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What every surgeon should know about Ceramic-on-Ceramic bearings in young patients

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- Based on the exceptional tribological behaviour and on the relatively low biological activity of ceramic particles, Ceramic-on-Ceramic (CoC) total hip arthroplasty (THA) presents significant advantages
- CoC bearings decrease wear and osteolysis, the cumulative long-term risk of dislocation, muscle atrophy, and head-neck taper corrosion.
- However, there are still concerns regarding the best technique for implantation of ceramic hips to avoid fracture, squeaking, and revision of ceramic hips with fracture of a component.
- We recommend that surgeons weigh the potential advantages and disadvantages of current CoC THA in comparison with other bearing surfaces when considering young very active patients who are candidates for THA.

Keywords: total hip arthroplasty; Ceramic-on-Ceramic; young patients

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Introduction

Ceramic-on-Ceramic (CoC) articulating surfaces are well known to combine properties of a high-strength, scratch-resistant material with very low coefficients of friction averaging 0.02, mimicking those of a normal joint. Their superior wettability and hydrophilic surfaces aid in lubrication. Furthermore, the most recent studies have demonstrated new long-term advantages with current ceramic-bearing couples. However, the most important current concerns about CoC bearings are squeaking and fracture of ceramic. From the foregoing, the advantages and disadvantages of current CoC total hip arthroplasty (THA) should be carefully considered in younger, more active patients.

Ceramic-on-Ceramic bearings decrease wear and osteolysis

The theoretical advantages of alumina-alumina (Al-Al) bearings are related to a decrease of wear and osteolysis as compared with polyethylene. Hernigou et al[1] investigated wear and osteolysis in bilateral arthroplasties (one ceramic-ceramic and the contralateral ceramic-polyethylene) of patients who had survived 20 years without revision and without loosening of either hip. Osteolysis was identified on anteroposterior pelvic radiographs and three-dimensional volume from CT scans.

The number of lesions was higher on the side with the ceramic-polyethylene (PE) couple. With a similar length of follow-up on each side, the surface wear and the volume of osteolysis were consistently higher on the side with the ceramic-PE couple. The CT scan also provided more accurate information than did standard radiographs with regard to the volume of osteolysis. With an Al-Al hip, the volume of osteolysis was always lower than with a ceramic-PE hip when the comparison was made on the same patient. Their report suggests that using an Al-Al couple, a near absence of periprosthetic radiographic osteolysis could be expected. Wear comparison between the two bearing surfaces was possible due to the long follow-up and some revisions. The average linear wear rate with ceramic-on-PE was low (0.05 mm/year) in their study but, correspondingly, did not compare favourably with the wear rates of *in vitro* studies of Al-Al replacements. They looked at the rate of wear of ceramic bearings whose bearing surfaces were made to the same specifications, principally by the same manufacturer and in the same period (20 years ago). They reported with this first generation ceramic a mean rate of wear of 9 µm per year for the femoral head and 6 µm per year for the acetabular socket.

Ceramic-on-Ceramic bearings decrease the cumulative long-term risk of dislocation

Since wear has previously been suspected as a risk for late dislocation, from a theoretical point of view the risk of late dislocation should be decreased with CoC bearing surfaces. Hernigou et al[2] determined whether the first-time risks, as well as the cumulative long-term risk dislocations were different according to the couple of friction.They investigated patient factors that could affect the risk of dislocation, and

analysed the different hip surgery factors (wear, joint exploration at revision, histology) that could affect the risk of dislocation in the two different bearing surfaces (CoC or ceramic-PE). They retrospectively reviewed 126 patients (252 hips) with bilateral THA (one CoC and the contralateral ceramic-PE) who had THA performed between 1978 and 1985. All patients received the same implants except for the cup. The ceramic head was 32 mm in diameter on each side and anchored through a Morse taper.

For hips with PE liners, the cumulative risk of a first-time dislocation was 2% and rising to 13% at 30 years for patients who were alive and had not had a revision by that time. For hips with ceramic liners, the cumulative risk of a first-time dislocation was 2% at one year and then did not change at 20 years and at 30 years for patients who were alive and had not had a revision by that time. At the most recent follow-up the cumulative number of dislocations (both first time and recurrent dislocations) were 31 for hips treated with PE cups *versus* four with ceramic liners. The reasons for the lower rate of dislocation with CoC bearings are probably the difference between the capsule of the hips with the two bearing surfaces (fibrous and thick with CoC; thin with PE cups). A fibrous and thick capsule present in CoC hips was present at all revisions that were performed whatever the cause of revision, contrary to a thin capsule with less resistance present in hips with PE cups. The reasons for these differences are probably due to the different biological response of the capsule to wear debris. A possible explanation is that the thick capsule of CoC hips protected against late dislocation when general factors, such as age or cognitive and neuromuscular-related disorders, occurred in these patients.

Ceramic-on-Ceramic decreases muscle atrophy

Little is known about muscular changes after total hip replacement. Hernigou et al[3] investigated CT-based measurements of skeletal muscle fat atrophy in patients with THA with different bearing surfaces (CoC or PE), and analysed bone and muscle progenitors around the hip of these patients. They retrospectively reviewed 240 patients (240 hips) who had THA revision with a contralateral normal hip. All patients had received the same implants for the primary arthroplasty (32 mm head) except for the bearing surfaces (80 hips with CoC, 160 with PE). Before revision, osteolysis, muscle atrophy and fatty degeneration were evaluated on CT scan and compared with the contralateral side. There was a greater extent of fatty muscle atrophy on CT scan in hips with osteolysis (PE hips) as compared to hips without osteolysis (CoC hips). For the 80 hips with CoC no osteolysis was detected before revision; there was no muscle fatty degeneration of the gluteal muscles (GM) on CT scan or histology. For the 160 hips with PE liners, osteolytic lesions in acetabulum and femur were observed in 100% of the hips; the fatty muscle degeneration observed on CT scan or on histology increased with the amount of osteolysis ($p = 0.01$).

Bone muscle progenitors were evaluated by bone marrow mesenchymal stem cells (MSCs) and satellite cell-culture for muscle. These two abnormalities (bone osteolysis and fatty atrophy) were associated with a decrease of MSCs in bone and in muscle. It is well known that skeletal muscle has a close relationship with bone mass, starting in the embryonic period. Developmentally, osteoblasts and muscle cells arise from a common mesenchymal precursor. There is a positive correlation between muscle strength and bone mass. It appears that in the case of osteolysis there is osteolysis-associated reduced bone regenerative capacity with a decrease in MSCs and that this is accompanied by a reduced muscle mass and an increased fatty degeneration. The cause of the reduced regenerative capacity of bone and muscle in PE hips is probably related to the toxicity of PE particles since this is not observed with ceramic bearing surfaces. Whether this toxicity is linked to a direct contact or can be mediated at a distance is unknown. The overall impression is that ceramic particles are biologically inert. In comparable doses, the biological response is less intense with ceramic *versus* PE particles. This study also showed that there was a significant decline of MSCs at distance from bone osteolysis and of satellite muscle cells (in the absence of PE debris in the muscle) in patients with osteolysis. To our knowledge the toxicity of PE particles on satellite cells of humans has never been tested previously.

Morse taper technology and ceramic

The ceramic femoral head arthroplasty is a polycrystalline form of industrial sapphire. It is obtained from aluminium oxide powder pressed under hot isostatic pressure at a temperature between 1600°C and 1800°C and then sintered and polished to obtain a smooth surface. The ceramic head has excellent compression strength and currently a 32 mm head tested in compression sustains a 102 kN load. This exceeds the mechanical resistance of the femoral diaphysis to static load which is only 20 kN. So probably the risk of fracture with ceramic has nothing to do with the activity or the weight of the patients. In view of this excellent compression strength, jumping and sports may be allowed if the compression load is not reached during these activities. However improper selection, placement, positioning, alignment and fixation of the femoral head on the Morse taper[4,5] may result in unusual stress conditions which may lead to a fracture. Inadequate cleaning of the Morse taper (removal of surgical debris) can lead to abnormal impaction of and position of the head on the trunnion. It is necessary to use clean gloves when handling or touching the Morse taper.[6] It is also important to avoid the use of a metallic hammer when seating a ceramic head. A nylon or a PE-seating instrument must be used. It is necessary to avoid an excessive force but it is also necessary to impact the head on the Morse taper with enough force to seat the

head on the taper. The impact has to be exactly in the direction of the axis of the taper. Twisting the head allows a position on the taper but is not satisfactory because the weight of the patient will later impact the head on the taper in a direction that is not exactly in the direction of the axis of the cone.

For the ceramic liner component, appropriate surgical technique is essential in order to assemble properly the liner in the metal back, but this is not always achieved and a number of factors may contribute to this. Intra-operatively the titanium shell can deform diametrically because the titanium shell has a thinner wall than the ceramic, and the material stiffness of titanium is lower than that of ceramic. The risk is to produce a limited contact of the shell with the liner on two diametrically-opposing areas, which increases the risk of poor fixation of the liner, micro-mobility and fracture. Reduced shell thickness and increased bone stiffness may increase deformation of the shell. Entrapment of soft tissue and bone or hydroxyapatite (HA) fragments are other possible mechanisms that may generate non-uniform loading of the liner. The design[4] may also be relevant in poor liner canting, and the mating taper angle in particular. A small angle generates a smaller window of insertion for which the taper will engage. Increasing the taper angle may allow easier insertion of the liner, but the required force at the interface for static friction to keep the assembly together will be higher. Jamming of the liner can occur also producing vacuum mechanism of suction of the head during the manoeuvres of push and pull by the surgeon to check stability.

Ceramic head decreases head-neck taper corrosion

Ceramic is known for its inert and electrically insulating properties. In an *in vitro* study analysing fretting corrosion between zirconia ceramic heads and cobalt-alloy stems compared with metal (cobalt-alloy) heads and cobalt-alloy stems, there was less fretting corrosion in the ceramic group.[7] The recent retrieval study[7] analysed fretting corrosion in matched groups of 50 CoC heads and 50 cobalt-chrome (Co-Cr) heads on metal tapers. The corrosion scores were lower for the stems in the ceramic group, suggesting that taper corrosion may be mitigated but not eliminated by using ceramic heads. Data on taper corrosion are generated from *in vitro* and retrieval studies. Given that *in vitro* studies cannot precisely reproduce all the *in vivo* conditions, these results should be interpreted with caution. Retrieval studies also have limitations as they involve analysis of clinically failed implants and these findings may not necessarily reflect the well-functioning, unrevised implants. In addition, among the implants in a given study, there is often heterogeneity in the bearing surfaces used, head size, offset, stem type, stem alloy and implant manufacturer which may have implications on taper corrosion.

Fixation of the metal-back on the bone

Since the early 1990s, it has been recognised that ceramic liners should never be fixed with cement;[8-11] the dominant design is a porous coated titanium shell.[12-14] This design has generated excellent rates of survival and patient satisfaction results. However, assembling the acetabular component intra-operatively into the shell is not easy and some rules need to be respected. A sufficient force across the interface between the titanium shell and the bone is required to maintain the friction force that keeps the titanium component shell fixed in the bone. Impacting the shell into the acetabulum should slightly expand the bone and generate circumferential tensile stress in the bone. The bone then acts like an elastic band on the shell and generates circumferential compressive stress in the interface between the titanium metal back and the bone. Appropriate surgical technique is essential in order to properly fix the shell in the bone[8,15] but this is not always achieved due to surgical difficulties. Using the reamer intra-operatively in an asymmetric method can deform[16] the cavity produced in the bone by 2 mm diametrically which will give a larger diameter than the shell and a poor fixation. If the hole in the bone is not perfectly circular but elliptical, this may be sufficient to limit the contact of the shell with the bone to two diametrically-opposing areas which decreases the fixation. A thin metal shell can be deformed by sclerotic bone, jeopardising the engagement of the ceramic liner, and if no jamming occurs, this could increase the risk of squeaking. Soft tissue entrapments are other possible mechanisms that may prevent uniform seating of the shell and generate non-uniform loading of the shell on the bone and this may compromise the bone fixation. Increasing the diameter of the shell to improve fixation will transfer the problem onto the bone with a risk of fracture of the acetabulum at the time of impaction.

Revision of a ceramic hip in the absence of a fracture

Due to cone technology, a cone that has already received a ceramic head is theoretically damaged and engineers and manufacturers will advise that the cone be replaced for a new ceramic head. When another ceramic head is seated on the same taper, there is an increased risk of ceramic fracture if the cone is damaged. If during a revision it is necessary to remove a ceramic head, the ceramic should not be directly stroked to avoid a fracture of the head or damage to the taper. A hammer stroke should be made on the shoulder of the stem in the same direction of the stroke that had fixed previously the femoral head. With the reaction force, the femoral head moves proximally on the taper and is gently removed by hand without taper damage. When the ceramic femoral head is removed, the taper causes an imprint[5] in the bore of the head. The imprint is normally a homogenous ring. When the direction of the stroke that

has fixed the head is out of the taper axis, the imprint is asymmetrical. If the imprint is asymmetrical, this means that the femoral head was not correctly fixed on the taper and that the taper may probably be damaged. A new ceramic head should not be used on such a taper. If the imprint is a perfectly symmetrical ring this means that the taper has no damage and that a new ceramic head could probably be used.

The cone of the stem is provided with circumferential ridges that are crushed down at the moment of the impaction of the ceramic head. A new head, in case of revision, cannot be used on the same cone from a theoretical point of view. To avoid this problem, when possible it is preferable to keep the ceramic femoral head on the taper when only cup revision is necessary. However, this of course makes the cup revision more difficult and it may be necessary to remove the femoral head to improve the approach to the acetabulum. The concern is that the trunnion is likely to be damaged during removal of the femoral head and damaged areas may lead to stress risers responsible for the initiation of a fracture in a newly-implanted ceramic head. If the head is not securely fixed onto the damaged taper, there may be a risk of increased wear due to the abnormal movements at the head-neck junction. In a study[17] reporting cases in which ceramic heads were re-implanted onto well-fixed titanium stems at revision of CoC prostheses, no fractures of the head had occurred. Those authors suggested that this approach is acceptable as long as taper inspection revealed only minor scratches and the newly-implanted ceramic head had a stable fit on the taper. As this practice is against manufacturers' recommendations, the surgeon should consider the potential legal implications in cases of subsequent head fracture. It has been suggested that the use of a titanium alloy adaptor sleeve might help prevent the recurrence of fracture.

Squeaking

Squeaking remains a concern for ceramic bearings.[5,15] This problem affects the patient's quality of life when noises emanating from ceramic bearings are high. Rates vary from 0% to 33% with several theories on the origin of squeaking. Fortunately, clinically, the problem is minor in the majority of patients. The exact mechanism is still unclear and is probably multifactorial. Some authors revealed an association with a particular prosthetic design or found a clear relationship between the prevalence of squeaking and the type of femoral component implanted. Alternatively, there are studies that did not report any squeaky hips.

As a ceramic head passes over the wear stripe, it could generate a vibration, but the ceramic vibration frequency is not audible; however, the metallic parts (femoral stem and acetabular shell) may amplify this vibration by resonating, changing the frequency of the vibration, resulting in an audible sound.

Ceramic fracture

Contemporary ceramic materials[13,18] are very different to those associated with the high rates of fracture[15] reported in the 1970s. Improved materials and hot isostatic pressing have allowed the reduction of grain size and the increase in the density of the ceramic with improvement in its mechanical properties. Ceramic fractures can be explained by the propagation of a crack initiated in the material by the imperfection of the material or by a specific event that initiates the crack. Because of the grain structure of the material, the initial crack will grow and lead to a fracture fatigue. Clean assembly[6] of the components is therefore important, but sometimes difficult to achieve during surgery. Failure to engage the tapers of the titanium shell and ceramic liner properly may also be responsible for fracture of the liner or for liner chipping on insertion.

Concerns with revision for a fracture of a ceramic component

A fracture of a ceramic[19] component should be recognised early, because the abrasive effect of ceramic particles can cause catastrophic destruction of the neck taper or metal back resulting in metallosis originating from the metallic debris. When the fracture appears on the ceramic head with a ceramic liner without fracture, the ceramic liner can be conserved, but of course it is necessary to use a new ceramic femoral head. However, due to the fact that the breakage of the ceramic head may have altered the Morse taper surface, this may be a risk of high point pressure on the taper with initiation and propagation of a crack that predispose the new ceramic femoral head to re-fracture! Therefore, a ceramic femoral head probably should not be used on an old Morse taper at the time of revision for a fracture of the femoral head. This concept necessitates removal of the femoral stem to get a new taper (this may be difficult if the stem is stable). When the fracture appears on the ceramic head with a PE cup, it is necessary to remove the cup at the time of revision, even when it appears normal macroscopically. If the PE cup is not removed, ceramic particles will produce three-body abrasive wear with a metal head. However, a new ceramic head may be coupled with a PE liner; in this case, the possible microscopic ceramic debris will be embedded in the plastic, and the ceramic head will not be damaged in any case by it. After the cup has been removed, a new bearing couple has to be chosen. Because of the risk of ceramic particles in the joint or in the neosynovium even after debridement and extensive synovectomy, the best bearing surfaces are CoC. But as previously (with a ceramic cup) this may necessitate removal of the stem to implant a new ceramic head on a new taper. A metal-on-metal bearing surface should be avoided because the ceramic is harder than metal and rapid three-body abrasive wear can

occur. If the surgeon does not want to remove the stem (old patient, stable stem difficult to remove, etc.), the femoral head should be made of reinforced specially forged cobalt chromium or metal with the surface reinforced with diamond. As previously mentioned, for revision of a ceramic head without fracture, the existence of special ceramic heads with metal sleeves, may be applied on a taper already used thus excluding the revision of the stem; however, in the presence of a fracture of a ceramic head, the risk of a partially worn out taper is increased and the problem is to know how much wear of the taper is acceptable to avoid any secondary deformation of the sleeve, which of course also represents a risk for a fracture of the new head.

For a fracture of a liner, the problem is exactly the same: the new liner should be a ceramic liner; for the same reasons it will be necessary to remove the shell to obtain a new Morse taper.

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