ORIGINAL ARTICLE

CERAMIC-ON-CERAMIC HIP RESURFACING

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Summary

Hip resurfacing is a bone-conserving method for restoring the hip joint. Hip resurfacing patients have superior clinical function, better overall survivorship, and fewer revision procedures compared to patients with total hip replacements (THR). The surgical approach, method of implant fixation to bone, and the material used to make the resurfacing implants are all of interest to patients.

It has not been solved which implant type provides the best wear characteristics, function, and safety. Conventional metal-on-polyethylene implants were subject to wear and failure. Metal-on-metal (MoM) hip implants are safe and effective for many patients but can fail in patients with femoral head diameter less than 50 mm, which includes essentially all female and many smaller male patients.

In THR, ceramic-on-ceramic (CoC) bearings have a 45-year clinical history of favorable wear. However, this success is offset by a greater risk of implant fracture. The rate of femoral head fracture has decreased by using BIOLOX®*delta* ceramic implant (CeramTec GmbH, Plochingen, Germany). However, the rate of acetabular component fracture in THR has remained constant at 0.03%. Resurfacing acetabular components have a larger internal diameter than THR. Also, they are subject to greater loads because of the increased functional demands of resurfacing patients. In resurfacing, the retained native femoral neck is larger than in a THR and, therefore, there is a greater chance of impingement and edge loading. The ceramic acetabular component fracture rate in resurfacing patients is higher compared to THR patients.

Ceramic-on-ceramic prostheses are very popular in Europe. Squeaking occurs with CoC hip prostheses and is the reason they never became popular in the United States. Fractured ceramic implants are a devastating complication, as the fractured granular material cannot be removed effectively, which exposes the revision implants to accelerated wear and need for additional revision in most instances. From 5% to 6% of patients receiving a CoC hip resurfacing prosthesis have required revision.

Highly cross-linked polyethylene is the safest acetabular bearing choice for most patients for hip resurfacing. To date, there have been no bearing surface failures in hip resurfacing patients with highly cross-linked polyethylene implants.

Introduction

The search for the perfect bearing surface for hip implant arthroplasty has continued for three generations. Suitable femoral choices have been cobalt chromium, ceramic-coated titanium, and ceramic (Fig. 1).

Fig. 1. A BIOLOX®*delta* CoC resurfacing prosthesis.

The first resurfacing implants in the 1930s -1950s only involved the femur to avoid the problems with applying an acetabular surface. However, when resurfacing only the femur, 30% of patients continued to experience pain and sometimes erosion of the retained native acetabulum.

Haboush[1] tried acetabular resurfacing using methacrylate acrylic in 1951. It was very abrasive and failed in months. Charnley used Teflon™ in 1958 and it failed within a few years.[2] Townley used polyurethane in 1960 and it failed after several years but caused little adverse reaction in the tissues.[2,3] Polyethylene use began in 1971. Polyethylene took many years to fail, but it caused important osteolysis in some patients.[2-5]

Metal-on-metal has been used for 25 years with generally favorable outcomes in patients with femoral head sizes larger than 50 mm.[6-8] However, failure from the adverse reaction to the small-size wear debris particles has led to difficult revision procedures for some patients.[9] Metal-on-metal hip resurfacing has declined by 90% since 2010.

Hip resurfacing with a highly cross-linked acetabular component has a 97.5% success rate. Hip resurfacing patients have superior function, survivorship, and a lower revision rate compared to THR.[6-8,10,11]

Ceramic-on-ceramic has been successful for THR. Ceramic-on-ceramic has been used since 1972 almost entirely in Europe, especially in France. Squeaking and component fracture, particularly of the acetabular component, have led to very limited use for ceramics in hip resurfacing (Figs. 2 and 3).[12]

Fig. 2. This photograph shows a fractured BIOLOX®*delta* ceramic acetabular component with intense black synovial reaction.

Fig. 3. This BIOLOX®*delta* prosthesis has fractured from edge loading.

Development of Ceramics for Hip Resurfacing

My personal experience with ceramics for hip resurfacing began in 1990.[19] Dr. Charles O. Townley and I were frustrated with the wear-related failure of the conventional polyethylene we used for hip resurfacing. Also, the acetabular component was thick and impractical. We needed a thin and wear-resistant bearing surface choice.

The ceramics available at that time from Europe were disappointing because of squeaking and fracture. Also, suitable dimensions for hip resurfacing were not offered. We decided to create a new ceramic material. Dr. Louis Serafin, Dr. Townley, and I drove across Canada from Port Huron, Michigan to Alfred University in Western New York, and entered into a creative process with their ceramic engineers. There are many choices for the chemical formulation of the ceramic powders. We settled on a magnesium-stabilized zirconium. This material produced a white ceramic with very favorable resistance to fracture and wear (Fig. 4).

Fig. 4. A magnesium-stabilized zirconium femoral resurfacing prosthesis with a modular curved stem.

We began using the newly created material for femoral hip resurfacing in 1992 and continued using it until 2003. It proved to be very strong and wear resistant and it soon was adopted by several companies for the femoral head component used in THR.[13] However, production ceased after Dr. Townley passed away in 2006. It was expensive to manufacture in a market dominated by MoM. We used the magnesium-stabilized ceramic for large-dimension hemiarthroplasty and THR procedures. It produced less articular wear of the native cartilage compared to cobalt chromium. Femoral heads as large as 55 mm are available (Fig. 5).

Fig. 5. Magnesium-stabilized zirconium femoral head prosthesis for hemiarthroplasty and THR.

As a hemiarthroplasty procedure, this ceramic performed better than bipolar implants and the procedure was less complicated to perform. The same ceramic was also used in shoulder and thumb implant arthroplasty procedures.

The Smith & Nephew Company (Memphis, TN) produced an oxidized zirconium material for hip femoral heads and femoral components for knee replacement. It proved to be a useful material, particularly for metal-sensitive patients. There is less wear and reduced heat production with oxidized zirconium compared to cobalt chromium.[14] However, oxidized zirconium does not have the necessary resistance to abrasion to make it an ideal choice for resurfacing. Ceramic coatings on a base titanium alloy implant with Titanium Nitride have been very effective for the femoral component of hip resurfacing (Fig.6).[11, 15]

Fig. 6. A cementless ceramic-coated acetabular shell and a highly cross-linked polyethylene liner.

The use of a fully ceramic acetabular prosthesis for resurfacing proved to be more of a challenge. The shape of the implant is important to avoid soft-tissue conflict and impingement. The porous-coated cementless shell for resurfacing should be 2 mm thick. A shell of this dimension is subject to deformation when placed, making it difficult and unforgiving to seat the ceramic liner. Applying the porous coating directly to the implant can be a solution but this would create a one-piece acetabular component, thus prohibiting placement of screws through the shell for adjunctive fixation. Also, one-piece acetabular components do not have the option of changing the bearing surface independently if necessary for infection, wear, or other needs.

Wear testing under extreme conditions is necessary to validate the safety of any acetabular bearing surface. The acetabular resurfacing implant thickness should be 3.5mm - 5.5mm. The capacity should be 40mm - 52mm. However, 1% to 2% of ceramic implants under extreme load continued to fracture. This fracture rate is above the acceptable limit given the severity of the complication and the almost certain need for multiple revisions should fracture occur. The ceramic debris cannot be removed completely after fracture no matter how meticulous the technique. The literature on CoC fractures shows generally very poor long-term outcomes.[16-18]

Current Ceramic-on-Ceramic Resurfacing Initiative

Ceramic-on-ceramic bearings from CeramTec have a 45-year clinical history in THR. These bearings demonstrate greatly reduced wear rates compared to alternative materials. Until recently, this benefit was offset by a significant fracture rate. However, the last decade of world-wide experience with BIOLOX®*delta*, a fourth-generation material, has demonstrated much improved safety. Data from patient registries show that BIOLOX®*delta* performs well. Ceramic-on-polyethylene is generally considered a very good bearing combination. Its main limitation to even wider use is the increased cost of the ceramic head. All the major implant vendors except Smith & Nephew offer BIOLOX®*delta* femoral head implants. Smith & Nephew continues to offer oxidized zirconium. The reduction in fracture risk with BIOLOX®*delta*, however, only applies to the femur. The acetabular component fracture rate for THR remains at 0.03%.[16-18] There are many advocates for CoC as the superior bearing surface combination for THR.

Chemical Composition

BIOLOX®*delta* is a platelet-reinforced aluminum oxide ceramic material, containing over 72% Ab03, which is considerably stronger than aluminum oxide ceramic materials such as the predecessor material, BIOLOX®*forte*. It is a significant improvement over the BIOLOX®*forte*, with increased mechanical strength. The composition and manufacturing method of the BIOLOX®*delta* ceramic material has not changed since 1998.

A current offering is a BIOLOX resurfacing prosthesis (Fig. 1). It is a cementless all-ceramic, anatomically shaped hip device that is designed to reduce psoas impingement. The ensemble consists of a stemmed femoral head resurfacing component and a hemispherical acetabular cup with a contoured rim. Both implants are designed for press-fit fixation, although the femoral head can be cemented. Both components are manufactured from BIOLOX® Delta ceramic and coated with a porous titanium coating followed by a hydroxyapatite outer layer.

Typically, resurfacing femoral heads are produced in a range of up to 10 sizes. The standard acetabular components are also supplied in a range of 10 outer diameter sizes. Current CoC bearing couples are offered only in monoblock design. The anatomical contoured edge of both the acetabular and the femoral head reduces the incidence of iliopsoas tendon impingement. Most other acetabular devices such as the Birmingham® Hip Resurfacing (Smith & Nephew), Conserve® acetabular component (Wright Medical, Memphis, TN), and ReCap® (Zimmer Biomet, Warsaw, IN) have extended to a near hemisphere in these key regions. The anatomic countered edge did not start with the current CoC implants. It has been a feature of the Townley (BioPro® Rimmed Acetabular Cup, Port Huron, MI) and B-P™ Hemispherical Acetabular Component (Endotec, Sante Fe Springs, CA) (Fig. 6). It originated for resurfacing with the Indiana Conservative Hip and Townley TARA (Depuy, Warsaw, IN) in 1972.[3-5,11]

Large Diameter Total Hip Replacement

Total hip replacement where a resurfacing socket is used with a large femoral head failed with Metal-on-Metal bearings. It has been successful however, using cross linked polyethylene and ceramic-on-ceramic[20]. With polyethylene the femoral head can be a bipolar or large diameter ceramic[21]. The advantages are increased range of motion and stability. These benefits allow improved recovery, no restriction of range of motion with superior leisure and vocational activity participation.

Fig 7. Bipolar ceramic coated femoral head with highly cross linked resurfacing acetabulum (Tripolar)

Ceramic Acetabular Component Fracture

Any implant component fracture is disturbing [Figs. 2, 3] and always requires a difficult revision surgery. The outcomes for revision of fracture ceramic components for THR have been poor.[17,18] It is recommended to continue with a ceramic femoral component rather than switch to metal, as most patients experiencing a ceramic femoral head fracture would prefer, because the abrasive fracture debris cannot be removed completely. Continuing with CoC for a fractured acetabular component is generally not acceptable to the patient and, in such cases, I perform a revision using a highly cross-linked polyethylene acetabular component.

For a THR, the femoral head component is exchanged easily but a resurfacing femoral component is fixed to the femur and cannot be removed easily. Therefore, revision of a fractured ceramic resurfacing component will require revision to THR in most instances.

It is impossible to make a ceramic implant that will not fracture. The Food and Drug Administration (FDA) requires that mechanical wear testing must continue until a fracture occurs. Despite such testing, not all fractures can be predicted. Fractures of ceramic resurfacing implants are more common than fractured THR acetabular components. The exact frequency of fracture of ceramic resurfacing implants will take several years to determine. The reason for the higher incidence of resurfacing implant fracture is because of dimensions used and the active lifestyle of the typical resurfacing patient. An additional concern is impingement by the necessarily larger native femoral neck with resurfacing compared to the reduced neck of a THR.

Squeaking Ceramic-on-Ceramic Hips

One specific problem of hard-on-hard bearings is noise generation. With ceramic-on-ceramic hips, femoral head component sizes 32-36 mm are used for most THR. Squeaking occurs in 17 to 21 % of hips[22,23]. For femoral head component sizes 40-44 mm which are useful for hip resurfacing and some large diameter THR squeaking occurs in 23%. Squeaking is associated with larger head diameter, younger age, and a higher UCLA score. For sizes 48 mm as are often used in hip resurfacing 44% of ceramic-on-ceramic hip have squeaking.[20]

As the bearing diameter increases, the frictional moment increases and more articular work is generated and converted to mechanical vibration. Our studies show for dry ceramic-on-ceramic have a 5 fold increase in fraction compared to a lubricated surface. Larger heads, patient factors and perception contribute to a greater amplification of audible friction induced vibration. In refractory cases viscosupplements are an inconvenient and expensive but effective solution. Squeaking has been accepted by patients in Europe and Canada but not the USA.[20]

Recommendation for Use of Ceramics in Hip Resurfacing

The benefits of low wear offered by ceramic articulations are important for resurfacing patients. The BIOLOX®*delta* femoral implant would be a good choice for hip resurfacing. This femoral choice could be matched with a highly cross-linked polyethylene acetabular component. Currently, however, this combination is not approved for use in the United States. The BIOLOX®*delta* acetabular component has an unacceptably high risk of fracture. A polyethylene acetabular component matched with a magnesium-stabilized zirconium femoral component is no longer offered in the United States but could return to the market in the future depending on patient and surgeon interest.

Conclusion

A highly cross-linked polyethylene acetabular component matched with a ceramic-coated titanium femoral implant is the superior choice. Results of this combination have been very favorable in both wear simulator and clinical outcome studies.[11,15] Until the fracture risk of CoC is reduced substantially, it is not safe to use CoC implants for hip resurfacing. Long term squeaking is not acceptable to most patients in the USA.

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