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ORIGINAL PAPER

Cementless total hip arthroplasty with ceramic-on-ceramic bearing in patients younger than 45 years with femoral-head osteonecrosis

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Abstract Despite improvements in the quality of alumina ceramics, osteolysis has been reported anecdotally after total hip arthroplasty (THA) with use of a contemporary alumina-on-alumina ceramic bearing. The purpose of this study was to evaluate the clinical and radiographic outcomes of THA using alumina-on-alumina ceramic bearing and to determine osteolysis using radiographs and computed tomographic (CT) scans in young patients. Consecutive primary cementless THA using alumina-on-alumina ceramic bearing were performed in 64 patients (93 hips) who were younger than 45 years of age with femoral-head osteonecrosis. There were 55 men (84 hips) and nine women (nine hips). Average age was 38.2 (range 24–45) years. Average follow-up was 11.1 (range 10–13) years. Preoperative Harris Hip Score was 52.9 (range 22–58) points, which improved to 96 (range 85−100) points at the final follow-up examination. Two of 93 hips (2%) had clicking or squeaking sound. No hip had revision or aseptic loosening. Radiographs and CT scans demonstrated that no acetabular or femoral osteolysis was detected in any hip at the latest follow-up. Contemporary cementless acetabular and femoral components with alumina-on-alumina ceramic bearing couples function well with no osteolysis at a ten year minimum and average of 11.1-year follow-up in this series of young patients with femoral-head osteonecrosis.

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Introduction

The primary threat to the longevity of total hip arthroplasty (THA) in recent years has come from wear at the bearing surfaces, resulting in production of periprosthetic wear debris, subsequent osteolysis and eventual loss of fixation. The challenge today is to develop new bearing surfaces that have the ability to function at a high level for a long period, particularly as THA is now increasingly being used in younger, more active patients.

One potential improved bearing couple is alumina-on-alumina ceramic. Osteolysis has only rarely been reported in association with ceramic-on-ceramic bearing couples, and reports are generally limited to cases involving first generation alumina ceramic bearings or loosened prostheses [2]. Contemporary alumina ceramics have shown progressive increase in hardness, burst strength and flexion resistance, along with greater purity and smaller grain sizes owing to innovations such as hot isostatic pressing, laser etching and proof testing [4, 22]. Despite improvements in the quality of alumina ceramics, recently anecdotal cases of osteolysis have been reported after THA with contemporary alumina-on-alumina ceramic bearings [3, 18].

We evaluated a consecutive series of 93 primary cementless alumina-on-alumina THAs in 64 patients younger than 45 years with femoral-head osteonecrosis to determine the clinical and radiographic outcomes and the rate and extent of osteolysis after a minimum of ten years of follow-up.

Materials and methods

Demographics

The senior author performed 102 consecutive cementless THAs using alumina-on-alumina ceramic bearing surfaces in 73 patients (29 patients had bilateral THAs). The study was approved by our institutional review board, and all patients provided informed consent. We excluded three patients because they refused to participate, leaving 70 patients available for participation. Six patients were lost to early follow-up (before one year), leaving 64 patients (93 hips), who comprise the focus of this study. There were 55 men (84 hips) and nine women (nine hips). The average age at the time of the index arthroplasty was 38.2 (range 24−45) years. Average patient weight was 68.6 kg, with a range of 51 to 90 kg. Average height was 169.8 cm (range 155−183 cm) and the average body mass index (BMI) was 23.8 kg/m^2 (range 17.6–30.5 kg/m^2). All hips with osteonecrosis of the femoral head had Ficat and Arlet stage III or IV [7]. The presumed cause of osteonecrosis was ethanol abuse in 39 patients (61%), idiopathic in 17 patients (27%) and steroid use in eight patients (12%). The average follow-up was 11.1 (range ten to 13) years.

Prosthesis

A cementless Duraloc Option acetabular component (DePuy, Warsaw, IN, USA) with an alumina forte liner of inner diameter 28 mm was used in all hips. The inner diameter of the alumina forte liner (Biolox forte™; Ceramtec AG, Plochingen, Germany) was 28 mm in all patients regardless of the acetabular component size. All patients received an Immediate Postoperative Stability (IPS; DePuy, Leeds, UK) cementless femoral component with a 28-mm alumina forte femoral head (Biolox forte™; Ceramtec AG, Plochingen, Germany). The IPS femoral component is an anatomical metaphyseal fitting titanium stem with a polished and tapered distal stem, designed to provide fixation in the metaphysis only, thereby avoiding metal-to-bone contact below this point. The proximal 30% of stem was porous coated with sintered titanium beads, with a mean pore size of 250 µm, to which a hydroxyapatite coating was applied to a thickness of 30 µm.

Surgical procedure

All operations were performed through a posterolateral approach. The femoral component was inserted with a press-fit technique. The largest broach that would fill the metaphysis and leave little cancellous bone remaining was used. The acetabular component was fixed with a press-fit only without using a screw in the 84 hips, and one or two screws were inserted for additional fixation in the remaining nine hips. Patients were allowed to stand on the second postoperative day, and they progressed to full weight bearing with crutches, as tolerated.

Clinical evaluation

Clinical follow-up was performed at three months, one year and yearly thereafter. Harris Hip Scores were determined before surgery and at each follow-up examination [10]. Patients subjectively evaluated thigh pain on a 10-point visual analogue scale (0 = no pain; 10 = severe pain). The level of activity of the patients after THA was assessed with the activity score of Tegner and Lysholm [21]. The activity grading scale, with which work and sports activities are graded numerically, was used as a complement to the functional score. Patients were given a score, according to the activities in which they engaged in daily life, ranging from 0 points for a hip-related disability to 10 points for participation in competitive sports at a national level.

Radiographic evaluation

Radiographic follow-up was performed at three months, one year and yearly thereafter. A supine anteroposterior radiograph of the pelvis with both hips in neutral rotation and 0° of abduction was made for every patient. Femoral bone type was determined in preoperative radiographs using Dorr’s classification [6]. Definite loosening of the femoral component was diagnosed if there was a progressive axial subsidence of >2 mm or varus or valgus shift [12, 15]. A femoral component was considered to be possibly loose when there was a complete radiolucent line surrounding the entire porous-coated surface on both the anteroposterior and lateral radiograph [12]. Definite loosening of the acetabular component was diagnosed when there was a change in the position of the component (>2 mm vertically and/or medially or laterally) or a continuous radiolucent line wider than 2 mm on both the anteroposterior and the lateral radiograph [12, 15].

Radiographic evaluation of osteolysis

The presence and locations of areas of osteolysis in the acetabulum were recorded in the anteroposterior and lateral radiographs according to the system of DeLee and Charnley [5], and those in the femur were recorded also in the anteroposterior and lateral radiographs according to the system of Gruen et al. [8]. Osteolysis was defined as a sharply demarcated lucent area adjacent to the acetabular and/or femoral component that was not evident on the immediate postoperative radiographs.

Computed tomographic evaluation of osteolysis

Although radiological evaluation of osteolysis is a direct measure, the current methodology is insensitive and subject to operator error. A more sensitive computed tomography

(CT) image sets provide three-dimensional data, but the beam-hardening artifacts from the prosthesis itself make these images difficult to interpret and use. To address the beam-hardening artifacts, as well as to measure the volume of lytic lesions, we developed an algorithm to diminish the effect of beam-hardening artifacts. We then developed a segmentation algorithm to segment the lytic lesions from image data and to measure their volumes. CT images were acquired using Siemens AG (Munich, Germany) with 1-mm collimation, pitch of 1.5, and 14- to 22-cm field of view. Raw data was reconstructed for 1-mm slices. The area within 5 cm from the prosthesis−bone interface in all directions was evaluated. The volume of osteolysis was calculated by Virtual Scopics (Rochester, NY, USA).

Statistical methods

Survivorship analysis was performed with the Kaplan-Meier method [11], with revision for any reason as one end point and revision due to mechanical failure (clinical and radiographic evidence of aseptic loosening) at the time of follow-up as the other end point. We determined differences in continuous variances (Harris Hip Score, range of motion, BMI) between preoperative and postoperative results using Student's paired *t* test, and in categorical variances (details of functional evaluation and deformity according to the Harris Hip Score) and limb length between preoperative and postoperative evaluations using chi-square test. Univariate regression analysis was used to evaluate the relationship, if any, between osteolysis and the variables of age, gender, weight, diagnosis, duration of follow-up and acetabular inclination and anteversion. The level of significance was set at $P<0.05$.

Results

Clinical outcome

Mean preoperative Harris Hip Score was 52.9 (range 22−58) points, which improved to 96.1 (range 85−100) points at the final follow-up. Sixty-one patients had no detectable limp, and three had a mild limp. The ability to put on footwear, to cut toenails and to use stairs and public transportation was improved markedly after the operation. Many patients were quite active despite our admonitions to avoid activities involving high impact after the THA. All but three patients had an activity score of 5 or 6 points [12] after THA, indicating participation in strenuous farm work (a score of 5 points) or playing recreational sports such as tennis (a scores of 6 points). The three patients with low back pain had a score of 3 points. One active farmer complained of clicking in the left hip three years after the surgery. The hip clicked when he bore weight on it, but he did not have pain or other symptoms. Another active patient complained of squeaking in the right hip seven years after the surgery. The hip occasionally squeaked when he lunged forward, with the hip flexed to 70° with extreme internal rotation. He was advised to avoid that movement. The hip otherwise functioned well. Abduction and anteversion angles of the acetabular components in these two patients were acceptable (45° vs. 47° and 25° vs. 26°, respectively).

Radiographic results

No hip had aseptic loosening of any acetabular or femoral component. All stems had a satisfactory canal fill on radiographs, and all hips had Dorr type A or type B bones. The mean inclination and anteversion of the acetabular component was 42.3° (range 39°−45°) and 21° (range 19°−23°), respectively. Calcar rounding off was observed in all hips, but no hip had stress-shielding-related proximal femoral bone resorption. No hip had femoral-head or acetabular ceramic liner fracture.

Radiographic and computed tomographic results of osteolysis

A radiograph and a CT scan (Fig. 1) demonstrated that no acetabular or femoral osteolysis was detected in any hip at the latest follow-up. Although the precise measurement of penetration of alumina-on-alumina couple was not possible, no detectable gross penetration was found.

Complications

One hip (1%) had recurrent dislocation, and the acetabular component was revised for a position change. Alumina femoral head and acetabular liner in this hip were revised because of a severe dark, metallic-appearing stain on the femoral head and acetabular liner. One hip (1%) was dislocated seven days after the operation and was treated successfully with closed reduction and an abduction brace for three months. No further dislocation was observed in this hip at the final follow-up. One hip had deep infection and open debridement was performed, followed by intravenous antibiotics for *Staphylococcus epidermidis* for six weeks. The patient had no recurrent infection at the latest follow-up.

Revisions and survivorship

One of the 93 hips (1%) had a revision of the acetabular component for a recurrent dislocation. With revision of either the acetabular or the femoral component for any reason considered to be a failure, the rate of survival of

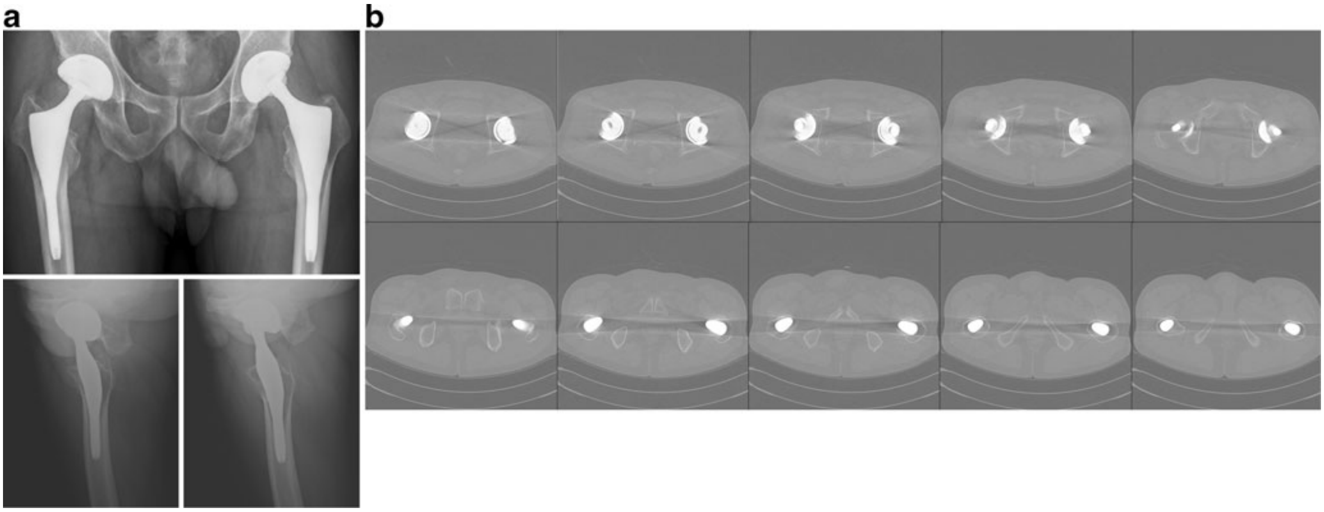

Fig. 1 Radiographic and computed tomographic (CT) scanning evaluation of osteolysis of both hips of a 43-year-old man with osteonecrosis of both hips. **a** An anteroposterior radiograph of both hips 10 years after surgery demonstrated that Duraloc optional cementless cups are fixed in a satisfactory position by bone ingrowth. There in no radiolucent line or osteolysis around the acetabular or femoral components. Grade 3 bone loss is observed in the calcar region of both hips. **b** CT scanning of both hips taken 10 years after surgery reveals no evidence of osteolysis around the acetabular or femoral components

the acetabular component was 99% [95% confidence interval (CI) 96−100] and the survival of the femoral component was 100% (95% CI, 96−100) at 11.1 years after the operation. When revision of either component due to aseptic loosening or osteolysis was the end point, the survival rate of the acetabular and femoral prostheses was 100% (95% CI, 96−100) at 11.1 years after the operation.

Discussion

At a 11.1-year follow-up, the young patients in this series performed well clinically and radiographically. These results are consistent with those in other studies of third-generation alumina-on-alumina ceramic bearings [2–4, 13, 17, 23]. In one report on 301 alumina-on-alumina ceramic bearings, the revision rate for any reason was 3.0% (nine of 301 hips) and mean Harris Hip Score was 95 points at an average of 6.5 years [17]. In another report on 380 alumina-on-alumina ceramic bearings, the revision rate was 0.5% (two of 380 hips) and mean Harris Hip Score was 96 points at an average follow-up of eight years [3]. Another report on 222 alumina-on-alumina ceramic bearings demonstrated that the revision rate was 2.7% (six of 222 hips) and mean Harris Hip Score was 97 points at an average of five years [4]. In the other report on 100 total hip arthroplasties with an alumina-on-alumina ceramic bearing followed for a minimum of five years, mean Harris Hip Score was 97 points, and there was only one reoperation due to ceramic fracture sustained in a motor-vehicle accident [23].

Osteolysis had seldom been reported in association with alumina-on-alumina ceramic bearing THA. The few reported cases were associated with earlier generations of ceramic, particularly the Mittelmeier total hip systems (Smith & Nephew, Memphis, TN, USA) [9]. In these hips, the acetabular component of the Mittelmeier hip prosthesis typically loosened and migrated into a steep (vertical) position, reducing the load-bearing area [19]. This edge loading leads to greater wear [23], and more wear particles increase the risk of osteolysis [2]. Recent studies of third-generation alumina bearings showed little or no osteolysis [3, 17, 23]. In our study, no hip had osteolysis. This finding contrasts with other observations in patients with traditional metal-on-polyethylene articulations in whom osteolysis is the major cause of revision, with rates of radiographically apparent pelvic osteolysis raging from 11% to 36% in medium- to long-term follow-up studies of series ranging in size from 77 to 168 patients [15].

It is believed that the wear rates of well-functioning alumina-on-alumina ceramic bearings are extremely low and that such wear rates are insufficient to cause osteolysis [9]. Nevertheless, if their size, shape and volume are optimal, alumina particles can induce biological responses similar to those induced by polyethylene [1]. In our series, we found no osteolysis. We postulate that extremely low wear and a little microdamage of the surfaces appeared to be insufficient to cause osteolysis.

Black discoloration, such as that observed on the alumina ceramic liner and head in two patients in this series, is not an uncommon finding [14, 16]. Such a dark metallic stain has been previously reported as the result of metal transfer from the edge of the acetabular shell [14, 16]. The transfer occurs even after relatively minor contact, and its severity is related to increased bearing-surface roughness [14, 16]. Moreover, transferred metallic debris probably increases bearing-surface wear via an abrasive or a third-body wear mechanism. In our patients, metal transfer might have occurred intraoperatively when the head was scratched by the acetabular metal shell during reduction. However, we believe these extensive metal transfers most likely occurred due to recurrent dislocation of the femoral head. These findings suggest that caution is required to avoid contact of the alumina head with metallic materials and that the surgeon should reduce the femoral head under direct vision during THA when using an alumina-bearing coupling. At revision surgery for a recurrent dislocation of the femoral head, a new femoral-head and acetabular ceramic liner should be used.

In conclusion, the current generation of anatomic tapered cementless femoral components with alumina-on-alumina ceramic bearing couples functioned well, with no osteolysis at a ten year minimum and average of 11.1-year follow-up in this series of young patients with osteonecrosis of the femoral head.

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