Femoral head diameter considerations for primary total hip arthroplasty

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ABSTRACT

The configuration of total hip arthroplasty (THA) implants has constantly evolved since they were first introduced. One of the key components of THA design is the diameter of the prosthetic femoral head. It has been well established that the risk of dislocation is lower as the head diameter increases. But head diameter impacts other variables beyond joint stability; wear, cam-type impingement, range of motion, restoration of biomechanics, proprioception and groin pain. The introduction of highly cross-linked polyethylene and hard-on-hard bearings has allowed surgeons to implant large-diameter heads that almost completely eliminate the risk of dislocation. But as a result, cup liners have become thinner. With femoral head diameters up to 36 mm, the improvement in joint range of motion, delay in cam-type impingement and reduction in dislocation risk have been clearly demonstrated. Conversely, large-diameter heads do not provide any additional improvements. If an “ecologically sound” approach to hip replacement is embraced (e.g. keeping the native femoral head diameter), hip resurfacing with a metal-on-metal bearing must be carried out. The reliability of large-diameter femoral heads in the longer term is questionable. Large-diameter ceramic-on-ceramic bearings may be plagued by the same problems as metal-on-metal bearings: groin pain, squeaking, increased stiffness, irregular lubrication, acetabular loosening and notable friction at the Morse taper. These possibilities require us to be extra careful when using femoral heads with a diameter greater than 36 mm.

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1. Introduction

Over the years, the use of large-diameter replacement femoral heads has become increasingly common in orthopedics. The National Joint Registry of England, Wales and Northern Ireland points to a considerable increase in the use of 36-mm heads, which represented 5% of total hip arthroplasty (THA) implants in 2005, 26% in 2009 and 35% in 2011 [1].

One of the main reasons for this trend is clearly the decreased risk of dislocation linked to increased jumping distance and range of motion. This is clearly demonstrated in the National Joint Registry of England, Wales and Northern Ireland, where dislocations have decreased from 1.12% to 0.86% between 2005 and 2009 [1].

This decreased risk of instability is all the more important given the current desire to reduce the costs of THA complications. In France, revision surgeries due to post-THA instability represented 10% of all revision surgeries in 2012 [2]. In a previous American study on Medicare beneficiaries, the dislocation rate was 3.9% only 6 months postoperative [3].

In addition to reducing joint instability, other very attractive advantages related to large-diameter replacement femoral head and improved head/neck ratio have appeared, such as increased joint range of motion and reduced risk of cam effect. Of course, these advantages led to the widespread use of increasingly larger replacement heads.

However, the history of total hip arthroplasty does not favor large-diameter heads, especially because conventional polyethylene (PE), which was the material of choice for many years, has a greater risk of wear. The relatively recent development of hard-on-hard bearings and the introduction of cross-linked PE have, not surprisingly, led to the reintroduction of this concept.

This lecture aims to review the literature on the current state of the art for replacement head diameters used in total hip arthroplasty. It breaks down the “large diameter” concept to assess its advantages and disadvantages and evaluate its risks.
2. An “ecologically sound” approach to total hip arthroplasty

2.1. Concept and definition

There is currently no consensus on what constitutes a “small-diameter” or “large-diameter” head. We suggest the following classification:

- small: 22 through 28;
- medium: 28 through 36 mm;
- large: more than 36 mm;
- anatomical: the implanted femoral head matches the diameter of the patient’s native femoral head.

The “ecologically sound” concept implies an “anatomical” vision of joint replacement surgery, where the goal is to keep the same biomechanical factors as those of a normal hip joint in terms of limb length, femoral offset, stress transfer to the proximal femur, hip proprioception and the native diameter of the femoral head. This concept must be adapted to the shape of each hip. As a consequence, the implanted head should be 53-mm for men and 49-mm for women on average [4]. Only hip resurfacing with a metal-on-metal (MoM) bearing can meet these specifications. In fact, metal-on-metal THA implants with a large-diameter head have shown their limits. The heads in ceramic-on-ceramic (CoC) THA bearings cannot be made that large and cross-linked PE cups cannot accommodate heads larger than 42 mm because of the required minimum liner thickness.

2.2. Advantages

2.2.1. Dislocation, sports and daily activities

Large head diameters after hip resurfacing have been proven effective in terms of reducing the dislocation rate. In fact, many studies have found this risk to be very low or even nonexistent [1,2,4,5]. This supports the “ecologically sound” vision of a prosthetic hip that addresses the risk of instability by restoring anatomy.

This advantage, together with automatic restoration of hip joint biomechanics and preservation of proprioception allows high-impact sports and physical activities to be resumed [5,6]. These advantages are referred to collectively as the “big femoral head effect”. In a consecutive series of 202 hip resurfacing procedures, the rate of return to sports activities was 98% [5] and running could be resumed in 91.6% of cases [6]. The authors emphasized that the consequences of resuming intense sports on the outcome of the implants (particularly the acetabular fixation) were unknown [5,6].

2.2.2. Proprioception and gait analysis

It is now well established that restoring the diameter of the femoral head gives patients the same temporospatial gait measures as those of healthy subjects [7–10]. In one study comparing subjects who have undergone hip resurfacing with healthy subjects, Bouffard et al. [7] found the center of gravity to be identical in both groups. This was confirmed by stability testing and did not depend on the type of constraint (single-leg or double-leg hop test, eyes open or closed) [8].

Gait parameters (temporospatial measures, moment of force, and muscle strength) were analyzed by comparing patients with hip resurfacing to others with THA. The hip resurfacing patients were found to have better gait measures, better stability and better abductor strength [9]. Finally, dynamic hip stability was analyzed by studying the center of mass during maximum instability testing. This confirmed that dynamic posture was restored to normal after hip resurfacing [10].

2.2.3. Joint range of motion and cam effect

Impingement is defined as contact between surfaces leading to a change in a system’s geometry. After total hip arthroplasty, impingement occurs because of contact between the femoral neck and acetabular cup when the patient’s range of motion exceeds the amount of implant clearance.

Although hip resurfacing resolves the “implant” impingement between the neck and the cup, it creates a risk of a “bone” impingement between the native femoral neck and the cup. In fact, given the low head/neck ratio, impingement seems inevitable after hip resurfacing and it is completely logical that it would restrict joint ranges of motion. However, these are considered satisfactory and are the same as those obtained after THA [11–13].

2.3. Disadvantages

Groin pain seems to be more severe after hip resurfacing than after THA. There are many reasons for this, including infection, loosening, metal hypersensitivity, impingement with adjacent anatomical structures, iliopsoas impingement, capsule irritation and heterotopic ossification [14]. Risk factors such as youth, high activity level [15], and female gender [16] have been proposed. After hip resurfacing, some teams have reported a nearly 10% rate of groin pain [16]. The quality of the technique and the implant design were determining factors [16]. Pain is drastically reduced when a meticulous technique is used that combines sparing the tendon of the gluteus maximus at the linea aspera with performing a partial posterior capsulotomy and optimizing the head/neck ratio. Also, in acetabular implants with rounded edges and no significant macrostructures, groin pain is minimal and identical with THA (2.7% after 2 years of follow-up) [17].

3. A “conventional” approach to total hip arthroplasty

3.1. Clinical consequences of large-diameter heads

3.1.1. Dislocation

A prospective THA study in three groups who received different head diameters (<36 mm, 36 mm and >36 mm) clearly showed there was no clinical differences between groups. However, the dislocation rate was significantly lower in the group with >36 mm head (0% in this group compared with 1.25% in the <36 mm group) [18].

This phenomenon has been confirmed by a large number of studies, all of which have found the dislocation rate to be inversely correlated with the head diameter [18,19], including after implant revision [19]. This is explained by the increased head/neck ratio and jumping distance (the distance needed for dislocation). A finite element study by Crowninshield et al. [20] showed this distance to range from 5-mm for a 22-mm head to 23-mm for a 40-mm head.

3.1.2. Impingement and range of motion

Increased head diameter goes hand in hand with an increased head/neck ratio, decreased risk of impingement, and improved range of motion. Impingement seems to be very common after THA (51.3% according to Marchetti et al. [21]). After THA with hard-on-hard bearings, it seems especially to pose a risk of instability and wear. After THA with hard-on-hard bearings, it poses not only a risk of instability but of fracture as well (especially of the ceramic parts) and abnormal production of wear debris (ceramic particles, metal ions, etc.) [22].

In two groups of patients with implants, increasing the head diameter from 26 mm to 32 mm produced a significant increase in...
flexion (about 10°) [23]. This was confirmed by D’Lima et al. [24], who found an 11° difference in flexion between patients with a 32-mm head and those with a 26-mm head. According to the mathematical formula of Yosimine et al. [25], flexion is 12.5° for a 26-mm head and 133° for a 32-mm head.

Optimizing the head/neck ratio makes it easier to perform activities of daily living, such as putting shoes on and taking them off, cutting toenails, etc. that require at least 120° of hip flexion [26]. A 32-mm head makes these activities possible in 93.7% of cases compared with only 84% for a 26-mm head [27].

Many authors have confirmed that heads larger than 32-mm in diameter not only improve range of motion but completely eliminate the risk of neck/cup impingement [20–27]. Nonetheless, there is a threshold effect at 38 mm, after which the impingement risk becomes negligible [27,28]. It is not only the head diameter that matters, but the head/neck ratio. Heads larger than 36 mm raise this ratio to more than 2 (for a 12/14 neck) and eliminate impingement.

3.1.3. Impingement of the adjacent muscles

This advantage is seriously offset by the risk of contact between a large head and the iliopsoas muscle. In fact, besides the demonstrated risk of iliopsoas irritation by some types of cups used in hip resurfacing, there is also the possibility of impingement by the large-diameter THA implant due to a simple “volume effect”. The greatest risk of impingement is at the beginning of flexion (between 0° and 30°) because the pressure on the iliopsoas muscle on the femoral head is greatest at that point [15].

3.2. Bearings with polyethylene

For a given cup diameter, a large-diameter head increases the bearing size and reduces the actual polyethylene (PE) thickness. Choosing such a head contradicts one of the founding principles of Low Friction Arthroplasty: use of a small-diameter head (22.22 mm) to reduce friction and wear of the thickest possible liner.

This wear is directly linked to the head diameter. For a given range of motion, a large-diameter head increases both the slide distance (between the head and the liner) and the head’s movement speed in the liner; this places considerable stresses on the PE, resulting in mechanical deterioration. Thus, the use of large-diameter heads in combination with PE has long been discouraged.

In theory, the introduction of cross-linked PE allows this principle to be reconsidered. For a “hard-on-soft” bearing using cross-linked PE, the minimum PE thickness could be less than that of standard PE liners. Unfortunately, data on this subject is still inconsistent. In a simulated wear study on a cross-linked PE liner (X3 Stryker Orthopedics, Mahwah, NJ, USA) coupled with a 36 mm head, Johnson et al. [29] noticed that the thinner the PE, the greater the wear, which does not support the use of large-diameter heads; in fact, after 2.4 million cycles, the wear volume was 5 mm³/million cycles for a 1.9 mm thick liner, while it was 2.2 mm³/million cycles for a 7.9 mm liner [29]. However, it should be noted that these wear rates are very low regardless of the liner thickness, and much lower than those of conventional PE [30].

Furthermore, there are questions about the lower strength of cross-linked PE, which is worse for very thin layers of PE, especially for liners located inside a metal cup [29]. This is the reason vitamin E supplemented cross-linked PE has been recently introduced.

Finally, some authors [29] consider that the minimum recommended thickness of PE, traditionally 6 mm, can be reduced to 3.9 mm with cross-linked PE. While it seemed inadvisable to use a 36-mm head with a conventional PE cup measuring less than 48 mm in diameter or a 32-mm head with a PE cup measuring 44 mm, the development of cross-linked PE was thought to have changed this rule. A minimum thickness of 3.9 mm for cross-linked PE would make it possible to use 36-mm heads for a 44-mm cup and 32-mm heads for a 40-mm cup. However, this 3.9-mm limit addresses only the question of wear without taking strength into account, and therefore cannot yet be validated.

Moreover, these configurations are intended for a cemented PE cup without a metal-back cup. If a metal-back cup is used, the thickness of the metal shell (which is often around 4 mm) must be added to the minimum thickness of the PE to calculate the smallest cup diameter that can be coupled with a given head diameter.

Thus, given the current data on wear and fatigue resistance, and the lack of long-term follow-up on cross-linked PE, we must not get carried away and must continue to comply with the traditional 6-mm thickness, even with cross-linked PE. Therefore, it seems that for a 36-mm head, the smallest usable metal-back cup should be at least 56-mm in diameter.

3.3. Ceramic-on-ceramic (CoC) bearing

3.3.1. Modular and preassembled cups

Currently, the liners of THA implants with CoC bearings can be either modular or preassembled with the metal cup to avoid the complications associated with intraoperative assembly.

To date, the most commonly used ceramic is a composite ceramic with grains of zirconium oxide and strontium, which reduces the risk of crack propagation (Delta ceramic). In theory, this property allows a thinner liner, and thus a larger head diameter, to be used. The cups containing Delta ceramic are designed to accommodate large-diameter heads (from 32 mm to 48 mm depending on the manufacturer), with an outer metal cup diameter of 14 mm to 18 mm greater than the replacement femoral head for modular cups.

It is hard to determine a minimum thickness for the ceramic composite. The minimum thickness (cup and liner) of the available preassembled cups is around 5 mm. It is interesting to note that their geometry is very often identical to that of resurfacing cups (minimum cup thickness, opening angle less than 180°, etc.), but their materials differ (titanium cups for the CoC bearing and cobalt/chrome for hip resurfacing). The thickness of the preassembled metal-back cups is 2 mm to 2.5 mm, depending on the model. This type of cup allows manufacturers to authorize use of larger head diameters with thin liners (up to 2.5 mm or 3 mm).

In modular cups, the thickness of the metal-back shell is more important. It is approximately 4 mm to 4.5 mm with a minimum composite ceramic thickness of around 4 mm for the commercially available cups (i.e., a 52-mm cup for a 36-mm head). For alumina ceramic, the minimum thickness is approximately 6 mm (i.e., a 52-mm cup for a 32-mm head).

However, it is important to emphasize that Delta composite ceramic has not been around very long (and there are questions about how it ages), while alumina ceramic, which has been used for a long time, has almost disappeared. Finally, it seems more reasonable to continue using a 6-mm thickness for ceramic liners and not give in to the temptation of using thinner liners.

3.3.2. Large-diameter ceramic heads

Large-diameter ceramic heads (>36 mm) have another advantage. In addition to reducing instability, they are the closest thing possible to the “ecologically sound” concept of matching the patient’s anatomy. However, they exert intense pressure on the edges of the ceramic liner, which is even greater in the case of a verticalized cup [30]. In addition, the design of the cups coupled with large-diameter heads poses a risk of microseparation given their small opening angle, as well as a risk of liner delamination [27].

The increased head diameter creates many other complications for the CoC bearing, such as squeaking, ceramic fracture, groin
pain, etc. [31]. Thus, the Delta Motion ceramic bearing (DePuy, Warsaw, Indiana), which belongs to the first generation of pre-assembled cups, designed to reduce the squeaking phenomenon, has not achieved its goal. The increased head/neck ratio was supposed to reduce the risks of impingement and dislocation, and therefore the resulting squeaks. In a consecutive study of 208 Delta Motion cups, coupled with 32-mm and 48-mm heads, (depending on the cup diameter) at 21 months of follow-up, there were 143 (68%) quiet hips, 22 (11%) with noises other than squeaking, 17 (8%) with squeaking that could not be reproduced during the clinical exam and 26 (13%) with reproducible squeaking [31]. The head diameter of the “noisy hips” averaged less than 40 mm. In the authors’ opinion, it is an interruption in the lubrication film of these large-diameter replacement heads that causes noise due to high friction moments. This phenomenon was confirmed in other studies [32].

Thus, although large-diameter ceramic heads produced less friction under conditions of continuous lubrication, they also seemed much more sensitive to a lack of lubrication. In this situation, high friction moments were also found with THA inserts using “large head” metal-on-metal (MoM) bearings. This phenomenon was amplified in cases of ceramic debris, which increased friction, with a multiplier coefficient of 26 compared with normal function in serum [32].

The main cause of THA implant failures when large-diameter metal-on-metal bearings are used (aseptic loosening and poor cup fixation, wear of the Morse taper) is related to excessively high friction forces, especially at the head–Morse taper junction. This does not seem limited to this type of bearing. In fact, these phenomena can occur with all types of “hard-on-hard” bearings as soon as lubrication is disrupted. Thus, large-diameter heads used in CoC bearings pose the same risks as those of MoM bearings [33]. It even seems that in cases of insufficient lubrication with the same head diameter, the friction in the CoC bearing is twice that in the MoM bearing. The only advantage of the large-diameter CoC bearing over the large-diameter MoM bearing is that ceramic has better wetting properties, which gives it greater protection against an interruption in the lubrication film.

Morlock et al. [32] have reported that, under conditions of poor lubrication, a 48-mm ceramic head diameter causes a 5-times greater friction moment than that of a MoM bearing of the same diameter. They concluded that for the CoC bearing, the theoretical benefits of a large diameter have to be weighed against their drawbacks in the case of inadequate lubrication. The appearance of abnormal noises is thought to be the result of abnormal lubrication, and therefore the first sign of bearing malfunction.

Moreover, the torque resistance at the 12/14 Morse taper–head interface is limited to less than 10 Mm along the neck axis [33], while a CoC bearing with a 36-mm head diameter generates 25 Mm torque on the same Morse taper. This explains the wear-induced failures of the Morse taper caused by a ceramic head [34]. It also seems imprudent to implant a large-diameter ceramic head on a short femoral stem because of this same risk of excessive stress on the stem/implant interface [35].

Thus, the increased pressure on the bone/cup interface and the generation of high friction on the Morse taper by a large ceramic head increase the risk of aseptic loosening of the implants.

Finally, improper placement of the cup (especially excessive inclination) is conducive to subluxation and microseparation, with a high risk of liner fracture or delamination.

3.4. Metal-on-metal bearing

Because of the above reasons for failure of large-diameter MoM THA implants, MoM bearings are no longer used in this configuration. However, it should be noted that it is the presence of a large-diameter hard-on-hard bearing combined with a femoral stem that poses a problem because of the excessive pressure on either side of the head. The failures resulted either from wear of the Morse taper or aseptic loosening of the cup, which was subjected to elevated friction forces and implant rigidity.

The junction between the Morse taper and the head, through a connector or spacer, brought about massive corrosion (even greater in cases of different metal alloys), a release of metal particles, and the recurrence of pseudotumors, which were attributable not to the MoM bearing itself, but to the presence of too many friction interfaces. Therefore, the problem of metal corrosion was directly correlated with the excess modularity of these implants.

This phenomenon is clearly demonstrated by the correlation between the trunion length and metal ion levels. A short neck (−4 mm) generates a blood cobalt concentration of 0.8 μg/L, a 0-sized neck 1 μg/L, a long neck (+4 mm) 2.2 μg/L and an extra-long neck (+8 mm) 4.7 μg/L. These increased cobalt levels are directly linked to the poor contact between the trunion and the head observed with long or extra-long necks. In fact, a small contact area increases the risk of micromotion at the interface, corrosion and abrasion of the Morse taper [36]. Therefore, the problem is not caused by the MoM bearing itself, which explains the absence of this type of complication with hip resurfacing where the absence of a stem avoided these setbacks, as well as with conventional THAs with a MoM bearing and 28-mm or 32-mm heads with more than 15 years of follow-up [2].

It must be remembered that large-diameter MoM THAs were initially introduced in response to femoral failures after hip resurfacing. It was easy to retain the cup in place and implant a stem coupled with a large metal head. The use of these implants should have been very limited. However their use spread very quickly because of the excellent initial clinical outcomes, especially the very low to nonexistent levels of dislocation and improved patient satisfaction when compared to a 28-mm head, probably related to better proprioception, improved fit with the patient’s anatomy, and the lack of a cam-type impingement [37]. This led to a very large number of primary THA procedures when there was still insufficient follow-up [37]. This is very strangely reminiscent of the massive and rapid introduction of large-diameter zirconia ceramic CoC bearings.

4. Conclusion

The choice of replacement head diameter for THA depends mainly on the size of the acetabulum and the all too common “philosophy” of implanting the largest diameter “no matter the cost” to reduce the risk of dislocation.

The risks of dislocation feared by all surgeons and of impingement that can lead to implant failure have accelerated the introduction of heads of increasingly large diameters by manufacturers. This is the result of pressure from surgeons and the introduction of new materials (highly cross-linked polyethylene and zirconia ceramic). Manufacturers responded to market demand and placed increasingly thinner cup liners on the market. It is interesting to note that the changes have pertained mainly to the acetabular side and not to the femoral side. In fact, the stems and/or Morse tapers were not changed to adapt to them to the larger head diameters.

There is currently little experience with these new configurations; the failure of large-diameter MoM THA implants calls for extreme caution when using large diameters heads with the other hard-on-hard bearing (CoC) and very thin, highly cross-linked PE. In addition, it is important to remember that the diameters proven to be effective are considerably smaller than those commonly used these days (22.2 mm and 28 mm for PE, 32 mm for alumina ceramic and 28 mm for composite ceramic).
Estimating liner thickness based on head diameter requires a thorough understanding of the implant to be used. A liner thickness of 6 mm remains the "gold standard", regardless of the type of bearing chosen.

In 2014, aside from the anatomical configuration of hip resurfacing, implanting a large-diameter head coupled with a femoral stem involves accepting a largely unknown risk of failure (acetabular fixation, liner rupture, etc.). Therefore, it seems inadvisable to implant heads with diameters greater than 36 mm during THA (regardless of the type of bearing chosen). For CoC heads greater than 36 mm, longer follow-up is essential before we "venture into the unknown on behalf of the patient" according to Tricot and Gouin [38].

Disclosure of interest

J. Girard is a consultant for Smith and Nephew and Wright Medical Technology.

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