Femoral Head Size in THR: Rationale for Reassessment

Summary of Investigations Conducted in the Orthopedic Biomechanics Laboratory at the MGH

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INTRODUCTION

Sir John Charnley's initial endeavors in total hip replacement (THR) made use of a femoral head that was 41.5mm in diameter[1]. The rationale for a component of this size was that the femoral head must be anatomically similar to the natural hip in order to restore the natural function of the hip. However, Charnley's initial attempts proved unsuccessful due to excessive wear of the mating bearing materials and subsequent component loosening. The recent advent of electron beam highly crosslinked ultra-high molecular weight polyethylenes (UHMWPE) has allowed for the reevaluation of larger femoral head sizes, as these materials have demonstrated extremely low wear *in vitro* regardless of femoral head size.

Irradiation of UHMWPE produces a host of free radicals throughout the material. If left untreated, they can persist for long periods of time and oxidize the material by reacting with oxygen diffusing in from the surrounding environment. However, if the UHMWPE is irradiated with a high-energy electron beam and melted immediately after irradiation, the free radicals react with each other to form crosslinks that provide the material with exceptional oxidation resistance. Crosslinking gives the UHMWPE a more entangled molecular structure and hence exceptional wear resistance. The dramatic improvement in wear resistance as compared to conventional UHMWPE THR bearing materials has been demonstrated *in vitro* in both pin-on-disk studies[2,3,4,5,6,7] as well as in studies utilizing a physiological hip joint simulator[5,8].

There are a number of UHMWPE acetabular liners now on the market that claim to be crosslinked. However, to date, only two highly crosslinked polyethylenes (Durasul™ of Sulzer Orthopedics, Inc. and Longevity™ of Zimmer, Inc.) have demonstrated an extremely low wear rate that is independent of femoral head size, a phenomenon not seen with conventional polyethylene bearing materials. Hip simulator testing has shown that UHMWPE irradiated with an electron beam and subsequently melted provides exceptionally low wear for femoral head sizes up to 46 mm[5]. Considering this behavior, it is reasonable to revisit the use of a larger femoral head in THR.

Conceptually, the advantages of larger femoral heads are increased range of motion and joint stability. There is some debate in the literature on whether THR dislocation is a significant problem, although one must consider that the cause of dislocation is multifactorial[9] and that recurrent dislocation is a cause for early revision[10,11]. Even though dislocation rates for primary THR are typically reported to be low, some studies have reported rates as high as 5.8%[12,13]. Dislocation rates for revisions have been reported to range from 4.8% to 13%[13,14,15]. 30%[13,16] to 65%[17,18] of THR dislocations become recurrent. An inverse relationship has been shown between the number of THRs performed by a surgeon and the rate of dislocation[19,20,21]. Other factors that affect the potential for dislocation include preoperative diagnosis, surgical approach, postoperative management, component position, and component design.

Considering that impingement can be a precursor to dislocation, total hip designs which provide increased range of motion before impingement may be more stable. Several studies have shown that increasing the head/neck ratio results in an increase in range of motion[22,23,24]. One means of increasing the head/neck ratio is to increase the diameter of the femoral head.

Larger femoral heads can also increase joint stability by increasing the displacement between the femoral head and acetabulum required for dislocation. This greater displacement produces greater tension on the soft tissues surrounding the hip during subluxation, resulting in a greater reaction force that acts to keep the head within the socket.

MATERIALS AND METHODS

Range of Motion Testing

Range of motion tests were conducted on a three dimensional anatomic goniometer[24], which consists of a Sawbone® pelvis and femur into which total hip components are implanted. A 61 mm OD acetabular shell (Interop®, Sulzer Orthopedics, Austin, TX) was placed in the left acetabulum of the Sawbones® pelvis (Pacific Research Laboratories, Vashon, WA). The acetabular shell was positioned in 45° of abduction and 30° degrees of anteversion.

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Two femoral components with different neck geometries were used in the Sawbones® femur: the Natural® stem (Sulzer Orthopaedics, Austin, TX.) which has a straight cylindrical neck with a less prominent collar, and the cemented Versys® stem (Zimmer, Inc., Warsaw, IN), which has a tapered trapezoidal neck with a more prominent collar. These two neck designs are believed to be representative of many currently available neck geometries. Both stem types in this study used a 12/14 morse taper and therefore allowed for the testing of all femoral head diameters and lengths on both stems types. Each femoral component was inserted in neutral varus/valgus angulation, with varying degrees of femoral anteversion (0, 15, and 30 degrees).

This setup was used to test the range of motion in pure flexion, internal rotation at 90° of flexion, and external rotation at 0° of extension. The femoral head sizes tested were 28 mm, 32 mm, 38 mm, and 44 mm in diameter. The 28 and 32 mm heads (Zimmer, Inc. Warsaw, IN) were tested in five head-neck lengths; -3.5, 0, +3.5, +7 (skirted), and +10.5 (skirted) mm. The 38 mm and 44 mm heads (Sulzer Orthopedics, Austin, TX) were tested in -8, -4, 0, +4, and +8 mm neck lengths, none of which were skirted. For each case, the amount of motion as well as the type of impingement (i.e. component-on-component, component-on-bone, bone-on-bone) was recorded.

Dislocation Testing

To evaluate joint stability, a novel device was constructed to enable replication of hip flexion to the point of dislocation. The device consists of a Sawbones® hemipelvis, a fiberglass femur (Pacific Research Laboratories, Vashon, WA), and a cradle that supports the pelvis. Flexion of the hip was produced by rotating the cradle about an axis aligned with the center of the femoral head. A precision voltage potentiometer was mounted on the shaft about which the cradle (i.e. pelvis) rotated, which allowed for the continuous measurement of flexion angle via a computer data acquisition system (Omega Engineering, Inc., Stamford, CT). The entire device was mounted into a mechanical testing machine (MTS, Eden Prairie, MN) and load provided by the MTS combined with the load of a dead weight produced a joint reaction force in the anterior-medial direction in accordance with data from Kotzar *et al*.[25] The load was also continuously measured by the computer data acquisition system.

One set of dislocation tests was conducted with the femoral component (Natural®, Sulzer Orthopaedic, Austin, TX) fixed at 15° of anteversion but with the 61mm OD acetabular component in three different positions (10º, 30º, and 45º) of acetabular anteversion. In this test, the 28 mm, 32 mm, 38 mm, and 44 mm femoral heads were evaluated at neutral neck lengths in the dislocation simulator. Because the larger femoral heads do not require any countersinking within the polyethylene, the acetabular component made for the 38mm and 44mm heads had a very shallow (nearly zero) chamfer. Each test was conducted three times and Student's t-test was performed to evaluate the significance of the resulting translation and flexion required for dislocation.

RESULTS AND DISCUSSION

Note: *A complete manuscript containing all data and figures has been submitted to and is under review for the Journal of Bone and Joint Surgery.*

Range of motion testing showed that an increase in head size resulted in an increase in range of motion in all directions tested, up to the 38mm femoral head size. For reasons discussed below, the 44mm head did not provide any additional range of motion as compared to the 38mm head. The increase in range of motion when going from smaller head sizes (i.e. 28mm and 32mm) to a 38mm head was several degrees (2º-4º). However, at longer neck lengths where the smaller heads require a skirt, the improvement in range of motion with the larger heads was more dramatic (10+ degrees). The fact that larger femoral heads do not require a skirt to achieve longer neck lengths is of great benefit, as a skirted neck reduces the head/neck ratio and therefore limits range of motion, increasing the risk of dislocation.

When observing the type of impingement, larger heads exhibited virtually no component-to-component impingement, which was fairly prevalent with smaller head sizes. The absence of component-to-component impingement with the larger heads was due to the absence of the skirt at longer neck lengths as well as the greater range of motion achieved with the greater head/neck ratio. In the case of the large head, bone-to-bone impingement occurs prior to component-to-component impingement. As a result, once bone-to bone contact occurs, no further improvement in range of motion will be achieved by further increasing the femoral head size. Thus, there was no difference in range of motion between the 38mm and 44mm head. These trends in ranges of motion and types of impingement were observed for both femoral neck designs tested.

Increasing femoral anteversion resulted in greater amounts of pure flexion and internal rotation at 90º of flexion for all head sizes tested. However, increasing femoral anteversion also produces a decrease in the amount of external rotation at 0º of extension. The anatomic goniometer testing showed that 30º of femoral anteversion combined with a 38mm femoral head still allowed for 45º to 50º of external rotation with the hip in extension.

In our dislocation simulations, we found that increasing head size resulted in greater flexion as well as greater displacement between the femoral head and acetabulum to produce dislocation. For the different acetabular anteversions tested, only the 38mm and 44mm femoral heads produced a significant increase in flexion and displacement required to produce dislocation.

The *in vitro* analysis summarized here supports the conceptual advantages of larger femoral head sizes in THR. There is also clinical support for the use of larger femoral head sizes for increasing joint stability. *In vivo* experience with bipolar reconstructions[26], femoral head surface replacements[27], and larger head diameters used with conventional polyethylene[28] in cases of recurrent dislocation strongly supports the findings of this *in vitro* study. The use of large femoral heads, now made possible by the advent of highly crosslinked UHMWPE, offers promise in improving the functionality and stability of THR.

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