

Large-Diameter Femoral Heads in Total Hip Arthroplasty: An Evidence-Based Review

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Abstract

Recent advances in the wear characteristics and material properties of highly cross-linked polyethylene and fourth-generation ceramic bearings have led to increasing use of large-diameter (≥ 36 mm) femoral heads in total hip arthroplasty (THA).

In this article, we review the current concepts and principles behind use of large-diameter ceramic or cobalt-chromium femoral heads on polyethylene bearings in THA. We specifically review the biomechanics, some of the early concerns about polyethylene wear and rim fractures, recent improvements in material properties of polyethylene and ceramic bearings, dislocation rates, and clinical and functional outcomes of large-diameter heads in THA.

Recent literature suggests that the incidence of dislocation has been substantially reduced because of improvements in jump distance and impingement-free range of motion with use of large-diameter heads. Limited evidence suggests excellent short-term and midterm clinical and functional outcomes with these heads.

A common cause for total hip arthroplasty (THA) revision is joint instability.^{1,2} The reported incidence of dislocation in primary THA ranges from 0.4% to 5.8%,³⁻⁵ but this rate increases after revision surgery.^{1,3-8} Use of large-diameter femoral heads has been proposed to decrease the risks for instability and to improve impingement-free range of motion (ROM).

The biomechanical rationale for using large-diameter femoral heads is that they must travel farther before subluxation or dislocation occurs (jump distance). Despite these benefits, there were initial concerns that catastrophic failure and high levels of volumetric wear would occur if these heads were used with conventional polyethylene liners. These concerns led to

the development of alternative bearing surfaces, particularly metal-on-metal bearings, which offered theoretical benefits of large-diameter articulations that improved stability while purportedly being highly wear-resistant.⁹⁻¹¹ However, concerns about adverse local soft-tissue reactions and high blood concentrations of metal ions tempered the initial enthusiasm for metal bearings.¹²⁻¹⁶ Fortunately, highly cross-linked polyethylene and fourth-generation ceramic bearing surfaces, with improved toughness and better wear properties, may allow use of large-diameter heads without the need for metal-on-metal bearings.^{17,18}

In this article, we review the concepts and principles behind use of large-diameter ceramic or cobalt-chromium femoral heads on polyethylene-bearing surfaces in THA with particular attention to biomechanics, early concerns about polyethylene wear and rim fractures, recent improvements in material properties of polyethylene and ceramic bearings, dislocation rates, and clinical and functional outcomes.

Definitions

For this review, we define *large-diameter femoral heads* as having diameters of 36 mm or more and *conventional* or *small-diameter femoral heads* as having diameters between 22 and 32 mm.

Biomechanics

Head-Neck Ratio, Impingement-Free ROM, and Jump Distance

Several implant design principles have been proposed to reduce the risks for impingement and dislocation. Of these, large femoral head diameters have been extensively studied.^{19,20} It is well known that impingement of the femoral neck on the cup edge promotes edge loading and higher wear rates. In addition, impingement increases the tendency of the head to sublux from the acetabulum. One strategy for avoiding this component-to-component impingement is to increase the head-neck ratio (HNR), the ratio of the femoral head to the neck diameter. Biomechanically, increased HNRs lead to delayed contact between the femoral neck and the acetabular liner.^{21,22} Therefore, with large femoral heads, which have large HNRs, impingement occurs later and at larger ROMs—compared with small-diameter

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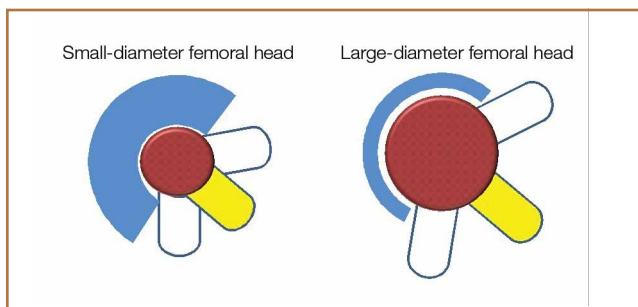


Figure 1. Large-diameter (≥ 36 mm) femoral heads offer more prosthetic impingement-free range of motion than small-diameter heads.

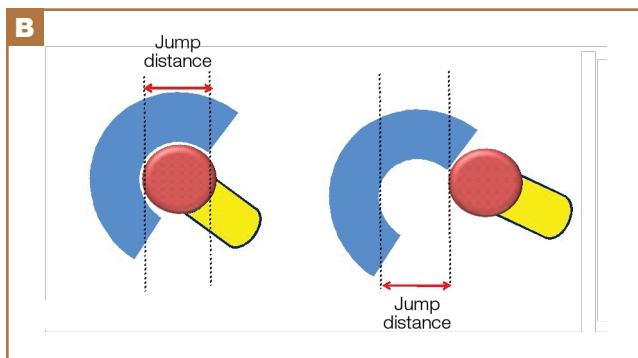
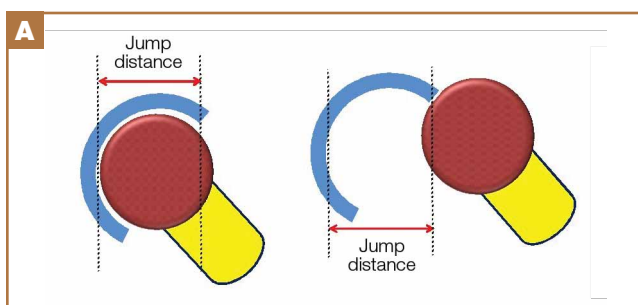


Figure 2. (A,B) Large-diameter heads have larger jump distances than small-diameter heads.

femoral heads, which have lower HNRs and are more prone to early impingement and subluxation (Figure 1).²³⁻²⁶

In a cadaveric study of 6 hips, Bartz and colleagues²³ reported a significantly higher preimpingement ROM when the prosthetic head size increased from 22 mm to 28 mm ($P < .05$). They found a change from prosthetic to osseous impingement when the head size increased from 22 mm to 32 mm. Similar results were observed in a computer simulation model by Cinnotti and colleagues,²⁷ who demonstrated that increasing the femoral head size from 28 mm to 38 mm resulted in a 5° improvement in ROM. However, the largest gains were observed when the heads with the smallest diameters were upsized; ROM improved only marginally when femoral head size was further increased from 32 mm to 38 mm. The primary reason

for the lack of expected improvement in ROM with head sizes of more than 32 mm is often bone-on-bone impingement. Burroughs and colleagues²⁸ demonstrated that the 38-mm and 44-mm heads virtually eliminated component-to-component impingement except in extremes of external rotation. However, there were no differences in ROM between 38-mm and 44-mm heads because of osseous impingement. In addition, large heads are less likely to sublux or dislocate, as they need to travel farther before reaching the edge of the acetabular cup before dislocation. This is known as the jump distance, and it corresponds to the depth of the acetabular shell, which in turn equates with the radius of the femoral head (Figures 2A, 2B). For this reason, the larger the femoral head diameter, the farther the jump distance and, correspondingly, the lower the risk for dislocation.²⁹

Elevated liners historically were used to increase the jump distance for dislocation.³⁰ These liners, however, can increase impingement at the extremes of motion.³¹ Some of these problems can be avoided with use of larger heads, which have increased jump distances without additional risks for impingement. Moreover, large heads create a suction effect that provides passive resistance to dislocation.³² With head diameters beyond 38 mm, impingement-free ROM often plateaus. However, the jump distance required for dislocations to occur continues to increase as femoral head diameters increase in size. Thus, patients may experience fewer motion benefits but continue to benefit from overall stability with femoral head sizes increasing beyond 38 mm.

Current evidence suggests there may be substantial benefits toward improved stability from increasing head diameters from 22 mm to 38 mm because of the increase in jump distances and improvements in prosthetic impingement-free ROM. However, there may be little gain in ROM from increasing the head diameters beyond these dimensions because of the potential risks of bony impingement. Nevertheless, there may be some additional benefits toward stability from improvement in jump distances with incremental head sizes beyond 38 mm.^{29,33,34}

Finite Element Analysis Studies

Finite element analysis of large-diameter heads in THA has shown that, at optimal cup inclination (45°), most stresses occur on the articular surface of the liner. However, these stresses remain well below the yield strength of the polyethylene liners.²⁹ With increasing abduction angles, the stress concentration increases substantially because of the decreased contact surface area. At these angles, the point of maximum contact moves toward the rim of the polyethylene liner, which can lead to rim fractures or failure of locking mechanisms.^{29,35,36}

Early Concerns With Large-Diameter Femoral Heads: Wear, Liner Failure, and Fracture of Ceramic Components

Use of small-diameter femoral heads started with the first report by Charnley³⁷ of “low frictional torque arthroplasty.”

Charnley initially considered a 41.5-mm femoral head, but he thought it would increase risks for acetabular loosening from high frictional torque generated by the large head, and he switched to a small-diameter (22.5 mm) design. One of the tradeoffs with smaller diameter heads was decreased jump height in addition to increased linear wear.

Large femoral heads used with cemented polyethylene acetabular components historically have been associated with increased rates of volumetric wear but low rates of linear wear, which potentially may increase the risk for osteolysis.³⁸⁻⁴⁰ However, newer highly cross-linked polyethylene liners have shown improved in vitro and in vivo volumetric wear characteristics and potentially lower linear wear rates compared with earlier designs (Table 1).^{28,41-43}

Another concern about earlier generations of large femoral heads was the risk for catastrophic liner failure on conventional polyethylene. This was originally reported by Berry and colleagues,⁴⁷ who described wear-through and failure in patients with thin (< 5 mm) acetabular cups. However, these concerns have been largely addressed by the development of highly cross-linked polyethylene, which has improved wear characteristics and fatigue resistance.⁴⁸

Recent Improvements in Material Properties of Polyethylene and Ceramic Bearings

The development of highly cross-linked polyethylene and fourth-generation ceramics has renewed interest in large-diameter bearings in THA. These bearing surfaces improve wear, enhance material properties, and have superior oxidation resistance.^{42,48-53}

We now briefly describe the methods used to improve the material properties of polyethylene and ceramics. Studies have shown that increasing the radiation dose (up to 200 kGy) increases cross-linking and causes an inverse exponential decrease in polyethylene wear.^{28,41,48-51} However, increasing radiation doses also increases production of free radicals, which diminish the material strength of these polyethylenes. The

current generation of highly cross-linked polyethylene liners is produced through a variety of manufacturing strategies to improve cross-linking and reduce wear. These strategies include differential radiation doses (50-100 kGy), techniques (electron beam, radiation), and thermal treatments (melting, annealing). Moreover, to enhance the material properties and reduce the incidence of rim cracking and delamination, authors have proposed using vitamin E supplementation to minimize the amount of subsurface oxidation that occurs as an inevitable consequence of free radical formation during fabrication.^{54,55} A terminal sterilization process (eg, gas plasma, ethylene oxide, or gamma sterilization in nitrogen) is needed to make commercial, highly cross-linked polyethylene.^{52,53}

Fourth-generation ceramics manufactured with nano-sized yttria-stabilized tetragonal zirconia particles in a stable alumina matrix have more fracture toughness and improved wear characteristics.^{54,55} In addition, oxide additives (eg, chromium oxide, strontium oxide) improve hardness and dissipate energy by deflecting cracks to prevent their propagation.⁵⁶ Moreover, the smaller grain sizes of fourth-generation ceramic bearings compared with third-generation designs (0.8 μm vs 1-5 μm) cause less disruption of the fluid film layer, which ultimately results in improved wear performance.⁵⁷

Multiple studies have found reduced wear rates with metal and ceramic large heads coupled with highly cross-linked polyethylene-bearings (Table 2).^{17,41,50,58} Bragdon and colleagues,⁵⁸ using radiostereometric analysis in 25 patients, found no significant differences in mean head penetration rates between 36-mm and 28-mm cobalt-chromium (Co-Cr) heads articulating with highly cross-linked polyethylene cups at a mean follow-up of 3 years (0.035 mm/y vs 0.046 mm/y; P = .11). Geller and colleagues,⁶⁴ in their study of 42 patients with large-diameter (> 32 mm) Co-Cr femoral heads, found low mean (SD) linear wear rates of 0.06 (0.41) mm/y at a mean follow-up of 3 years. D'Antonio and colleagues,⁶⁵ in a multicenter study, reported low average linear wear (0.015 mm/y) and volumetric wear (12.1 mm³/y) over 5 years using sequentially annealed cross-linked polyethyl-

Table 1. In Vivo Wear Rates for Large-Diameter Femoral Heads on Polyethylene Bearings

Study (Year)	No. of Hips (Patients)	Mean Follow-Up, y	Bearing	Head Diameter, mm	Linear Head Penetration, mm/y		Volumetric Wear, mm ³ /y	
					Mean	SD	Mean	SD
Bragdon et al ⁴⁴ (2013)	297	5	MOP	36	0.08	0.17	75.5	81.9
Bragdon et al ⁴⁴ (2013)	105	5	MOP	32	0.01	0.10	9.3	29.2
Lachiewicz et al ⁴⁵ (2009)	102 (90)	5.7	MOP	≥ 36	0.08	0.04	156.57	21.228
Geller et al ⁶⁴ (2006)	31 (29)	3.3	MOP	≥ 36	0.06	0.41 ^a	NR	NR
Bragdon et al ⁵⁸ (2007)	25	3	MOP	36	0.05	0.03 ^a	NR	NR
Sychterz et al ⁴⁶ (2000)	81	7	COP	32	0.09	0.07	NR	NR
Sychterz et al ⁴⁶ (2000)	43	6.8	MOP	32	0.07	0.04	NR	NR

Abbreviations: MOP, metal-on-polyethylene; COP, ceramic-on-polyethylene; NR, not reported.
^aStudy reported wear rates as median values.

ene. In vitro reports suggest that large-diameter ceramic heads may have lower wear properties than Co-Cr heads do. Galvin and colleagues,⁶⁶ in an in vitro hip simulator study, found that large-diameter ceramic heads on highly cross-linked ultrahigh-molecular-weight polyethylene had 40% reductions in steady-state wear rates compared with Co-Cr heads on highly cross-linked bearings (4.7 vs 8.1 mm³/million cycles; $P < 0.01$).

Dislocation Rates

Several patient, surgeon, and implant factors affect the rate of dislocations after THA. Multiple implant options utilize the biomechanical advantage that large-diameter heads have in improving stability. Various alternatives include use of constrained tripolar heads, dual-mobility bearings, and conventional large-diameter heads with standard liners.⁶⁷⁻⁶⁹

Large-Diameter Heads

Despite the biomechanical advantages of large-diameter metal-on-polyethylene bearings, prior studies have questioned use of these bearings because of risks for increased wear and rim failures. However, the improved wear properties of highly cross-linked polyethylene, elaborated earlier, have led to a

reappraisal of this option (Table 2).^{4,70} Howie and colleagues,⁷¹ in a randomized control trial of 644 patients, also found significantly lower rates of dislocation after primary THA with 36-mm heads compared with 28-mm heads (1.3% vs 5.4%; $P = .012$); in addition, fewer dislocations occurred with 36-mm heads than with 28-mm heads (4.9% vs 12.2%; $P = .27$) in a series of 44 patients in revision settings. Similarly, in a study conducted with 39,271 Medicare patients between 1998 and 2007, Malkani and colleagues⁷² found a decrease in the dislocation rate, from 4.21% to 2.14%, with use of large-diameter femoral heads. These results have been confirmed by several other authors.^{34,66,73,74} Similar results were observed in 65,992 patients in the Australian National Joint Replacement Registry by Conroy and colleagues,⁷⁵ who reported a significant decrease in the risk for dislocation with large heads (≥ 30 mm) compared with 22-mm heads (relative risk, 1.0 vs 3.1; $P \leq .001$).

Few studies have analyzed the role of large-diameter femoral heads in the presence of compromised soft tissues around the hip. Kung and Ries,⁷⁶ evaluating the influence of large-diameter heads in the presence and absence of a deficient abductor mechanism, demonstrated statistically significant reductions in rates of dislocation after 230 revision THAs when

Table 2. Head Sizes and Dislocation Rates Reported in Published Studies

Study (Year)	No. of Hips	Bearing Surface	Head Size, mm	Mean Follow-Up, y	Dislocation Rate, %
Primary THA					
Berry et al ⁷³ (2005)	3559	NR	32	10.5	3
Geller et al ⁶⁴ (2006)	45	MOP	> 32	3.3	2.2
Conroy et al ⁷⁵ (2008) ^a	12,778	NR	> 30	NR	0.4
Lombardi et al ⁵⁹ (2011)	337	MOP	≥ 36	2.6	0
Lombardi et al ⁵⁹ (2011)	48	COP	≥ 36	2.6	0
Cho et al ⁷⁴ (2011)	80 ^b	MOP	≥ 36	3	0
Gagala et al ⁹⁴ (2011)	32	COP	≥ 36	3.3	0
Howie et al ⁷¹ (2012)	299 ^c	NR	36	1	1.4
Lachiewicz & Soileau ⁶⁰ (2013)	122	COP	≥ 36	1	4
Cai et al ⁶¹ (2012)	51	COC	36	3	1.9
Park et al ⁶² (2012)	170	COC	> 32	2.1	0
Plate et al ⁶⁸ (2012)	52	NR	≥ 36	5.2	0
Revision THA					
Beaule et al ⁹⁴ (2002)	12 ^d	MOP	≥ 40	6.5	8.3
Kung & Ries ⁷⁶ (2007)	42 ^e	MOP	36	2.3	0
Skeels et al ⁶⁷ (2009)	26	MOP	≥ 36	1.4	17
Garbuz et al ⁶³ (2012)	92	MOP	≥ 36	5	1.1

Abbreviations: THA, total hip arthroplasty; NR, not reported; MOP, metal-on-polyethylene; COP, ceramic-on-polyethylene; COC, ceramic-on-ceramic.

^aAustralian National Joint Replacement Registry data. ^bPatients with femoral neck fracture. ^cPrimary and revision THAs were included. ^dAll were recurrent dislocators undergoing revision THA. ^eRevision THA with abductors intact.

the abductor mechanism was intact with use of 36-mm heads compared with 28-mm heads (12.7% vs 0%; $P = .015$). With abductor deficiency, though, the positive effect of large heads in reducing dislocation rates was substantially reduced and was similar to that of small heads ($P = .74$).⁷⁶

Large heads considerably improve overall stability and lower dislocation rates in THA. With the development of newer ceramics and highly cross-linked polyethylenes, the wear rates reported in multiple studies appear to be less concerning.

Constrained Tripolar Heads

Tripolar heads have been proposed as treatment options for improving stability in patients with chronic and recurrent instability after THA. The tripolar implant consists of a metal head that snap-fits into a polyethylene liner with a polished Co-Cr backing. This bipolar head articulates with a polyethylene bearing that is press-fitted onto a metal acetabular shell and constrained by a metal ring snapped to the outer polyethylene bearing. The bipolar component behaves as a large-diameter femoral head, and the metal ring provides additional restraint, further improving stability.

Williams and colleagues⁷⁷ performed a systematic review and reported on the outcomes of constrained tripolar liners in 1199 hips at a mean follow-up of 4 years (range, 2-10 years). The mean dislocation rate was 10%, and the mean rate of revision surgery unrelated to instability was 4%. In a study of 43 hips at a mean follow-up of 4 years (range, 2-9 years), Zywił and colleagues⁷⁸ reported on the clinical and radiographic outcomes of tripolar constrained liners. Their study group had a mean Harris Hip Score (HHS) of 82 points (range, 38-100 points) and overall survival of 91%, with no evidence of radiographic loosening during follow-up. Despite the improvements in stability with constrained tripolar liners, some authors have reported multiple mechanisms of failure with these devices.⁷⁹⁻⁸¹ In a study of 43 failed constrained tripolar liners with a mean time to failure of about 2 years, Guyen and colleagues⁷⁹ identified 5 different failure modes (types 1-5) involving all 4 interfaces in these components.

Encouraging outcomes have been reported at midterm follow-up with tripolar constrained liners. However, concerns about failure at the interfaces suggest that use of these components should be restricted to patients with deficient abductor mechanisms or neuromuscular compromise, low-demand elderly patients, and salvage cases of recurrent dislocations.⁷⁹

Dual-Mobility Bearings

For more than 20 years, different dual-mobility bearings have been used for difficult acetabular reconstructive scenarios and prevention of instability.^{82,83} Dual-mobility cups provide constructs that snap-fit a small-diameter femoral head within a large polyethylene insert that articulates with a fixed metal shell. This effectively increases the functional head diameter.

Various authors have reported excellent survivorship rates (92%-99%) and low dislocation rates for these bearings at 5- to 10-year follow-up.^{82,84-90} Philippot and colleagues,⁸⁶ in a recent study of 438 hips with dual-mobility cups, reported

excellent survivorship (96%) and no early or late instability within a 15-year follow-up. Bouchet and colleagues⁶⁹ compared dual-mobility bearings (105 hips) with conventional metal-on-polythene bearings (108 hips) and found significantly ($P < .05$) lower dislocation rates for the dual-mobility implants at a minimum 1-year follow-up. The French Society of Orthopaedics and Traumatology performed a multicenter analysis of 3473 hips with dual-mobility cups implanted in France between January 1998 and December 2003.⁸⁷ During a mean follow-up of 7 years (range, 5-11 years), there were 15 dislocations (0.43%), 14 of which occurred early, within 3 months of implantation (0.4%). Aseptic implant survivorship was 95% at 10-year follow-up.

Use of these bearings has recently increased in the United States. Short-term and midterm follow-up data show low rates of dislocation and wear. Long-term data are to come.

Clinical and Functional Outcomes of Large-Diameter Femoral Heads

There is a paucity of long-term outcomes data on use of large-diameter heads with highly cross-linked polyethylene bearings. Short-term and midterm clinical results appear to be excellent, with low rates of wear, osteolysis, and aseptic loosening.^{28,41,73,89-92}

Plate and colleagues⁹¹ compared the effects of large-diameter (≥ 36 mm) and small-diameter (26 mm, 28 mm) metal heads on highly cross-linked polyethylene bearings. At a mean follow-up of 5 years (range, 4-8.4 years), the large-head cohort had a mean HHS of 90 points (range, 50-100 points) and no dislocations or radiographic evidence of stem or cup loosening. Similarly, Meftah and colleagues⁹³ reported 100% stem survivorship and excellent clinical outcomes—a mean Western Ontario and McMaster Universities Arthritis Index (WOMAC) score of 30 points—for 72 hips with use of large ceramic heads (≥ 32 mm) on highly cross-linked polyethylene at a mean follow-up of 3 years. Gagala and colleagues⁹⁴ reported excellent clinical and radiographic outcomes in 50 hips (18 ceramic on ceramic, 32 ceramic on polyethylene; 36-mm heads) at a mean follow-up of 3.5 years. Mean HHS was 94 points, and there was no evidence of liner fractures, aseptic loosening, or osteolysis.

In summary, large-diameter femoral heads in THA have become increasingly popular because of improvements in the material properties and wear characteristics of highly cross-linked polyethylene and fourth-generation ceramics. Despite the potential advantages of large heads in preventing dislocations, the basic surgical tenets of placing the acetabular component in appropriate alignment remain firmly established. Implants with functionally large heads (eg, dual-mobility bearings, constrained tripolar liners) may play an important role in patients at high risk for dislocation—particularly elderly patients with poor neuromuscular muscle coordination or deficient abductors, trauma patients, and patients with prior dislocations. Short-term and midterm results are excellent; rates of wear, aseptic loosening, and osteolysis are low. However, long-term outcomes data are needed to support widespread use of large heads in younger and more active patients.

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