Ceramic Liner Fracture and Impingement in Total Hip Arthroplasty

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Received: 7 January 2014/Accepted: 15 August 2014/Published online: 21 October 2014
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Abstract *Background:* Ceramic-on-ceramic bearing surfaces were developed to provide an alternate to metal-on-polyethylene to decrease wear-induced osteolysis in total hip arthroplasty patients. In an effort to decrease the risk of ceramic acetabular component fracture or damage during implantation, a raised metal rim was added. *Questions/Purposes:* How many fractures or impingements have occurred in our population of patients with ceramic liners with raised rims? *Methods:* With IRB-approved consent, a case series was reviewed from a single center registry and 4 of 169 patients were identified who had revision hip surgery with the ceramic liner with a raised metal rim: one for ceramic liner fracture and three for metallosis, pain, and squeaking. Implant alignment and operative findings were reviewed. *Results:* One ceramic liner fracture and three cases of metallosis from impingement of the femoral neck on the posterior elevated metal rim of the acetabular liner were observed at revision. The femoral neck in each patient had a

divot that corresponded to a divot in the posterosuperior liner rim. Three of the four patients had audible squeaking or clicking prior to revision. A total of 3% of patients in this series had clinically significant impingement with this implant type. *Conclusion:* Acoustic phenomenon in a ceramic on ceramic bearing surface should be investigated with a cross-table lateral radiograph to evaluate component position. If symptomatic impingement is demonstrated, revision should be considered to avoid failure from metallosis or fracture.

Keyword total hip arthroplasty · ceramic fracture · metallosis · ceramic bearing · acoustic phenomenon

Introduction

Ceramic-on-ceramic bearing surfaces were developed as an alternative to metal-on-polyethylene in an effort to decrease wear-induced osteolysis in total hip arthroplasty (THA) patients. The development of this alternative bearing surface is particularly relevant to younger, more active patients to prevent the need for future revision or to decrease the amount of polyethylene wear-induced osteolysis. Wear rates for ceramic-on-ceramic bearing surfaces have been calculated to be 1,000 times less than metal-on-polyethylene and 40 times less than metal-on-metal bearing surfaces [4, 20]. Ceramic on conventional polyethylene pairings have wear rates two to four times lower than the metal on conventional polyethylene combination [3, 9] and seven times lower in a ceramic on highly crosslinked polyethylene coupling [14, 17], but the wear rates are not as low as ceramic-on-ceramic bearing surfaces. In addition, the biologic reaction to the ceramic wear particles is less inflammatory than polyethylene wear particles, resulting in a decreased immune response and subsequent bony destruction [4, 20].

Early ceramics had significant fracture rates due to large grain size and impurities [4, 20, 23]. Ceramic fracture can have severe consequences. The resulting revision requires an extensive capsulectomy to prevent accelerated wear of the new bearing surface from potentially retained ceramic within the soft tissue [21]. Newer ceramic bearing surfaces have

Level of Evidence: Level IV - Case series (no, or historical, control group)

Electronic supplementary material The online version of this article (doi:10.1007/s11420-014-9415-7) contains supplementary material, which is available to authorized users.

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improved wear characteristics [23] (2) with much lower fracture rates, on the order of 0.004% for femoral heads manufactured after 1994 [8, 23].

Ceramic liner fractures are thought to be less frequent than femoral head fractures. A retrospective review of 3,710 ceramic prostheses implanted between 1993 and 2004 reported a 0.22% liner fracture rate [6]. In contrast, rates of current generation ceramic femoral head fractures have been estimated between 0.06% and 0.4% when articulating with a ceramic liner [8, 9]. Possible causes of ceramic liner fracture include dislocation, impingement, microseparation, trauma with implantation, and malposition [6, 16]. In an effort to decrease the risk of ceramic acetabular component fracture or damage during implantation, a raised metal rim was used in the Trident (Stryker, Mahwah, NJ) ceramic acetabular component (Fig. 1). The ceramic insert is surrounded by a thin titanium sleeve and is recessed below the lip of the sleeve, leaving an elevated metal rim. The goal of the titanium sleeve is to reduce the risk of chipping or damage of the ceramic liner with insertion and to protect the ceramic liner from fracture if prosthetic impingement from the femoral neck occurs postoperatively [7]. A study by D'Antonio looking at 3–5-year results of this implant showed no ceramic chips, fractures, or ceramic bearing failures [7]. One center has recently reported one single ceramic liner fracture out of 764 hips using a ceramic liner with a metal rim [5].

The goal of this study was to examine the particular risk of ceramic-on-ceramic hip implants for revision due to fracture of the ceramic liner or impingement of the femoral prosthesis.

Patients and Methods

With IRB-approved consent, a case series was reviewed from a single center registry, which is refused by less than 1% of patient. All patients from a single surgeon's series examined a total of 169 patients receiving an implant with a

Fig. 1. A raised metal rim was added in the Trident (Stryker, Mahwah, NJ) ceramic acetabular liner to decrease the risk of ceramic acetabular component fracture or damage during implantation.

ceramic liner with a raised metal rim from 2000 to 2011. This group of patients was 55% females and 45% males with an average age of 54 years. The average body mass index was 28.1. The diagnosis was osteoarthritis in 86%, avascular necrosis in 8%, and post-trauma, rheumatoid arthritis, or dysplasia in the remaining 4%. All patients had a 1-year follow-up with the mean for the cohort of 3 years of follow-up. Symptomatic patients or patients with acoustic abnormality (17%) were followed up yearly.

All patients were over 18 years of age and undergoing an elective total hip arthroplasty. Patients were excluded if they did not give consent for use of data in the registry. The initial implants in all patients were the Trident PSL® acetabular cup (Stryker, Mahwah, NJ) with a metal-backed ceramic liner, the Super Securfit Plus® (Stryker, Mahwah, NJ), and an alumina BioloX® (Stryker, Mahwah, NJ) femoral head.

This cohort contains one patient with a ceramic acetabular liner fracture and three additional patients with impingement of the femoral neck on the raised metal posterior rim of the acetabular liner with significant metallosis. All four patients underwent revision arthroplasty. A fifth patient with similar impingement symptoms and excessive lumbar lordosis with compensatory forward flexion of the pelvis has not undergone revision.

The first patient, a 63-year-old female, presented 5-year status post-bilateral ceramic-on-ceramic THA for osteoarthritis. The patient had a 50-mm cementless acetabular cup and a liner with a 32-mm inner diameter. The femoral head was 32 mm.

The patient was noted to have significant lordosis of the lumbar spine with compensatory forward flexion of the pelvis. Five years after hip arthroplasty, a click followed by a grinding sensation was noted in the right hip with moderate discomfort but ambulation was continued. Physical examination revealed crepitation with all passive and active range of motion. Radiographs revealed a comminuted ceramic liner fracture.

Intraoperatively at revision, the liner was observed to be fractured into many fragments and the ceramic head remained intact (Fig. 2). The elevated metal rim of the liner had become worn, with a resultant divot in the posterosuperior aspect of the liner. A corresponding divot was noted in the femoral neck where impingement on the elevated metal rim had occurred. All fractured ceramic fragments were removed and a complete synovectomy was performed.

A 36-mm ceramic femoral head (BioloX®) was inserted to allow for a greater arc of range of motion prior to neck impingement. A 10° face-changing liner was used, placing the recessed portion at the site of prior impingement. The trunnion did not have any obvious damage, and a taper adaptor sleeve was used to protect the new ceramic head.

At 1 year postoperatively, the patient had no complaints and had excellent range of motion without any signs of impingement. The cross-table lateral radiograph revealed no impingement and the measurement of her anteversion was 44°.

The second patient was a 62-year-old male who developed left hip pain and squeaking 5 years after his initial

Fig. 2. The liner fractured into many fragments displayed after removal from the hip.

THA for osteoarthritis of the hip. The patient reported left-sided pain and noise that occurred when he went from extension to the swing phase of gait. The initial THA replacement was with a cementless ceramic-on-ceramic hip, press-fit femoral stem, and 32-mm/+4-mm alumina ceramic femoral head. Radiographs showed evidence of increased anteversion of the cup on the cross-table lateral view. Abutment of the elevated metal acetabular rim on the femoral neck was noted with a wear defect on the femoral neck (Fig. 3).

At the time of revision surgery, metallosis was seen in the hip capsule. The ceramic head and liner were intact without evidence of fracture or obvious damage to the trunnion. Impingement of the femoral neck on the raised metal acetabular shell was apparent with the hip in 30° of

Fig. 3. Cross-table lateral radiographs showed evidence of increased anteversion of the cup with abutment of the elevated metal acetabular rim on the femoral neck.

abduction and external rotation. The areas of metallosis were debrided. A 36-mm polyethylene liner with a 10° offset and contralateral cutout was placed with the cutout positioned in the area of contact with the femoral neck. A 36-mm/+7.5-mm cobalt chrome femoral head was placed, and the range of motion was again checked. No impingement of the femoral neck against the polyethylene liner was noted with extension and external rotation.

Postoperatively, the patient experienced relief of his pain and resolution of squeaking. The postoperative radiographs revealed satisfactory positioning of the prosthesis without impingement, with an anteversion angle measured at 41.5°.

The third patient was a 46-year-old female who underwent bilateral THA for degenerative joint disease secondary to developmental hip dysplasia. The implants were a cementless ceramic-on-ceramic press-fit femoral stem and 32-mm/+0-mm alumina ceramic femoral head.

The patient dislocated the left hip anteriorly 6 weeks postoperatively during intimacy. She underwent a closed reduction with no further episodes of dislocation. At 4 years postoperatively, she reported feelings of subluxation and pain in the left hip, with a squeaking sound. A cross-table lateral radiograph showed impingement of the femoral neck on the posterior aspect of the acetabulum.

The patient was revised for impingement and metallosis-induced synovitis. At the time of surgery, an obvious divot in the femoral neck and a corresponding divot in the posterior raised metal rim of the ceramic liner were seen (Fig. 4a, b). The patient had extensive metallosis in her hip capsule, which was debrided. A 36-mm polyethylene liner with a 10° offset and contralateral cutout was placed with the cutout positioned in the area of abutment. The ceramic head was exchanged for a BioloX® ceramic alumina head, size 36 mm/+0 mm. The trunnion had no obvious damage. A taper adaptor sleeve was placed onto the trunnion to prevent damage to the new ceramic head from the trunnion.

At her four month follow-up, she had no feelings of instability or subluxation, the squeaking had resolved, and her hip remained asymptomatic. A cross-table lateral radiograph showed no impingement of the femoral neck on the acetabular rim, with an anteversion angle measured at 56°.

A fourth patient, a 52-year-old male, developed hip pain and clicking 1 year after left THA for osteoarthritis. The implants used were a cementless ceramic-on-ceramic bearing surface, press-fit femoral stem, and a 36-mm/+5-mm alumina ceramic femoral head.

The clicking was audible at toe off on the left foot, when the hip was loaded in maximal extension. A cross-table lateral radiograph showed impingement of the femoral neck on the acetabular rim. Because of the patient's symptoms and evidence of impingement, revision was advised.

At the time of surgery, a divot was found in the femoral neck and a corresponding divot in the posterior aspect of the raised metal rim of the liner. Metallosis was seen in the capsule and surrounding hip soft tissues. A 36-mm polyethylene liner with a 10° offset and contralateral neck cutout was placed with the cutout positioned in the area of abutment with the femoral neck. The ceramic head was exchanged for BioloX® ceramic alumina head, size 36 mm/

a

b

Fig. 4. **a** A divot in the femoral neck and a corresponding divot in the posterior raised metal rim of the ceramic liner were seen at the time of surgery. **b** A divot in the posterior aspect of the raised metal rim of the liner noted at the time of revision surgery.

+7.5 mm. The trunnion did not have any obvious damage. A taper adaptor sleeve was used to protect the new ceramic femoral head from microscopic trunnion damage.

At his follow-up visit, the patient reported improvement in his pain and resolution of his squeaking. Cross-table lateral radiographs revealed no evidence of impingement with an anteversion angle measured at 46°.

Results

A total of 2% (4/169) of patients in this ceramic-on-ceramic series had clinically significant impingement. In all of the patients, the femoral neck had a divot that corresponded to a divot in the posterosuperior liner rim for each patient. Three of the four patients had audible squeaking or clicking prior to revision. After revision with a 10° face-changing liner with the recessed portion placed in the area of impingement, the symptoms resolved for each patient. Cross-table lateral radiographs revealed increased anteversion and obvious impingement of the femoral neck on the posterior rim of the acetabulum in all cases.

Discussion

Ceramic-on-ceramic bearing surfaces are an attractive option for younger, active patients due to low wear rates [6, 23]. Linear wear rates for this bearing surface are between 0.025 and 10 $\mu\text{m}/\text{year}$. Osteolysis is rare with linear wear rates below 0.1 mm/year in a polyethylene bearing surfaces. This would suggest a ceramic-on-ceramic couple would prevent osteolysis as a method of prosthetic failure. However, this does not mean that ceramic-on-ceramic couple is without the potential for failure as these cases demonstrate particularly when optimum cup position is not achieved. Ceramic fracture and the acoustic phenomena associated with this bearing couple have become identified modes of failure. We have identified another mode of failure unique to this prosthetic component: femoral neck impingement on the elevated acetabular metal liner with an associated acoustic phenomenon and the potential for ceramic liner fracture and metallosis when excessive anteversion is present in acetabular component position. The anteversion of the implanted cups was anatomic to the native acetabular anteversion in the fractured liner case. However, the measured anteversion via cross-table lateral was substantially greater as a result of pelvic flexion associated with loss of lumbar lordosis resulting in prosthetic impingement in normal gait. The remainder of the revised components anteversion was accepted at the time of the index surgery with each component demonstrating no evidence of prosthetic impingement in extension and external rotation intraoperatively.

The risk of fracture of ceramic head or liner has been well defined. Risk of fracture has been reduced with the newer generation of ceramics utilizing a smaller grain size in the manufacturing process. In spite of this improvement, fracture is a catastrophic event. The surgical resolution of this event has the subsequent hazard of accelerated wear of a polyethylene and metal bearing utilized during revision, secondary to retained ceramic fragments. Ranawat et al. [18] established a standard of care for this event with complete synovectomy and subsequent change of the bearing surface. They demonstrated successful conversion of the bearing surface, while others have demonstrated and reported the accelerated wear, metallosis, and early failure [1, 2, 11, 13, 21]. As a result of this risk of ceramic fracture, improvements in implant design have been instituted to provide greater safety. Most recently, as noted above, the change in grain size during the manufacturing process has improved the mechanical properties of the ceramic. Prior to this change, the risk of prosthetic impingement on the ceramic liner of the acetabulum was addressed by one manufacturer with an elevated metal rim surrounding the liner. This was designed in response to the chips that occurred during the insertion of the ceramic liner into an implanted titanium acetabular component or to the risk of prosthetic impingement of the femoral neck upon the ceramic liner. This component has shown excellent results [7].

These cases are the second report in the literature of a fracture of the ceramic liner in this system. One additional report of a ceramic liner fracture using this same implant is

available [5]. One case report of impingement of the femoral prosthesis neck on the acetabulum with metallosis but without fracture of the acetabular ceramic liner is published [15]. This report included one patient who demonstrated an extreme range of motion that created impingement both anterior and posterior–superior with corresponding divots in the rim of the prosthetic acetabular component. A second patient experienced impingement in extension and external rotation. Excessive anteversion of this cup was identified at the time of revision surgery. Both patients underwent revision of the acetabular component to achieve a successful hip implant.

The acoustic phenomena associated with ceramic-on-ceramic bearing surfaces had been reported between 0.7% and 20.9% [12] and represent another mode of failure of this implant. Several studies have attempted to identify movements, patient factors, or component position that can account for the squeaking [10, 12, 19, 22]. A variety of patient movements have been identified that create acoustic phenomena and one movement or position cannot be isolated as causative or position as causative [10, 12]. Acetabular cup position has been evaluated thoroughly. The hypothesis is that anteversion, either too little or too much, could be causative for the noises associated with ceramic-on-ceramic implants. Jarret et al. [10] had insufficient numbers to create a relationship between cup position and squeaking. Restrepo et al. [19] additionally failed to statistically demonstrate a difference between cup position and squeaking. However, this retrospective study did demonstrate mean anteversion of approximately 47° in the squeaking cups vs. 39.5° in the silent cups. Both population groups had anteversion values well above the optimum of 20° to 25°. This study had six patients who underwent revision for squeaking. Four of the six revised demonstrated indentation of the acetabular rim consistent with neck impingement. Edge loading and stripe wear were noted on these components. Clearly, optimal acetabular cup position as defined by Ranawat of 20° to 25° of anteversion gives the best cup position to prevent prosthetic impingement. However, other factors, as noted below, must be considered. In the reported cases of this review, either anteversion of the cup, forward flexion of the pelvis with dynamic increase in anteversion, extraordinary range of motion, or a combination of the three was instrumental in the prosthetic impingement.

Limitations of this study include the use of a single site and single surgeon for examination of patients. The small number of total patients may have skewed the number of fractured liners and impingement found. Comparison between groups was not possible with the small number of fractures and impingements in this patient group.

The acoustic phenomenon in a ceramic-on-ceramic bearing deserves thorough investigation in all patients where it exists. The history of the type of noise and the type of activity to create the noise are important to differentiate prosthetic impingement from vibration of the bearing surface. The cross-table lateral radiograph is a necessity to evaluate acetabular anteversion and femoral neck proximity. The potential for prosthetic impingement in hip extension and external rotation can be evaluated from this radiograph. As persistent prosthetic impingement leads to metallosis and

the potential for acetabular ceramic liner fracture, surgical intervention would be appropriate in the cases where radiographic evaluation, symptoms, and acoustic phenomenon exist. The conversion to a ceramic-on-polyethylene or metal-on-polyethylene bearing can be successful. Utilizing an elevated polyethylene liner with the elevated portion of the rim opposite the side of impingement can be a successful strategy to decrease the risk of impingement. Increasing the head size to alter the head–neck ratio and the thickness of the polyethylene liner will be additive in attempting to reduce impingement and retain the acetabular shell, resulting in a less morbid procedure for the patient. Short-term results have been successful in relieving pain, impingement, and acoustic phenomenon in the patients reported here but requires long-term follow-up. Clearly, optimum acetabular component position or optimum combined component position remains paramount to long-term success of total hip arthroplasty without regard to the bearing surface.

Disclosures

Conflict of Interest: Amy Steinhoff, MD, Victor Hakim, MD, and Richard Walker, MD have declared that they have no conflict of interest. Clifford W. Colwell, Jr., MD reports personal fees and research support from Medical Compression Systems and research support from Stryker and Novartis, outside the work. Steven N. Copp, MD reports other from Nuvasive and Stryker, outside the work.

Human/Animal Rights: All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008 (5).

Informed Consent: Informed consent was obtained from all patients for being included in the study.

Required Author Forms Disclosure forms provided by the authors are available with the online version of this article.

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