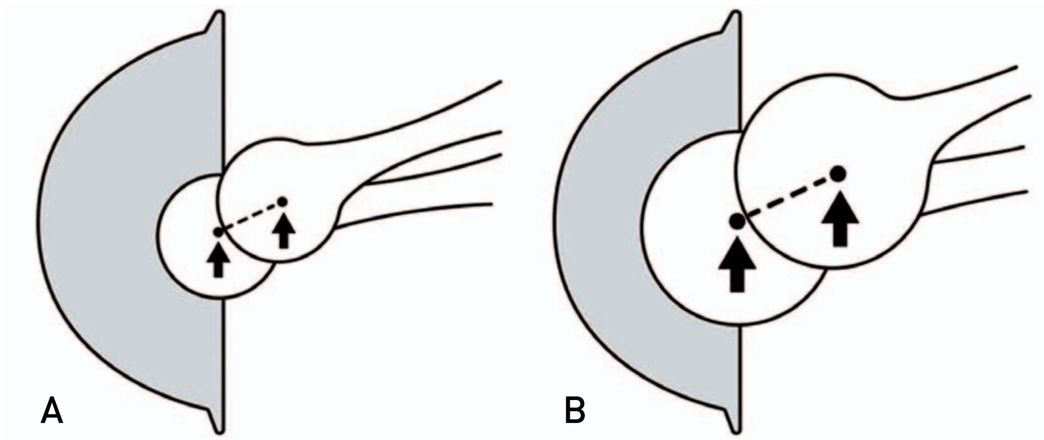

Fig. 2. A larger femoral head (B) must be displaced by greater distance than smaller one (A) for complete dislocation.

motion according to femoral head sizes with the hip in adduction, impingement in the hip during the flexion occurred at 84.6° ±2° in a 28 mm head and 96.3° ±1.9° in a 38 mm head, increasing by 11.7°. Flexion angles to dislocation were 105.2° ±4.0° in a 28 mm head and 112.0° ±4.0° in a 38 mm head, increasing by 6.8°. Component-to-component impingement may induce instability, subluxation, dislocation, component loosening and other complications in the hip by exerting stress at the cement-to-bone or component-to-bone contact. The use of larger femoral heads lowers the risk of component-to-component impingement, and increases the range of motion after removal of the bone causing impingement in cases of delayed bone-to-bone impingement[23]. Pasley[24] reported that impingement rates of the femoral neck against the edge of the liner were 94% in a 22 mm head and 64% in a 38 mm head, and a 44 mm head required an additional displacement of 9 mm to incur dislocation compared to a 28 mm head[25]. A skirt offers better stability of the trunnion and femoral head socket when using a long neck femoral head with thin groove, and can lead to an increase of head-to-neck ratio as the thickness of the neck increases twice the thickness of the skirt. As a result, the hip joint range of movement can be limited, thereby increasing the risk of dislocation. Since larger femoral heads do not require a skirt by allowing greater stability at the taper junction compared to smaller heads having the same contact surface area between the femoral head socket and trunnion[26].

WEAR ON TRUNNION-BORE INTERFACE

The modularity of the femoral head allows restoration of the leg-length and hip offsets, optimization of soft tissue tension, and easier exposure during revision surgery. However, this sophisticated procedure requires a strong Morse taper connection between the socket (bore, female taper) and the proximal end (trunnion, male taper) of the femoral stem. The principle of the Morse taper is a cone in cone design which provides better stability by compressing the socket wall of the femoral head and the connected trunnion. Intimate conical connection between the trunnion and bore enables firm contact. However, the ingress and micro-movement of fluid may occur during cyclical mechanical loading, since microscopic gap (crevice) may exist on the matins surface of male and female cones. This may increase the risks for disruption of the passive surface oxide layer and susceptibility to mechanically assisted crevice corrosion (MACC, tribocorrosion) on the metal surface. The development and deterioration of MACC are associated with taper design, metal-alloy mismatch (Galvanic corrosion), implant positioning, implantation time, joint loading magnitude, numbers of loading cycles, frictional torque at the bearing surface, patient and surgical factors (tissue inter-positioning, failure to achieve initial engagement) and others. Particulate debris and metal ions are released through mechanical and corrosive mechanisms, and these may lead to several adverse tissue reactions and even mechanical failure at the taper junction in the worse cases[27-34]. The use of larger head sizes increases frictional torque, and increased frictional torque elevates stress at the taper junction, thus causing an increase in bending moment with increased offset between the head center and trunnion interface center of pressure (Fig. 3). Trunnionosis-type wear may occur resulting from micro-motion between the male and female taper, thus

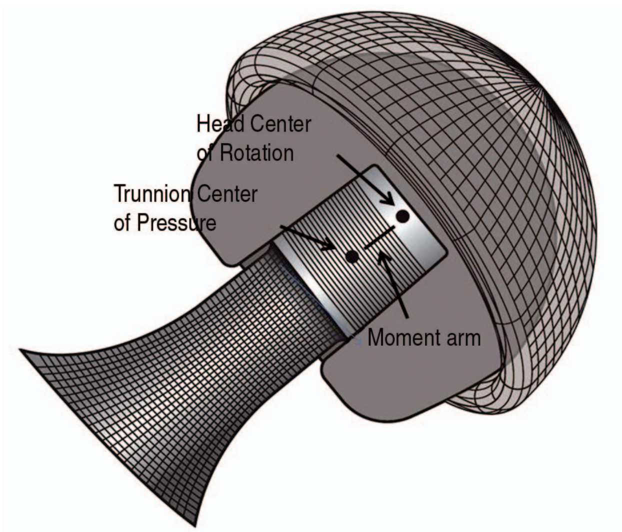

Fig. 3. When appropriately seated on the tapered trunnion of the neck, a moment arm exists between the center of rotation of the head and the center of pressure on the trunnion.

providing theoretical support for local adverse tissue reactions caused by metal particles from metal-on-metal articulation even when using metal-on-polyethylene as the articulating surface, due to metal debris from the taper junction. Stability improves about 10% as the head size increases from 32 mm to 36 mm, but only 4.7% when the head size increases from 40 mm to 48 mm, indicating that the increase of head size beyond a certain size has an insignificant influence on stability. On the other hand, peak stress imposed on the trunnion during ambulation increases with increasing femoral head diameter, elevating to 3.5%, 9.5%, 24%, 40% and 51% in 40 mm, 44 mm, 48 mm, 52 mm and 56 mm head, respectively. Considering stability and trunnion-related problems, the use of femoral heads smaller than 40 mm is recommended[33)].

ANTERIOR HIP AND GROIN PAIN

Large diameter femoral heads have also been linked to an increased likelihood of anterior hip and groin pain, which is thought to be related to anterior soft-tissue impingement, most commonly against the iliopsoas muscle or tendon[35-37)]. One recent study demonstrated that large-diameter bearings were associated with a significantly higher rate of groin pain (15% to 18% vs. 7%) compared with conventional implants[35)]. Although this condition can often be overlooked in outcome studies because it is not sufficiently symptomatic to lead to revision total hip replacement; anterior hip pain from large femoral heads can affect patients quality of life, and should not be ignored. Recently, so-called 'anatomically-contoured heads' have been introduced with the proposed benefit of decreasing this anterior soft-tissue impingement in large diameter total hip replacement[38,39)]. While these were designed to have no impact on resistance to dislocation or wear performance[38)], it remains to be seen whether these relatively small changes in head shape will improve clinical outcomes and reduce groin pain.

METAL ON POLYETHYLENE AS AN ARTICULATING SURFACE

Wear debris commonly occurs in the ultra-high molecular weight polyethylenes (UHMWPE) component with low strength after THA, and these particles are major causes for aseptic loosening. Moreover, polyethylene thickness is a critical factor leading to wear. Thin polyethylene materials accelerate wear with increases in contact stress. A minimum of 7 mm thickness is appropriate for conventional polyethylene liners[40-43)]. A first generation highly cross-linked polyethylene has demonstrated wear in an *in vitro* study after 20 million cycles using a 22 mm head. Liner wear rate was 0.015 ± 0.01 mm/million cycles (0.12 ± 0.01 mm/million cycles using conventional polyethylene material), and the mean total wear rate was 1.5 ± 0.1 mg/million cycles (14 ± 2 mg/million cycles using conventional polyethylene material). No difference was found in wear rate regardless of the increase in femoral head sizes (from 22 mm to 46 mm)[44,45)]. Based on these findings, the use of larger head sizes has begun and *in vivo* studies have revealed consistent outcomes on the decrease in wear rate during mid- and long-term follow-up periods. However, issues have been raised over the potential risk of fatigue fractures caused by changes in mechanical strength, despite reductions in polyethylene free radicals after a remelting process during the manufacturing of highly cross-linked polyethylene. Free radicals still exist in polyethylene even after an annealing process. For this reason, although a second generation highly cross-linked polyethylene after removal of the residual free radicals with vitamin E is used in clinical practice, the long-term follow-up results of *in vivo* studies have not yet been reported. Contact stress between the polyethylene liner and metal shell is a critical factor in the amount of wear[46]. Since reduction in polyethylene thickness is inevitable when using large femoral heads within the acetabular component (due to space limitations), polyethylene thickness has remained controversial when using larger heads. A high wear rate results from a thin polyethylene component and high contact stress. Catastrophic failure may occur due to wear-through and polyethylene destruction with the use of conventional polyethylene components with a wall thickness of less than 5 mm. Even though the thickness of conventional polyethylene components has to be 7 mm at minimum, Muratoglu et al.[44] have proposed the use of a first generation highly cross-linked polyethylene having a thickness greater than 5 mm. Thinner polyethylene components with changes in mechanical strength and oxidation due to the presence of free radicals increase the risk of fractures at the crack and polyethylene edge of the polyethylene notch with the thinnest thickness. Though previous studies have reported component mal-position as the cause of polyethylene fractures, cautious monitoring is warranted. Most studies recommend polyethylene components with a minimum of 6 mm thickness when using the first generation highly cross-linked polyethylene.

METAL ON METAL (MOM) AS AN ARTICULATING SURFACE

The use of larger femoral heads has been suggested to reduce wear of articulating surfaces as the coefficient of friction decreases with improvements in fluid film lubrication of articulating surfaces with increasing head sizes in case of MOM articulation. These advantages have been revealed by intermediate-term clinical results of current-generation modest-diameter MOM bearings. However, high short-term failure rates may be associated with increased metal ion, wear-associated adverse soft tissue reactions (metallosis, aseptic lymphocytic vasculitis-associated lesions, pseudotumors and adverse reaction to metal debri, etc) and other problems. Although these increasing concerns with the use of larger diameter heads send a strong warning about the use of MOM articulation, resurfacing arthroplasty is being performed in some young active patients excluding women?of childbearing age[31].

CERAMIC ON CERAMIC (COC) AS AN ARTICULATING SURFACE

COC articulation has the lowest wear rate as a result of excellent hardness and fluid film lubrication, and is commonly used for patients with higher levels of activity and longer life expectancy because of the biologically inactive property of ceramic particles released to the body from articulating surfaces. Since greater hardness enables the use of a thin liner, large femoral heads can be used with the small-sized acetabulum. However, concerns over noise, squeaking, micro-separation, increased susceptibility in component-to-component impingement and fracture risk still remain controversial. Despite these controversies, more careful monitoring is warranted when using COC articulation in larger heads, because some studies have suggested that stiff ceramic heads may increase stress over the trunnion compared to metallic heads[47].

CONCLUSION

Femoral head sizes greater than 32 mm offer multiple advantages in physical function and activity levels of patients by improving hip stability, decreasing dislocation rate and increasing range of motion. However, various concerns are encountered including wear debris generation at the trunnion-bore interface and increases in frictional torque and stress over the component-bone interface when using larger head sizes; more severely elevated metal ion levels and wear-associated adverse soft tissue reactions in MOM articulating surfaces with increasing head sizes; and increase in stress over the trunnion associated with stiff ceramic heads compared to metallic heads, squeaking and fracture risk in COC articulating surfaces. Careful consideration is required to maximize the benefits of using larger heads including selecting the most appropriate size and materials of articulations because many potential challenges still exist. Currently, the use of femoral head sizes less than 40 mm is recommended.

CONFLICT OF INTEREST

The authors declare that there is no potential conflict of interest relevant to this article.

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