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ORIGINAL PAPER

Do large femoral heads reduce the risks of impingement in total hip arthroplasty with optimal and non-optimal cup positioning?

Gianluca Cinotti · Niccolò Lucioli · Andrea Malagoli · Carlo Calderoli · Ferdinando Cassese

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Abstract The purpose of this study was to assess whether large femoral heads (36–38 mm) improve the range of motion in total hip arthroplasty compared to standard (28–32 mm) femoral heads in the presence of optimal and non-optimal cup positioning. A mathematical model of the hip joint was generated by using a laser scan of a dried cadaveric hip. The range of motion was assessed with a cup inclination and anteversion of reference and with non-optimal cup positions. Large femoral heads increased the range of motion, compared to the 28-mm femoral head, in the presence of a hip prosthesis correctly implanted and even more so in the presence of non-optimal cup positioning. However, with respect to the 32-mm femoral head, large femoral heads showed limited benefits both in the presence of optimal and non-optimal cup positioning.

Introduction

Large femoral heads have been introduced aimed at increasing the range of motion and reducing the risk of impingement and dislocation. This assumption is the result of clinical studies showing a reduced incidence of dislocations by increasing the diameter of the femoral head from 22 to 32 mm [1–3]. As a consequence, 22-mm femoral heads have become less and less popular in the last decade while 28- and 32-mm femoral heads have become the most frequently used. More recently, 36- and 38-mm femoral heads have been introduced to further reduce the risk of impingement and dislocation. These large femoral heads could theoretically improve the range of motion of the total hip to such an extent that, even when the positioning of the components is suboptimal, an impingement between the femoral neck and the liner should rarely occur.

Although the use of 36- and 38-mm femoral heads has rapidly increased in recent years, few studies have analysed the advantage of such implants compared to standard (28–32 mm) femoral heads [4, 5], and almost no study has assessed whether such potential advantages persist, or are even magnified, in the presence of a non-optimal cup positioning. In our investigation we assessed whether, and to what extent, a large femoral head improves the range of motion in the total hip arthroplasty with different cup orientations.

Material and methods

A mathematical model of the pelvis and the femur was generated using a laser scan of a dried cadaveric hip joint belonging to the Department of Human Anatomy.

A Real Scan USB 300 (3D Digital Corporation, Sandy Hook, USA) with an accuracy of 125 μ was used for laser scanning. The software included Rapid Form 2004 (INUS Technology Inc., Seoul, Korea) to create and manage the surfaces and Rhinoceros 3D 3.0 (Seattle, USA) to optimise the patch surface. The model was fixed on a rotating support, not subjected to vibrations, and 25 scans were performed for the pelvis and 43 for the femur.

Once the laser scans were performed, the final model was created through the recomposition and stratification of the images previously elaborated. In order to reduce the so-called "step" effect, a mean smoothing value of 0.5 was applied.

G. Cinotti (✉) · N. Lucioli
Orthopaedic Department, University La Sapienza,
Rome, Italy
e-mail: md3581@mclink.it

A. Malagoli · C. Calderoli · F. Cassese
DTM Technologies,
Modena, Italy

F. Cassese
e-mail: fcassese@dtm.it

Implant positioning

A femoral neck osteotomy was simulated on the mathematical model 10 mm proximal to the lesser trochanter and with an inclination of 55° from the horizontal plane. The selected implant (IPS, De Puy) was reconstructed by means of reverse engineering using a coordinate measure machine and its mathematical control (Fig. 1). Femoral stem features included: a neck-shaft angle of 126°, a femoral neck anteversion of 8°, and a femoral neck diameter of 12 mm. The latter led to a femoral head/neck ratio≥2.

The femoral stem was placed in a neutral position with respect to the native femoral neck which showed 7° of anteversion. As a result, the overall anteversion of the femoral component including the native femoral anteversion and that of the femoral neck prosthesis was 15°. A hemispheric cup of 52 mm was positioned in the acetabulum, taking care to restore the native centre of rotation. The cup was positioned with an inclination of 45° and an anteversion of 18°. As a result, a combined femoral and acetabular anteversion of 33° was tested in the position of reference.

A neutral liner was inserted, allowing positioning of a femoral head from 28 to 38 mm. A femoral head of +8.5 mm was used since this led to a neck length which better restored the native hip offset.

Range of motion and cup orientation

Range of motion up to the impingement was evaluated with different cup orientations and different head sizes, leaving the femoral stem unchanged during the tests. In particular, we initially assessed the range of motion of a cup with an inclination of 45° and an anteversion of 18° (cup positioning of reference). We then repeated the measurements with a non-optimal cup positioning, that is, with a reduced (35°) and increased (55°) cup inclination; with a reduced (5°) and increased (28°) cup anteversion and with different combinations of each position.

Range of motion up to the impingement was assessed during pure flexion–extension, abduction–adduction and external–internal rotation. We also assessed combined movements simulating daily activities. These included maximum flexion with the hip in 25° of abduction and 15° of external rotation while stooping [6] (position 1), and maximum external rotation with hip in 90° of flexion and 20° of abduction while crossing one's leg (position 2). A total of 224 tests were performed including pure and combined hip motions.

Solid Edge 17 software (UGS Inc., Italy) including a "collision check feature", i.e., a function to determine accurately the contact between the bodies, was used to assess the range of motion up to the impingement. The type of impingement, e.g. component-to-component, component-to-bone or bone-to-bone, was recorded.

The chi-square test was used to assess the difference between the type of impingement with the different femoral heads. A p-value<0.05 was considered statistically significant.

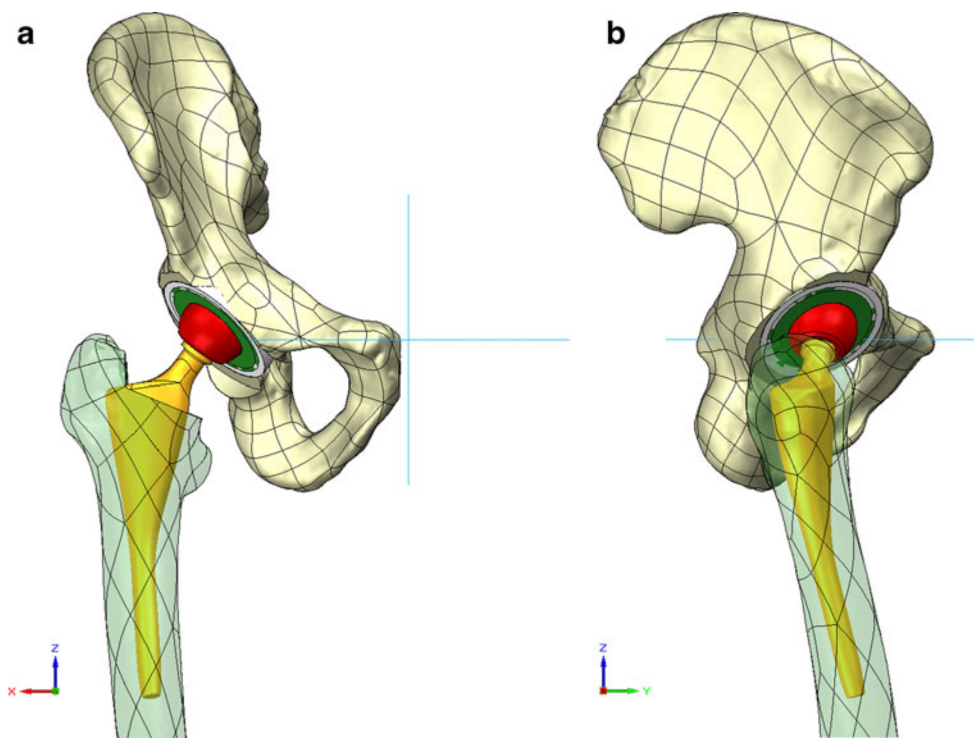

Fig. 1 Mathematical model generated by laser scanning of cadaveric hip joint with a total hip arthroplasty implanted. **a** Coronal view. **b** Sagittal view

Results

Range of motion with reference cup orientation (inclination 45°, anteversion 18°)

Range of motion with the cup positioning of reference is reported in Table 1.

Overall, the range of motion increased an average of 5.3° moving from the 28-mm to the 38-mm femoral head. The maximum advantage of the 38-mm femoral head, compared to the 28-mm, was found during extension (11°) and during flexion (10°) while no difference between the two was found during hip abduction and external rotation. No differences were found at any hip motion between the 32-mm and 38-mm femoral heads.

The combined motion of positions 1 and 2 increased 9° and 16°, respectively, moving from the 28-mm to the 38-mm femoral head and 0 and 2°, respectively, moving from the 32-mm to the 38-mm femoral head.

Hip flexion–extension and combined motion with reduced (5°) cup anteversion

Hip flexion–extension with reduced cup anteversion (5°) and with different cup inclinations is reported in Table 2.

Overall, flexion–extension increased an average of 10.8° moving from the 28-mm to the 38-mm femoral head. The advantage of the 38-mm femoral head with respect to the 28-mm was much more marked during hip flexion (average increase 21.3°) than during hip extension (average increase 0.3°), with each of the cup inclinations tested.

Hip flexion increased an average of 2°, moving from the 32-mm to the 38-mm femoral head. The latter showed the maximum advantage (5°), compared to the 32-mm, in the presence of a cup inclination of 45°. No difference was found between the 32-mm and 38-mm femoral heads during extension.

A difference between the 36- and 38-mm femoral heads (1°) was found only with a cup inclination of 35°.

The combined motion of positions 1 and 2 increased an average of 13.7° and 16°, respectively, moving from the 28-mm to the 38-mm femoral head and an average of 2° and 1°, respectively, moving from the 32-mm to the 38-mm femoral head (Fig. 2, left side of graph).

Hip flexion–extension and combined motions with increased (28°) cup anteversion

Hip flexion–extension with increased cup anteversion and with different cup inclination is reported in Table 3. Overall, flexion–extension increased an average 12.5° moving from the 28-mm to the 38-mm femoral head. Such an increase was found during flexion (average 9.6°) and even more during extension (15.3°).

Flexion–extension increased an average of 0.6°, moving from the 32-mm to the 38-mm femoral head. The latter showed the maximum advantage (4°), compared to the 32-mm femoral head, in the presence of a cup inclination of 35°.

A difference between the 36- and 38-mm femoral heads (1°) was found only with a cup inclination of 35°.

The combined motion of positions 1 and 2 increased an average of 9° and 9.3°, respectively, moving from the 28-mm to the 38-mm femoral head and an average of 2° and 1°, respectively, moving from the 32-mm to the 38-mm femoral head (Fig. 2, right side of graph).

Hip external–internal rotation with reduced cup anteversion (5°)

Overall, hip external–internal rotation with reduced cup anteversion and with different cup inclinations (35°, 45°, 55°) increased an average 8° moving from the 28-mm to the 38-mm femoral head. The latter led to a maximum increase (25°) in the internal rotation in the presence of a cup inclination of 55°.

External–internal rotation increased an average 0.7°, moving from the 32-mm to the 38-mm femoral head. No difference was found between the 36-mm and 38-mm femoral heads.

Hip external–internal rotation with increased cup anteversion (28°)

Overall, hip external–internal rotation with increased cup anteversion and with different cup inclinations increased an average of 3.5° moving from the 28-mm to the 38-mm

Table 1 Range of motion with reference cup orientation (inclination 45°, anteversion 18°)

Hip motion	Femoral head diameter			
	28mm	32mm	36mm	38mm
Flexion	115° (c-c)	125° (b-b)	125° (b-b)	125° (b-b)
Extension	55° (c-c)	66° (c-c)	66° (c-b)	66° (c-b)
Abduction	63° (c-c)	68° (b-b)	68° (b-b)	68° (b-b)
Adduction	24° (b-b)	24° (b-b)	24° (b-b)	24° (b-b)
External rotation	53° (c-c)	53° (c-c)	53° (c-c)	53° (c-c)
Internal rotation	78° (c-c)	86° (b-b)	86° (b-b)	86° (b-b)

(c-c) component-to-component impingement, (b-b) bone-to-bone impingement, (c-b) component-to-bone impingement

Table 2 Hip flexion-extension with reduced cup anteversion (5°)

Cup inclination	Femoral head diameter			
	28 mm	32 mm	36 mm	38 mm
Hip flexion				
35°	90° (c-c)	106° (c-c)	109° (c-c)	110° (c-c)
45°	98° (c-c)	116° (c-c)	120°(b-b)	121° (b-b)
55°	107° (c-c)	125° (b-b)	125°(b-b)	125° (b-b
Hip extension				
35°	65° (c-c)	66° (c-b)	66° (c-b)	66° (c-b)
45°	66° (c-b)	66° (c-b)	66° (c-b)	66° (c-b)
55°	66° (c-b)	66° (c-b)	66° (c-b)	66° (c-b)

(c-c) component-to-component impingement, (b-b) bone-to-bone impingement, (c-b) component-to-bone impingement

femoral head. The latter led to a maximum increase in the external (9°) and internal rotation (12°) in the presence of a cup inclination of 55°.

No difference was found between the 32-mm and the 38-mm femoral heads.

Hip abduction–adduction and combined motion with reduced cup inclination (35°)

Overall, hip abduction–adduction with reduced cup inclination and different cup anteversions (5°, 18°, 28°) increased an average of 4.2° moving from the 28-mm to the 38-mm femoral head. The latter led to a maximum increase of 10° in hip abduction in the presence of a cup anteversion of 18° while no difference was found in hip adduction with each of the cup anteversions tested.

A difference between the 32-mm and the 38-mm femoral heads (2°) was found only in hip abduction with a cup anteversion of 28°. No difference was found between the 36-mm and the 38-mm femoral heads.

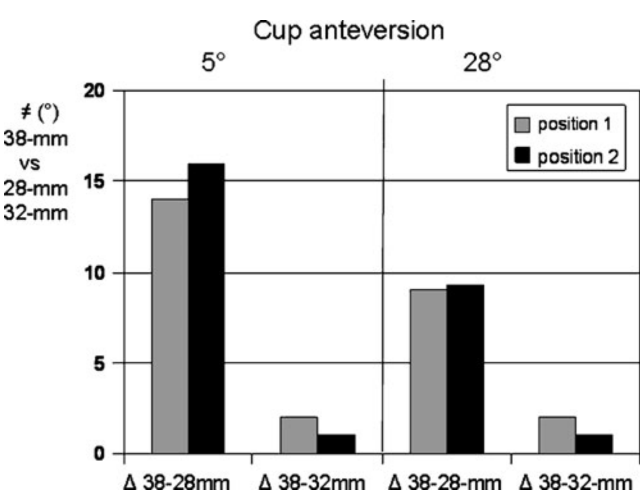

Fig. 2 Increase in the range of motion between the 38-, 28- and 32-mm femoral heads during combined motion of positions 1 and 2 in the presence of a cup anteversion of 5° (*left side of graph*) and 28° (*right side of graph*)

The combined motion of positions 1 and 2 increased an average 22° and 7.7 °, respectively, moving from the 28-mm to the 38-mm femoral head and an average 6° and 0°, respectively, moving from the 32-mm to the 38-mm femoral head (Fig. 3, right side of graph).

Hip abduction–adduction and combined motion with increased cup inclination (55°)

No difference was found in hip abduction–adduction between the 28-mm and the 38-mm femoral heads with each of the cup anteversions tested.

The combined motion of positions 1 and 2 increased an average of 0° and 17°, respectively, moving from the 28-mm to the 38-mm femoral head and an average of 0° and 3.3°, respectively, moving from the 32-mm to the 38-mm femoral head (Fig. 3, left side of graph).

Type of impingement

The type of impingement observed in the presence of the cup with reference orientation and in the presence of non-optimal cup positioning is reported in Fig. 4.

There was a significant difference between the type of impingement reported with the 28-mm femoral heads and with the 32-, 36-, and 38-mm heads (p=0.0001). No significant difference was found between the 32-mm and the 38-mm femoral heads (p>0.05).

Discussion

Large diameter femoral heads have been introduced to reduce the risk of impingement and dislocation after total hip replacement. Although most surgeons would agree on the rationale of this assumption, there is limited evidence on the benefits of large diameter femoral heads in clinical and experimental studies.

Berry et al. analysed the dislocation rate associated with femoral head diameter ranging from 22 to 32 mm and

Table 3 Hip flexion–extension with increased cup anteversion (28°)

Cup inclination	Femoral head diameter			
	28 mm	32 mm	36 mm	38 mm
Hip flexion				
35°	103° (c-c)	118° (c-c)	121° (c-c)	122° (c-c)
45°	115° (c-c)	125° (b-b)	125° (b-b)	125° (b-b)
55°	125° (b-b)	125° (b-b)	125° (b-b)	125° (b-b)
Hip extension				
35°	47° (c-c)	59° (c-c)	59° (c-c)	59° (c-c)
45°	44° (c-c)	59° (c-c)	59° (c-c)	59° (c-c)
55°	40° (c-c)	58° (c-c)	59° (c-c)	59° (c-c)

(c-c) component-to-component impingement, (b-b) bone-to-bone impingement, (c-b) component-to-bone impingement

different surgical approaches [1]. They found that when a posterolateral approach was used, the risk of dislocation was reduced from 12.1% to 6.9% and to 3.8% using 22-, 28- and 32-mm femoral head diameters. However, when an anterolateral approach was used, the risk of dislocation was reduced from 3.8% to 3% and to 2.4% using 22-, 28- and 32-mm femoral heads. Other authors reported a reduced risk of dislocation using a 32-mm or a 28-mm femoral head compared to a 22-mm femoral head [3–7]. Beaulè et al. found that in ten out of 11 patients who had had an average of four previous operations, jumbo-diameter femoral heads ranging from 40 to 50 mm were effective in preventing new episodes of recurrent dislocation [8]. However, Lachiewicz and Soileau, in a prospective study on 61 patients at high risk of dislocation in primary THA, found that the use of large femoral heads (36 and 40 mm) led to a prevalence of early dislocation (4.6%) similar to historical controls [9]. Other clinical studies failed to demonstrate that large femoral heads decrease the risk of implant dislocation [5, 10–13]. Peters et al. [5], in a prospective non-randomised study, analysed 160 patients in whom a 28-mm femoral head was implanted and 136 in whom a 38-mm femoral head was used. The surgical approach was lateral in the 28-mm-femoral-head group and posterior in the 38-mm-femoral-head group. Although in the former group the average length of follow-up was almost twice that of the 38-mm-femoral-head group, no significant difference was found in the dislocation rate between the two groups [5].

As dislocation is a multifactorial phenomenon, clinical studies may not entirely reflect the true benefits of the femoral head diameter on the stability of the hip joint [14]. Likewise, prosthesis impingement, which is thought to be affected by the diameter of the femoral head [15], may cause increased stresses at the bone–implant interface, but it may be difficult to detect in the clinical setting until accelerated wear and loosening of the components take place.

Experimental studies may accurately assess the behaviour of femoral heads of different diameter. Burroughs et al. [4] analysed in vitro the maximum flexion, internal and external rotation in a Sawbone hip using femoral head sizes of 28-, 32-, 38- and 44-mm in diameter. The acetabular component was implanted with 45° of abduction and 10°, 30° and 45° of anteversion. They found that when 28-mm and 32-mm

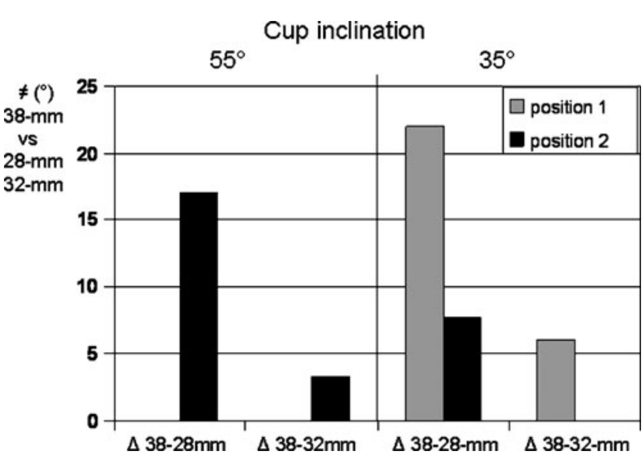

Fig. 3 Increase in the range of motion between 38- and 28- and 32-mm femoral heads during combined motion of positions 1 and 2 in the presence of a cup inclination of 55° (*left side of graph*) and 35° (*right side of graph*)

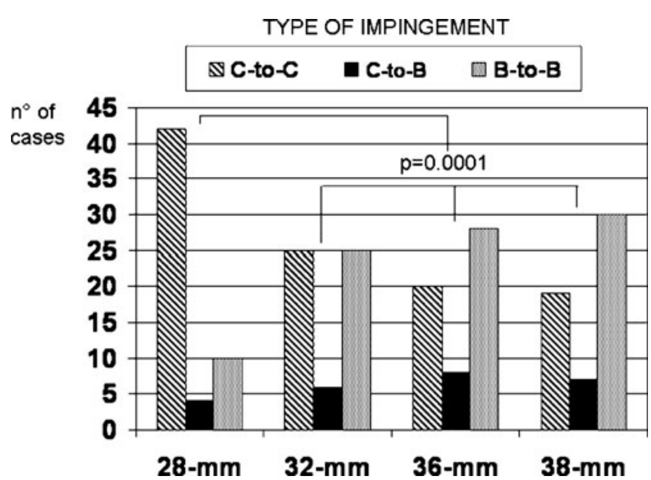

Fig. 4 Type of impingement with the different femoral heads. A significant difference was found between type of impingement with 28-mm and with 32-, 36-, and 38-mm femoral heads. *C* component, *B* bone

heads with a skirt were used, pure flexion was decreased by about 12° and 7°, respectively, compared to the 44-mm and 38-mm heads, which do not need a skirt for the same neck length. However, when a femoral head without skirt was used, such an advantage was limited to 1°. D'Lima et al. [15] used a three-dimensional model of a generic hip replacement prosthesis to test the range of motion up to the impingement with femoral head diameter ranging from 22 to 32 mm. They found a non-linear correlation between the diameter of the femoral head and the range of motion, since an increase in the head diameter from 22 to 26 mm resulted in a greater improvement in the range of motion than an increase in the head diameter from 28 to 32 mm. Bartz et al. found that the range of motion of the hip in flexion at dislocation was increased by using the 28-mm femoral head compared to the 26-mm head, while no significant differences were found between the 28- and 32-mm femoral heads [16].

In our study we found that when the acetabular component showed an optimal orientation, the overall range of motion increased an average of 5.3° moving from the 28-mm to the 38-mm femoral head, while no differences were found between the 32-mm and 38-mm femoral heads. The occurrence of bone-to-bone impingement was found to limit, to a similar extent, the hip range of motion of 32-, 36- and 38-mm femoral heads.

Several conditions, including revision cases, dysplastic hips and others, are known to increase the risk of implant malpositioning during total hip arthroplasty and eventually the risk of impingement and dislocation [17]. Such a risk could theoretically be reduced by using femoral heads of large diameter. For instance, it has been shown that the increased range of motion reported with the 32-mm femoral head, compared to the 22-mm, is further magnified in the presence of a vertical positioning of the acetabular component [15]. However, the benefits of large femoral heads (36 mm or more) with respect to standard 28- or 32-mm femoral heads, in the presence of different cup positioning, is not well known [18] .

In our investigation we simulated a non-optimal implant positioning by changing the cup inclination and anteversion in different combinations with respect to a reference position of 45° of inclination and 28° of anteversion. The results have shown that large diameter femoral heads (36- and 38-mm) increase the range of motion up to the impingement compared to the 28-mm head in the vast majority of the tests performed. Such an increase was almost twice that found in the presence of an optimal positioning of the cup. However, we were surprised to find that, when compared to the 32-mm femoral head, the 38-mm head led to an average increase in the range of motion of only 1° (range 0–5°), and in only four of the tests performed such an increase was greater than 3°. As in the presence of optimal cup positioning, the occurrence of bone-to-bone impingement was the reason why large femoral heads did not improve the range of motion compared with the 32-mm head. To our knowledge, this is the first study clearly showing that 32-mm femoral heads perform very closely to large heads in the presence of optimal and non-optimal cup position. If these results are confirmed in hip joints with different morphologies, it is not advisable to increase the acetabular reaming (beyond 50–52 mm) in order to use a 36-mm or 38-mm head when a smaller cup can be safely implanted with a 32-mm femoral head. This seems particularly true in young patients and in those with thin acetabular walls in whom the preservation of acetabular bone stock is crucial.

There has been little investigation into the effects of different types of impingement, i.e. component-to-component, component-to-bone and bone-to-bone, on the longevity of the implants. However, component-to-component impingement possibly causes the most deleterious effects since it may accelerate the wear and loosening rate of the components [19, 20]. Our results showed that 28-mm femoral heads caused component-to-component impingement in the majority of the tests performed, while the same occurred in a significantly lower number of cases with larger heads. Thus, in the presence of non-optimal implant positioning, increasing the femoral head diameter significantly reduces the risk of component-to-component impingement.

This study has a few limitations. First, despite the high number of tests performed, we investigated the behaviour of different femoral heads with different cup position in only one specimen of a female cadaveric hip joint; it may be that hip joints with different morphologies perform differently during the impingement tests. Second, although in our model we used a standard femoral neck osteotomy, we cannot rule out that results may differ by changing the level of femoral neck osteotomy. Third, large femoral heads are known to reduce the risk of dislocation since a greater translation between the femoral head and the acetabulum is needed for dislocation [4–17]. However, we limited our investigation to the risk of impingement because this is a frequent cause of dislocation [21–25] and because impingement is likely to be a major cause of implant wear and loosening [19, 20].

In conclusion, in the presence of a hip prosthesis correctly implanted, large femoral heads increase the range of motion compared to the 28-mm femoral head while the advantages are negligible compared to the 32-mm head. In the presence of non-optimal implant positioning, the advantages of large femoral heads appear to be greater than in the presence of optimal implant positioning, but only with respect to the 28-mm femoral head. The 32-mm femoral head was found to perform very closely to the 36-mm and 38-mm femoral heads even in the presence of non-optimal cup positioning. These results suggest that the 32-mm femoral head should be considered a valuable alternative to 36–38-mm heads, particularly in patients with poor acetabular bone stock in whom unnecessary reaming would be needed to position a cup for a 36–38-mm femoral head.

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