Ideal Femoral Head Size in Total Hip Arthroplasty Balances Stability and Volumetric Wear

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Abstract *Background:* Over the last several years, a trend towards increasing femoral head size in total hip arthroplasty to improve stability and impingement free range of motion has been observed. *Purpose:* The specific questions we sought to answer in our review were: (1) What are the potential advantages and disadvantages of metal-on-metal, ceramic-on-ceramic, and metal-on-polyethylene bearings? (2) What is effect that femoral head size has on joint kinematics? (3) What is the effect that large femoral heads have on bearing surface wear? *Methods:* A PubMed search and a review of 2012 Orthopaedic Research Society abstracts was performed and articles were chosen that directly answered components of the specific aims and that reported outcomes with contemporary implant designs or materials. *Results:* A review of the literature suggests that increasing femoral head size decreases the risk of postoperative dislocation and improves impingement free range of motion; however, volumetric wear increases with large femoral heads on polyethylene and increases corrosion of the stem in large metal-on-metal modular total hip arthroplasty (THA); however, the risk of potentially developing osteolysis or adverse reactions to metal debris respectively is still unknown. Further, the effect of large femoral heads with ceramic-on-ceramic THA is unclear, due to limited availability and published data. *Conclusions:* Surgeons must balance the benefits of larger head size with the increased risk of volumetric wear when determining the appropriate head size for a given patient.

Keywords femoral head size · total hip arthroplasty · volumetric wear · large femoral heads · dislocation

Introduction

Over the last several years, a trend towards increasing femoral head size in total hip arthroplasty to improve stability and impingement free range of motion has been observed [24]. As a result, orthopedic surgeons who perform total hip arthroplasty (THA) through a posterior approach have observed a significant decrease in the dislocation rate when using larger head sizes. [1, 2, 5, 6, 12, 20, 23, 24, 34, 38] The Norwegian Arthroplasty Registry found lower dislocation rates using 32-mm heads compared to 28- and 22-mm heads; however, equal dislocation rates were reported between 28 and 22 mm heads. [2, 8, 26] According to the most recent study in the literature, a femoral head size of ≥ 36 mm led to a significant decrease in the dislocation rate at 3 (1.12–0.86%), 6 (1.25–0.96%), 12 (1.42–1.11%), and 18 months (1.56–1.31%) after surgery compared to head sizes less than 36 mm. [24]

On the other hand, disadvantages of a larger femoral head size include more volumetric wear in metal on polyethylene bearings, and elevated metal ion levels in large metal-on-metal THA and hip resurfacings. In addition, there are concerns that adverse local tissue reactions (ALTR) and aseptic lymphocytic vasculitis-associated lesions (ALVAL) may occur more frequently with larger diameter metal on metal bearings. So the question is, “How big is big enough?”

In some respects, the bearing material and patient anatomy will limit the femoral head size the surgeon can use. Acetabular component size is determined by patient anatomy, and cup size influences the size of femoral head a surgeon can implant. As such, often times a surgeon will increase the size of the acetabular component in order to place a larger femoral head, thereby increasing the amount of acetabular bone removed.

The specific questions we sought to answer in our review were: (1) What are the potential advantages and disadvantages of large metal-on-metal, ceramic-on-ceramic, and metal-on-polyethylene bearings? (2) What is effect that femoral

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head size has on joint kinematics? (3) What is the effect that large femoral heads have on bearing surface wear?

Search Strategies

A PubMed search was performed using the following search terms and yielded the following number of results (in parentheses): “femoral head size” (940), “femoral head wear” (780), “large diameter femoral heads” (94), “femoral head size advantages” (4), “femoral head size disadvantages” (4), “fracture polyethylene” (1,123), “fracture ceramic” (2,154), “delta ceramic” (164), “dislocation femoral head” (3,056), “psoas impingement arthroplasty” (27), and “corrosion metal arthroplasty” (125). In addition, the 2012 Orthopaedic Research Society abstracts were searched for: “corrosion” (8). Articles were chosen that presented results of contemporary designs or implants (or materials), large series (>100 patients), and/or provided directed answers to the specific aims. Further, as this is proceedings publication, articles that were referenced in the senior author’s lecture were included, which included unpublished data from our institution.

Results

Metal-on-metal total hip arthroplasties and hip resurfacing arthroplasty were re-introduced to the USA market because of the ability to move to larger, near “anatomic” head sizes, supporting the beliefs that the risk of dislocation would be reduced and that there would be greater resistance to wear with hard bearings. [10, 30] As a result, surgeons began decreasing or even eliminating hip precautions after surgery as a result of the increased stability and increased range of motion provided by the large diameter heads. [37] Further, it was assumed that because the bearing was metal, patients could resume more extreme activities such as climbing, running, martial arts, without risk of fracturing the bearing or dislocating with extremes of motion. [36, 37] However, recent concerns of increased serum ions, ALVAL, ALTR, and product recalls have led to a recent decline in their use. [19] Further, psoas impingement has been observed after large diameter metal-on-metal total hip replacement, possibly directly due to the large head coming in direct contact with the psoas muscle, independent of the acetabular component. [11] Further, at short term follow up (average 5 years), large head metal-on-metal THA has shown increase wear at the trunion–head interface and

evidence of corrosion and fretting of the stem and head, which may lead to increase metal release into the body. [7, 16]

Ceramic-on-ceramic bearings, in general, are associated with lower wear rates compared to polyethylene [13, 21]; however, microseparation during swing phase can result in stripe wear on the head and liner rim. [10] As with other bearing materials, larger head ceramic-on-ceramic THA would allow for increased impingement free range of motion and stability leading to potentially less stripe wear without the higher risk of volumetric wear seen with larger heads on polyethylene. Although femoral head fracture (incidence range, 0.004–1.4%) [21] and acetabular liner fracture (incidence range, 0.01–2%) [21] and chipping is a potential concern, larger head ceramic-on-ceramic THA has an added advantage of potentially lowering the risk for femoral head fracture, seen with smaller diameter heads in early generation ceramic implants. [18, 39] In addition, by increasing the head–neck ratio, larger ceramic heads would lead to less impingement, which lowers the risk of acetabular chipping and cracking. However, currently, surgeons in the US are limited by the size of femoral heads available on the market, and data on large diameter ceramic-on-ceramic THA is limited. Further, it is believed the newer (Delta) ceramics with improved material composition reduces the risk of ceramic fracture; however, a prospective, randomized, multicenter trial of 263 patients (264 hips) at eight centers showed that, although rare, liner fractures can still occur even with the newer ceramics. [21] Finally, “squeaking” has been observed with an incidence of 0.48–7% by a poorly understood mechanism. Although, early results using Delta ceramics are encouraging, it is unclear whether newer generation ceramics with larger femoral heads will reduce the incidence of squeaking. [21]

In general, the advantage of a polyethylene bearing is that it doesn’t “squeak” or produce stripe wear. [10] However, polyethylene has greater wear rates than the hard-on-hard bearings, and larger metal heads lead to even more volumetric wear, leading to a potential increased risk of osteolysis. [10] Further, with larger femoral heads, the thickness of highly crosslinked polyethylene liner is reduced, thus potentially increasing the risk of polyethylene fracture [4]; however, early reports of thin (3.8 mm) ultrahigh molecular weight polyethylene did not show any increased short-term risk of fracture. [33]

There is a clear kinematic advantage to larger femoral head bearings in THR. It is known that increasing the femoral head size leads to an increased head–neck ratio,

Table 1 Average range of motion in cadavers with a 32, 40, and 44 mm femoral head

Head size	Limitations to range of motion	Flexion	Extension	Internal rotation	External rotation	Abduction	Adduction	Flexed internal rotation	Flexed external rotation
32 mm	Component impingement	119.0 (±4.0)	50.7 (±1.3)	128.9 (±3.0)	55.1 (±2.7)	56.3 (±2.7)	54.3 (±3.2)	32.3 (±0.8)	92.4 (±1.4)
40 mm	Component impingement	124.7 (±4.6)	59.1 (±1.8)	137.1 (±3.7)	63.7 (±3.2)	60.3 (±2.7)	58.4 (±3.4)	39.9 (±0.4)	100.4 (±1.1)
44 mm	Component impingement	127.5 (±4.9)	62.0 (±1.4)	139.5 (±4.9)	66.5 (±4.9)	61.5 (±3.5)	60.5 (±3.5)	42.0 (±0.0)	102.5 (±0.7)
	Bone impingement	124.9 (±8.9)	108.0 (±18.5)	135.6 (±6.5)	40.7 (±9.4)	76.0 (±6.4)	24.6 (±7.6)	44.9 (±5.3)	105.7 (±7.6)

Table 2 Adjusted mean total volumetric wear (cubic millimeter)

Head size (mm)	Mean total volumetric wear (mm ³)
26	88.431±36.341
28	95.519±21.719
32	34.290±23.945
36/40	159.64±33.430
	$p \leq 0.0134$

Adjusted for patient age, gender, body mass index, preoperative diagnosis, method of femoral component fixation, and activity component of the hip score

With kind permission from Springer Science+Business Media: Clin Orthop Rel Res, Femoral head size and wear of highly cross-linked polyethylene at 5 to 8 years, 467(12), 2009, 3290–6, Lachiewicz PF, Heckman DS, Soileau ES, Mangla J, Martell JM, table 3

which results in increased range of motion. [3] Chandler et al. showed that increasing femoral head size delayed contact between the femoral neck and the acetabular component, thus improving motion. [9] Similarly, in a controlled laboratory kinematics study using cadaveric specimens performed at our institution, seven cadavers (five males, two females; mean age, 71.4±21.1 years) underwent THA using a Stryker® (Stryker, Warsaw, IN, USA) Secure-Fit™ femoral component with a Trident® PSL® acetabular system. [17] Range of motion in flexion, extension, internal rotation, external rotation, abduction, adduction, flexion with internal rotation, and flexion with external rotation was measured for 28, 32, 36, 40, and 44 mm femoral heads using computer modeling. In addition, for each head size, it was determined whether bony impingement or component impingement occurred first in full flexion and in full flexion with internal rotation. Similar to previously published studies [3, 39], in regards to range of motion, the amount of motion possible with flexion and flexion with internal rotation increased as femoral head size increased (Table 1). Likewise, in straight flexion, six of the seven cadavers with a 28-mm head size were limited by component impingement first, whereas with the 44-mm head size, only one of the seven cadavers had an eventual block to flexion because of component impingement. These findings confirm those of a prior study. [3] Similarly, in flexion with internal rotation, a femoral head size between 28 and 36 mm had component impingement first at extremes of motion in all seven specimens. However, using a 44-mm head, only one specimen was limited by motion because of component impingement. Still, the question remains how much motion is needed following THA? Johnson et al. [25] found that in order to perform activities of daily living (ADLs), one must have hip flexion of 120°, hip abduction of 20°, and hip external rotation of 20°. Although a femoral head size of 44 mm is associated with the highest motion and less component impingement, a femoral head size of 32 mm is sufficient to achieve adequate range of motion for ADLs (Table 1).

The primary concern with larger diameter femoral heads is, of course, the potential for greater volumetric wear. Larger femoral heads require thinner acetabular bearings, such as highly crosslinked polyethylene (HXLPE). [24] Highly cross-linked and thermally treated polyethylenes

became available in the late 1990s. They were introduced to reduce wear, and the subsequent development of osteolysis; further, HXLPE has a greater resistance against oxidation. [27] Higher wear rates are associated with more osteolysis at shorter-term follow-up following THA [15, 29] In an attempt to establish a threshold, it has been shown that linear wear rates of less than 0.1 mm per year have been associated with a low incidence of osteolysis. [14, 15] As an example, Charnley THA's with 22 mm femoral heads showed very low rates of osteolysis with wear of less than 0.1 mm per year (38 mm³ per year), and survivorship rates were >90% at 25 years. However, survivorship at 20 years was <30% when wear rates were >0.2 mm/year. [15, 35] More recent studies of 28 and 32 mm femoral heads articulating with HXPPE show a low incidence of osteolysis with less than 0.1 mm per year (62 and 80 mm³ per year) of wear. [22, 28, 32] However, when discussing “wear” in regards to larger femoral heads on HXLPE, surgeons, and manufacturers should focus on decreasing volumetric wear, since laboratory analysis has shown linear wear of HXLPE is independent of head size [31]. A 4-year study [22] analyzing wear rates of HXLPE using 28, 32, 38, and 44 mm femoral heads demonstrated that the 28 and 32 mm head size had a linear wear (millimeter per year) of 0.023±0.011(range, 0.002–0.06), and a volumetric wear (cubic millimeter per year) of 16.7±8.2** (range, 4.3–54.6). Although the 38- and 42-mm heads had a similar linear wear (millimeter per year) rate of 0.021±0.012 (range, 0.01–0.06), they were associated with higher volumetric wear (cubic millimeter per year) of 29.1±14.8 (range, 8.4–112.8). In a similar study looking at wear rates of HXLPE using 26, 28, 32, 36, and 40 mm femoral heads at 5–8 years after surgery, Lachiewicz et al. [28] published the median linear wear rate of all components was 0.028 mm/year (mean, 0.04 mm/year), and the median volumetric wear rate was 25.6 mm³/year (mean, 80.5 mm³/year). The authors found no association between femoral head size and the linear wear rate, but observed an association between larger (36 and 40 mm) head size and increased volumetric wear rate and total volumetric wear (Table 2). The authors concluded that although the linear wear rate of polyethylene was not related to femoral head diameter, there was greater volumetric wear (156.6 mm³/year) with the 36- and 40-mm heads, and thus, pending long-term studies of large head sizes, caution is advised when using larger femoral heads in young or active patients and in those with a low risk of dislocation. From reported literature, it appears that volumetric wear of less than 40 mm³/year will be associated with low rates of osteolysis; however, wear rates of up to 80 mm³/year are likely to be tolerated.

Conclusion

As larger femoral heads are being introduced into the market using newer alternative bearings, we sought to answer the following questions: (1) What are the potential advantages and disadvantages of large head metal-on-metal, ceramic-on-ceramic, and metal-on-polyethylene bearings? (2) What is effect that femoral head size has on joint kinematics? (3) What

is the effect that large femoral heads have on bearing surface wear?

Femoral heads with larger diameters increase the head-neck ratio and range of motion before impingement, even with some variability in acetabular component position. Further, the jump distance is increased by a head with a large diameter, reducing the risk of postoperative dislocation, even when utilizing a posterior approach to the hip. However, although linear wear with highly cross-linked polyethylene seems to be independent of femoral head size, large diameter heads do have more volumetric wear, which may or may not cross the threshold for osteolysis. Future studies are needed to determine a safe threshold for volumetric wear with larger femoral heads on highly crosslinked polyethylene.

In respect to alternative bearings, the large head metal-on-metal hip replacement has not improved the success rates in THA, has led to a higher short-term revision rate in some series, and its use has decreased dramatically with reports of adverse reactions to metal debris. The large head ceramics are just now being introduced to the market; however, the literature is insufficient in terms of outcomes of large head ceramic-on-ceramic bearings with newer ceramic biomaterials to determine whether the incidence of squeaking, stripe wear, and fracture is actually lower.

In summary, it is still the opinion of the authors that, depending on available head sizes for a given acetabular component, a 28 or 32 mm cobalt chrome on highly cross-linked polyethylene is a safe, durable and effective bearing surface for THA that has the added benefits of a larger head (i.e., 32 mm), without an increased risk of volumetric wear and osteolysis.

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