8.3 Tips and Tricks: Fracture of a Ceramic Insert with modern Ceramic Total Hip Replacement

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Abstract

Results obtained with ceramic bearings in total hip arthroplasty have been disappointing because of increased component loosening rates primarily caused by design issues and use of low-quality ceramic, resulting in fracture and debris generation. Although new-generation ceramics have produced a reduced incidence of fracture, concerns still persist about the fracture of ceramic liners. After investigating the underlying cause of fracture in contemporary ceramic-on-ceramic bearings, we sought to determine the incidence of ceramic liner fracture and to formulate technical guidelines for avoiding catastrophic failure. Between January 2000 and January 2005, we prospectively studied a consecutive series of 147 patients (179 hips) who had undergone primary cementless total hip arthroplasty with modern ceramic-on-ceramic articulation so that we could detect ceramic liner fracture. The mean length of the follow-up period was 3.1 years (range, 2–6.5 years). By the latest follow-up examination, delayed ceramic liner fracture had occurred in 3 hips (1.7%). One liner was chipped during insertion because of eccentric seating of the liner. Head fracture occurred in 2 hips (1.1%). Despite the improved wear characteristics of modern ceramic-on-ceramic articulations, a catastrophic failure with ceramic liner failure was still observed during short-term follow-up monitoring. This finding prompted us to define important technical aspects to be considered to minimize ceramic liner fractures.

Introduction

Contemporary ceramic-on-ceramic articulations are harder, more scratch resistant, and more hydrophilic than other bearing materials, resulting in minimized wear and reduced particle-induced osteolysis. Results obtained with ceramic bearings in total hip arthroplasty (THA) have been disappointing because of increased component loosening rates primarily caused by design issues and use of low-quality ceramic, resulting in fracture and debris generation. The greatest concern with the use of ceramics today is fracture. Although new-generation ceramics have exhibited a reduced incidence of fracture, concerns still persist about the fracture of ceramic liners [1,8,11,15,16]. After investigating the underlying cause of fracture in contemporary ceramic-on-ceramic bearings, we sought to determine the incidence of ceramic liner fracture and to formulate technical guidelines for avoiding catastrophic failure.

Materials and Methods

Between January 2000 and January 2005, we enrolled a consecutive series of 147 patients (179 hips) who had primary cementless THAs with modern ceramic-on-ceramic articulation in a prospective study so that we could detect ceramic liner fracture. We obtained approval for this study from our institutional review board. Two patients (3 hips) died and 11 patients (12 hips) were lost to follow-up monitoring before the end of the minimum 2-year follow-up period; this left 134 patients (164 hips in 82 men and 52 women) as the subjects of this study. All patients were evaluated both clinically and radiographically. They were monitored for a mean of 3.1 years (range, 2.0–6.5 years). None of the 13 patients (8.8%) who died or were lost to follow-up monitoring had required revision of the implant. At the time of THA, the average age of the patients was 39 years (range, 20–55 years) and the average weight and height were 61 kg (range, 40–90 kg) and 164.5 cm (range, 145–180 cm), respectively. The preoperative diagnosis was osteonecrosis in 105 hips, osteoarthritis in 53, rheumatoid arthritis in 2, and infection sequelae in 4. We performed all of the procedures from an anterolateral approach, with the patient in the lateral position.

Four kinds of total hip systems were chosen because the patients were young and active and had good bone quality (Dorr type A or B [4]):

1. System I, used in 35 hips, was composed of a hemispherical titanium cup (Ti-6Al-4V; Plasmacup SC, Aesculap, Tuttlingen, Germany); a slightly tapered, rectangular, collarless titanium femoral component (BiCONTACT, Aesculap); and a 28-mm modular alumina femoral head and an alumina acetabular insert (Al_2O_3; BIOLOX Forte, CeramTec, Plochingen, Germany).
2. System II, used in 47 hips, was composed of a hemispherical cementless EPF-PLUS acetabular component (PLUS Endoprothetik, Erlenstrasse, Switzerland) and an SL-PLUS cementless femoral stem (PLUS Endoprothetik). The liner had an alumina inlay packed with polyethylene (sandwich type).
3. System III, used in 34 hips, was composed of a hemispheric cementless Duraloc acetabular component (DePuy, Warsaw, Indiana) and a fully porous-coated Anatomic Medullary Locking stem (DePuy). The bearing articulation was a 28-mm modular alumina head and an alumina acetabular insert.
4. System IV, used in 49 hips, was composed of a hemispheric cementless EP-FIT PLUS acetabular component (PLUS Endoprothetik) and an SL-PLUS cementless femoral stem (PLUS Endoprothetik). The liner was the BIOLOX Forte (CeramTec).

The postoperative rehabilitation protocol was the same for all patients, who were allowed progressive weight bearing as tolerated on the third day after surgery.

Each patient was assessed clinically and radiographically before surgery and after surgery at 4 weeks, 3 months, 6 months, and 12 months and annually thereafter. Statistical analysis of the relationship between various preoperative factors and ceramic liner fracture was conducted with SPSS software (version 12.0; SPSS Science, Chicago, Illinois). The level of significance was $p < 0.05$.

Results

By the latest follow-up examination, delayed ceramic liner fracture had occurred in 3 hips (1.7%), all in men, without trauma. The ages of the patients at the time of fracture were 33, 46, and 28 years. The mean age, height, and weight of these patients did not differ significantly from those of the overall group. The mean time interval between implantation and ceramic liner fracture was 9 months. All of these hips underwent revision surgery, and the retrieved implants and surrounding soft tissues were examined macroscopically and microscopically. All 164 hips had radiographic evidence of bone integration at the final follow-up examination. No acetabular cup or femoral stem was revised because of aseptic loosening. Head fracture occurred in 2 hips (1.1%). Another liner was chipped during insertion because of eccentric seating of the liner.

Case 1

A 34-year-old, 67-kg man who was 164 cm tall and who had advanced osteonecrosis of the right femoral head underwent primary THA in March 2003. A transgluteal approach was used to place a ceramic-on-ceramic bearing implant (system I). The acetabular cup had a 52-mm outer diameter and a machined interior that accepted a ceramic insert (BIOLOX Forte). The metallic shell was not recessed, so that it would protect the rim of the ceramic liner. The femoral stem was cementless with a proximal porous coating (BiCONTACT). A 28-mm short BIOLOX (–3.5 mm) head was used. The cup abduction angle was 39°, and the anteversion angle was 22° (Fig. 1a). The hip was confirmed to be stable, with no neck impingement in any direction, during surgery.

Figure 1a:
An anteroposterior radiograph of the pelvis of the patient in case 1, taken 4 weeks after surgery, shows a well-fixed cup and stem.

Postoperative progress was uneventful. Fourteen months after surgery, the patient felt crepitation without pain during hip motion. There was no history of trauma. A radiograph of the pelvis showed a comminuted fracture of the ceramic liner with fragments around the stem neck (Fig. 1b). The patient refused revision surgery. Seven months later, he felt pain, which was accompanied by increasing noise in the hip. Radiographs demonstrated increasing comminution of fragments of the ceramic liner, a well-fixed cup, and concentric placement of the ceramic head in the metal shell (Fig. 1c).

Figure 1b:
An anteroposterior radiograph of the right hip of the patient in case 1, taken 1 year 2 months after surgery, shows a comminuted fracture of the ceramic liner with fragments around the stem neck.

Figure 1c:
An anteroposterior radiograph of the right hip of the patient in case 1, taken 1 year 9 months later than Fig. 1b, demonstrates fragmentation and concentric placement of the ceramic ball within the metal shell.

The patient underwent revision surgery at our institution in December 2004. On arthrotomy, 4 large pieces of the ceramic liner and multiple small fragments were found (Fig. 1d). The ceramic liner was found within the metal shell, with marginal cracking in the peripheral portions (Fig. 1e). The liner and head were scratched and stained with black metal particles. There was no macroscopic wear of the ceramic liner or ceramic head. The metal shell and femoral stem were not loose, and the trunnion was undamaged macroscopically. On histologic examination, the granulation tissue excised around the cup revealed numerous foreign-body giant cells with ceramic particles. After the joint was thoroughly irrigated, a modular ceramic liner and a 28-mm BIOLOX long head (+3.5 mm) were implanted. The patient had a good recovery, with complete relief of previous symptoms.

Case 2

A 45-year-old, 68-kg man who was 176 cm tall and who had osteonecrosis of the femoral head had a ceramic liner fracture without trauma at 8 months after

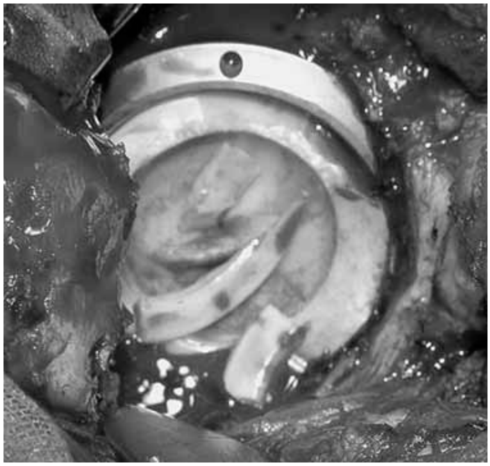

Figure 1d:
Intraoperative photograph of the patient in case 1 shows 4 large pieces of the ceramic liner and multiple small fragments.

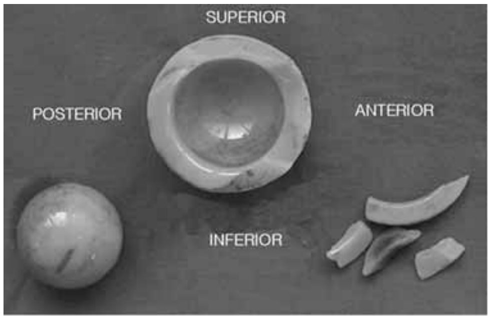

Figure 1e:
Multiple chipped fragments of the ceramic liner retrieved from the patient in case 1 are visible on the peripheral portion, especially on the anterior, superior, and inferior portions of the liner. The liner and alumina head are scratched and stained with black metal particles.

surgery (Fig 2a). System IV was used for this patient. Findings during revision surgery showed that the alumina insert was severely fractured, and a black discoloration of the alumina head was observed, with loss of its surface gloss (Fig. 2b). However, there was no evidence of alumina head fracture or recognizable damage to the Morse taper of the well-fixed stem. After extensive débridement and synovectomy to remove as much of the ceramic debris as possible, a new alumina-on-ceramic bearing was implanted; the stem and cup were left in place (Fig. 2c).

Discussion

Despite the improved wear characteristics of modern ceramic-on-ceramic articulations, we still observed catastrophic failure with ceramic fractures in a series of a relatively small number of patients with short-term follow-up. This finding prompted us to note important technical aspects that should be considered to minimize ceramic liner fractures.

Trauma, a high level of activity, and obesity may increase the risk of ceramic insert breakage by increasing the load across the joint surface [6,11]. Other factors that must be taken into account are mechanical properties of the ceramics, implant design, and surgical techniques used in implanting the prosthesis [16]. New-generation ceramic liners do not fracture at an impact force

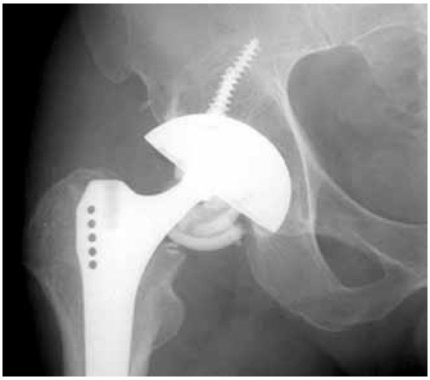

Figure 2a:
An anteroposterior radiograph of the patient in case 2, taken 8 months after surgery, shows a ceramic liner fracture without trauma.

Figure 2b:
This intraoperative photograph taken during revision surgery on the patient in case 2 shows a severely fractured alumina insert and black discoloration of the ceramic head.

Figure 2c:
A new ceramic liner and ceramic head were reimplanted after extensive débridement and synovectomy in the patient in case 2 to remove as much of the ceramic debris as possible. The stem and cup was left in place.

of 12 kN, a force greater than most estimates of the physiologic forces to which the hip is subjected during falls or stumbling. This suggests that ceramic liner fracture caused by impact force during normal life is unlikely to occur in vivo [7]. All modern ceramic components are subjected to a burst-strength examination before sterilization and shipping.

Correct placement of the ceramic head on the femoral component taper during surgery is critical for long-term survival. The locking mechanism of the ceramic insert with conical sleeving appears to be safe and reliable, but careful technique is required to correctly position the liner. Eccentric orientation of the liner relative to the shell during impaction can result in chipping or even liner breakage. In our series, eccentric placement of 1 liner resulted in liner chipping during insertion. The importance of gaining excellent exposure to safely insert a modular ceramic liner has been emphasized to allow insertion of the shell in a nearly ideal position, exposure of the rim of the shell circumferentially, placement and impaction of the liner concentrically, and identification of any crack or chip that may occur during impaction. During implantation of the head and liner, it is also important to avoid allowing any foreign body between the cone and the ceramic head, to avoid strong impaction of the head on the cone with the hammer, and to protect the cone from damage.

Optimal position of the component is also crucial with ceramic-on-ceramic components. Malpositioning of the component may generate uncontrolled peak stress in the ceramic, which may result in fracture [1,2]. The acetabular component should be placed at an angle of ≤ 45° to optimize the distribution of forces over the greatest amount of surface area of femoral ball head and the cup. Trial liner and femoral ball heads should be used in trial reduction to avoid any potential damage to the taper, cup, and ceramic components. Placement of ceramic liner and ball by hand is a relatively easy and safe method for avoiding damage to these implants.

Another possible mechanism of ceramic liner fracture is edge-loading when the hip is flexed, as with rising from a chair or climbing a high step [17]. Edge-loading may occur with subluxation of the bearing by subluxation–relocation motion [7]. Vertical cup placement could also enhance edge-loading [12].

The alumina articular liner with an outer lining of polyethylene (sandwich type) was developed to reduce the rigidity of the ceramic-on-ceramic bearing and to prevent impingement between the rim of the ceramic liner and the neck of the femoral stem [9]. However, this design modification resulted in a thinner alumina insert, which increased the likelihood of a peripheral chip fracture and subsequent crack propagation through the brittle alumina material under impingement conditions [10]. The causes of ceramic liner fracture with a sandwich insertion are stress concentration at the rim of the ceramic liner, thin ceramic (< 4 mm), and impingement between liner rim and prosthetic heads [8,16]. The failures of the ceramic liner of the nonmodular so-called sandwich-design ceramic-on-ceramic cup were caused by high torque transmitted from the femoral head to the ceramic liner, causing dislodgment of the ceramic liner from polyethylene. Walter et al. believe that the displacement of the ceramic liner occurs during subluxation and reengagement of the head and liner during deep flexion [17].

Repeated episodes of impingement between the prosthetic neck and the edge of the ceramic liner can cause liner fracture. Squatting, kneeling, and sitting cross-legged are more common in non-Western populations. The increased range of motion required to support these positions can result in impingement and liner fracture [13,18]. Evidence of femoral neck impingement of the acetabular rim has been recognized as a common occurrence after THA, with impingement being seen in 39% of 111 retrieved polyethylene acetabular liners [18]. Orthopaedic surgeons must advise their THA patients against repeated squatting, kneeling, and cross-legged sitting to avoid impingement. Impingement also can be minimized by combining a neck with optimal geometry with a larger femoral head, optimizing the head-to-neck ratio, thus improving range of motion and decreasing the risk of impingement [14]. Computer-based studies of motion simulation show that the optimal cup position for minimizing the risk of impingement is 45° to 55° abduction and 10° to 15° anteversion [18]. Recessing a ceramic acetabular liner in a metal shell protects the liner by preventing neck impingement and edge-loading of the ceramic material [3]. However, the use of a recessed metallic shell carries the risk that wear of the femoral neck will generate metallic debris.

Despite the improved wear characteristics of modern ceramic-on-ceramic articulations, we still observed catastrophic failure with ceramic liner failure after only short-term follow-up monitoring. We therefore remain concerned that the rate of ceramic liner fracture may increase with time.

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