Early results of ceramic-on-ceramic total hip replacement

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Background
The most common articulation used in total hip arthroplasty is metal on polyethylene. However, nowadays, with young and more active patients undergoing the procedure, other bearing surfaces such as metal on metal and ceramic on ceramic have been proposed as an alternative to metal on polyethylene as a solution to the need for reducing wears debris production with subsequent osteolysis and loosening.

Aim of the work
The aim of this study is to evaluate the early outcome of total hip replacement using the ceramic-on-ceramic articulations.

Patients and methods
This prospective study included 13 patients (15 hips) who had end-stage arthritic hips. All patients were subjected to clinical, laboratory, and radiological evaluation before surgery and up to 3 years postoperatively.

Results
There was a marked improvement in the Harris Hip Score (satisfactory results in 93.3% of the studied group at the last follow-up) especially in the range of motion of the hip joint and postoperative pain relief.

Conclusion
The results were very satisfactory and significantly in favor of using this bearing combination, taking advantage of both the hard, wear-resistant ceramic material and the cementless acetabular fixation. This choice also broadens the spectrum of candidates for total hip replacement including young active women of child-bearing age and men with renal impairment or any patient with less accepted bone quality.

Keywords:
ceramic on ceramic, durable articulation, end-stage arthritis, minimal wear, young patients

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Introduction

The goal of new hip-bearing materials is to extend implant life by markedly decreasing the amount of wear debris generated, thus considerably reducing or even eliminating the incidence of osteolysis and loosening [1].

The ceramic-on-ceramic bearing couple for total hip arthroplasties was introduced in the early 1970s. In the early years, poor-quality alumina, manufactured using inadequate technology, led to a high failure rate, mostly by fracture, of these products [2].

Ceramic-on-ceramic articulations were often coupled with poorly designed femoral and acetabular components, frustrating many surgeons. Discovering that a cemented all-ceramic acetabular component was associated with a high aseptic loosening rate was important. Improvements in biomaterials, tribology, implant design, and methods of fixation have contributed considerably to the advancement of this bearing couple [3].

The newest ceramic material is an alumina matrix composite, labeled Biolox Delta. It is composed of 82% alumina (Al_2O_3), 17% zirconium oxide, 0.6% strontium oxide, and 0.3% chromium oxide. Because alumina ceramics are highly oxidized, this oxidized chemical structure makes alumina biologically inert and resistant to further oxidation. This composite material has improved mechanical properties over standard alumina, with bending strength improved by 210%, burst strength improved by 160%, and fracture toughness improved by 150% [4].

The hardness of alumina creates a product with significant resistance to surface damage, and ceramics are much harder than other materials routinely used in orthopedic surgery. The hardness of alumina makes it very resistant to both abrasive and adhesive wear [4].

In-vitro wear studies have proved that alumina on alumina is a very low-friction couple; alumina has ionic properties and therefore, in combination with body fluids, has better wettability. The fluid film that develops on ceramic surfaces decreases frictional drag and adhesive wear. Studies have shown that alumina-on-alumina articulations show ~5000 times less wear than metal-on-polyethylene articulations do under experimental loading conditions [5].

Patients and methods

This prospective study was carried out at the Orthopaedic Department at Benha University Hospital, Benha,

Figure 1

The preoperative radiographs of some cases in this study with different causes of hip arthritis. (a) Avascular necrosis. (b) Systemic lupus erythematosis (SLE). (c) Postinfection. (d) Rhumatoid arthritis. (e) SLE (bilateral affection).

from April 2009 to May 2012. Accordingly, 13 patients (two bilateral cases) (15 hips) were included in this study. Each hip was considered as a separate case. There were 12 female patients (80%) and three male patients (20%). Their ages ranged from 22 to 56 years (mean 34 years). The underlying pathologies were different, but in most of cases (80%), the pathology was avascular necrosis. Other causes of hip affection included inflammatory arthritis [systemic lupus erythematosis (SLE) and humatoid arthritis] and old septic arthritis (Fig. 1).

In all cases, cementless, both femoral and acetabular, components with a ceramic-on-ceramic articulation with a head diameter of 28 mm were used, except two cases, in which a 32 mm ceramic head was used.

The patients were evaluated preoperatively. Evaluation included an assessment of complete history, physical examination, and scoring of the patients' condition according to the Harris Hip Score (HHS), laboratory evaluation, and a complete radiological evaluation.

Prophylactic intravenous antibiotics were started the day before surgery, and continued 7 days after surgery combined with thromboembolic prophylaxis. Oral antibiotics were continued until the removal of sutures.

The procedure was performed under spinal anesthesia in all cases. The posterior approach was utilized in 10 hips (66.6%), whereas the lateral approach was used in five hips (33.3%).

Monitoring was carried out in the immediate postoperative period and included assessment of the general condition of the patient, care of the wound and suction drains, neurological deficits, and determination of leg-length discrepancy. Patients were encouraged to get out from their beds on the first postoperative day. Ambulation was guided by the intraoperative stability of both the acetabular and the femoral components. In all the cases, there was marked intraoperative stability; thus, ambulation by full weight bearing was started from the second day. Second-day ambulation was very important for the patients psychologically; it is a clear and evident sign of the success of the surgery. The patients were instructed to ambulate on two crutches or a walking frame and bear weight gradually as tolerated by the patient in the first 6 weeks.

Our patients usually still admitted in our department for 1 week with intravenous antibiotics.

Stitches were removed 2 weeks after the procedure, except in three cases, where the cause of hip affection was inflammatory arthritis. There was clear sterile discharge with no pain or fever; stitches were removed in the third week, with completely healed scars. Regular follow-up visits were made and re-evaluation was carried out at 6 weeks, 3, 6, and 12 months and then yearly.

The follow-up period ranged from 19 to 36 months, average 26 months.

Results

The clinical results in this study were evaluated according to the HHS. Evaluation of radiological results includes assessment of both the femoral and the acetabular components.

Clinical results

The HHS is a comprehensive, widely accepted scoring system that is used for the clinical evaluation of patients, preoperatively and postoperatively at 6 weeks, 6 and 12 months, and yearly thereafter until the last follow-up. The score is considered excellent if it is between 90 and 100, good between 80 and 90, and fair between 70 and 80, whereas scores below 70 are considered poor.

Table 1 Results of Harris Hip Score in the last follow-up compared with the preoperative Harris Hip Score

Preoperative HHS		Last follow-up HHS		
Mean	SD	Mean	SD	*P*-value
37.6	10.47	91.8	14.5	0.001[a]

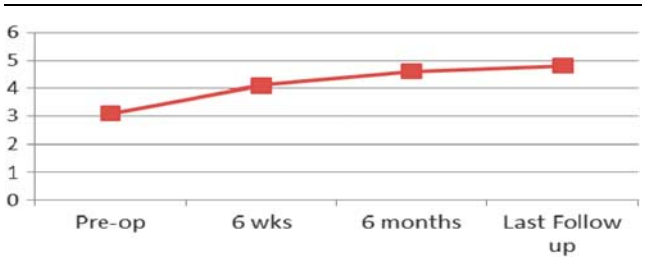
HHS, Harris Hip Score.
[a]Signifies the difference between the pre-operative HHS and HHS in the last follow up.

Table 2 Comparison between the mean preoperative and postoperative range of motion score

	Preoperative	6 weeks	6 weeks	6 months	6 months	Last follow-up
	3.08	4.1	4.1	4.6	4.6	4.8
P-value	0.0001*		0.04*		0.4	

*Significant.

Figure 2



The mean range of motion score before surgery and during the follow-up. Most of the improvement occurred during the first 6 months after surgery.

The preoperative HHS ranged from 25 to 48, with a mean of 37.6. The postoperative HHS in the last follow-up ranged from 72 to 95, with a mean of 91.8 (Table 1).

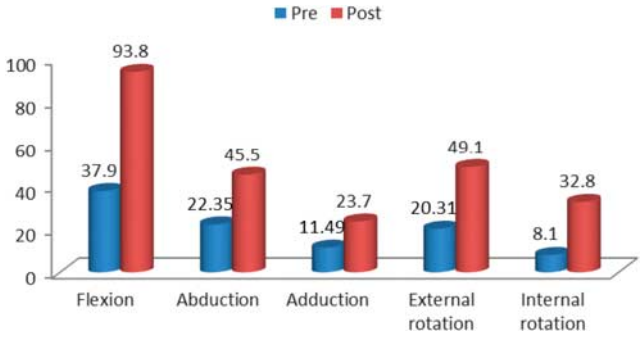
Excellent results (HHS $\geq$ 90) were obtained in 12 out of 15 hips, representing 80% of the studied group, and good results (HHS 80–90) were reported in two hips, representing 13.3%; a fair result (HHS 70–79) was achieved in one hip, representing 6.7%, whereas no patients had poor results (HHS $<$ 70) in the population studied.

Thus, satisfactory results (excellent and good results) were obtained in 14 hips, representing 93.3% of the studied group. The lack of difference in HHS between the cases with 28 ml and the cases with 32 ml heads may be because of the small difference between the two sizes.

Range of motion (ROM) accounts for 5 points of HHS. The preoperative scoring for ROM ranged from 1 to 3.5, with a mean of 3.1; the postoperative scoring for ROM in the last follow-up ranged from 3 to 5, with a mean of 4.8. There was a statistically significant increase in the ROM at 6 weeks compared with the preoperative score ($P = 0.0001$, $t = 4.2$); the difference remained significant between the postoperative scoring for ROM at 6 weeks and at 6 months postoperatively ($P = 0.04$, $t = 2.1$). This difference became insignificant at 6 months compared with the ROM score at the end of the follow-up ($P = 0.4$, $t = 0.8$) (Table 2 and Fig. 2).

The preoperative and postoperative ROM in the last follow-up for flexion, abduction and adduction, and internal and external rotation is shown in Table 3 and Figs 3 and 4.

Figure 3



Comparison between the preoperative and the postoperative range of motion at the end of the follow-up.

Table 3 Comparison between the mean range of motion preoperatively and at the last follow-up

	Flexion		Abduction		Adduction		External rotation		Internal rotation	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Preoperative	37.9°	13.5	22.35°	11.7	11.49°	5.7	20.31°	9.1	8.1°	6.7
Postoperative	93.8°	11.7	45.5°	6.4	23.7°	4.0	49.1°	4.0	32.8°	4.1
P-value	0.0001*		0.0001*		0.0001*		0.0001*		0.0001*	

*Significant.

Figure 4

The range of motion and stability of some cases in this study. (a) Avascular necrosis. (b) Systemic lupus erythematosis. (c) Postinfection.

Radiological results

Standard radiographs were obtained for all patients immediately postoperatively and at subsequent follow-up assessments.

Acetabular component inclination and position of screws

Acetabular inclination was determined in relation to the interteardrop line. Acetabular inclination in all hips ranged from 40 to 67°, with a mean of 46.8°. There was an insignificant correlation between the degree of acetabular inclination and the clinical outcome. All screws were in the dome of the acetabulum in the superiolateral part in the anterioposterior view of the pelvis and away from the greater sciatic notch in the lateral view (Fig. 5).

Femoral stem alignment

If the tip of the stem is central, it is in neutral alignment. If the tip is pointed or resting on the lateral cortex, it is in varus alignment. If the tip is pointed or resting on the medial cortex, it is in valgus alignment. All stems were in a neutral position, except one in slight valgus (Fig. 5).

Radiological follow-up

Standard radiographs were obtained for all patients at subsequent follow-up examinations. The radiographs were examined for radiolucent areas (gaps) behind the acetabular component, component migration, presence of heterotopic ossification, osteolysis, and loosening. Until the last follow-up:

(1) There were no radiolucent areas behind any cup in the last follow-up.
(2) There were no reported cases of early osteolysis.
(3) There were no reported cases with heterotopic ossification.
(4) There were no reported cases with a change in the stem position or migration.
(5) There were no reported cases with cup rotation or migration.
(6) There were no reported cases with broken heads.

In one case in which there was an intraoperative crack around the acetabular component, there was complete union of the crack with no change in the position of the cup (Fig. 6).

Discussion

Efforts to improve the survival of total hip arthroplasty implants have focused on alternative bearing surfaces to decrease wear and osteolysis [6]. The use of ceramics as bearing surfaces has had a long, successful history [7,8]. Refinements in the manufacturing process and improvements in component design have considerably reduced

Figure 5

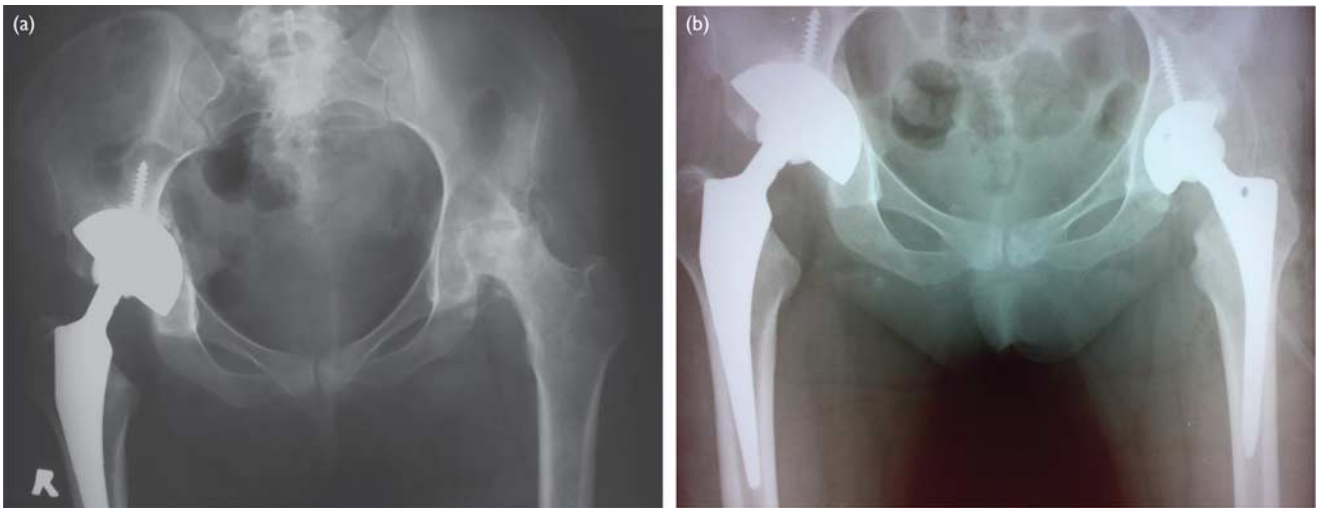
The postoperative radiograph of some cases in this study showing the cup orientation, screw positions, and stem alignment. (a) AP and lateral views of the case with avascular necrosis. (b) AP view of the case with systemic lupus erythematosis (SLE). (c) AP and lateral views of the case with postinfection hip arthritis (32 ml head). (d) AP view of the case with rhumatoid arthritis. (e) AP view of the case with systemic lupus erythematosis (SLE) (bilateral affection) with bilateral ceramic-on-ceramic THR (the right side done first). AP, anterior-posterior; THR, total hip replacement.

material-specific complications such as component loosening and ceramic fracture [9].

The modern generation of ceramic-on-ceramic total hip arthroplasty implants became available for widespread use in the USA in March 2003. Early reports have shown excellent clinical and radiographic results without the catastrophic failures associated with earlier designs [10]; it has been shown, *in vitro* and *in vivo*, that alumina wear debris is biologically inert and well tolerated [11]. Alumina particles induce very little cellular response and formation of granulomatous tissue. The small size of most alumina-on-alumina wear particles and the low volume of particles generated lead to a low level of bioactivity [12]. Giant cells have not been observed in contact with alumina wear debris. In contrast to polyethylene or metallic particles, foreign body reactions are routinely observed [13].

In fact, these are very important features in selecting a bearing surface for use in a young active patient with an end-stage arthritic hip especially in a woman of childbearing age where metal-on-metal hips cannot be used because of the theoretical risk of teratogenicity. Another technical advantage over metal-on-metal hips is that the ceramic liner used with a cementless metal shell with additional fixation by screws can be used safely in cases with less satisfactory bone quality as in inflammatory arthritis even on corticosteroids or if there is a small acetabular defect in contrast to metal-on-metal articulations, where cementless fixation really is cementless as all metallic cups are monoblock, with no additional fixation screws. Ceramic-on-ceramic articulation is versatile, with many options for use including different neck lengths and several head diameters including 28, 32 mm, and a large head diameter of 36 and 40 mm now available in the market.

Figure 6



(a) Iatrogenic intraoperative crack in the acetabulum, (b) the crack then completely healed, with no change in position. Case (Fig. 1e) Systemic lupus erythematosis (bilateral affection).

In every case, after standard acetabular preparation by removal of the labrum and medial osteophytes, if present, trials are conducted to ensure the proper stability and seating of the final acetabular component in the proper position for inclination and antiversion of the final prosthesis; a good intraoperative determinator for cup antiversion is the transverse acetabular ligament, which should be preserved in cases of primary hip replacement. After assessing the cup position and stability, additional stability could be ensured with the use of augmentation screws inserted mainly into the superior-lateral aspect of the acetabulum. The last step in acetabular component insertion is the application of the ceramic liner, which should be placed very gently and precisely so that it is fully seated in the metal shell all around without any force to avoid any cracking in the liner, which may lead to a full-blown fracture later. Finally, a towel is placed in the ceramic liner to protect it until the end of the operation. Now it's time to pay attention to the femoral component that was done in the standard way of doing a fell fixed cementless stem.

Trials with different neck lengths were conducted until we achieved the best stability, ROM, and proper leg-length equality. The wound was then closed in layers over a suction drain.

In this study, although some patients were on cortico-steroids because of either rheumatoid arthritis or SLE, none of them had any wound complications in terms of healing or infection or any problem in osteointegration and secure fixation between the implants and the host bone on both the femoral and the acetabular sides.

In my study, there was a case done after a history of old septic hip and massive osteomylitis of the femur treated by debridement and septobal beads inserted more than 25 years ago and the operation was done after exclusion of any signs of activity of infection clinically and serologically. It was a huge challenge to treat this case because of the abnormal shape of the femur and the risk of infection. In this patient – till the last follow-up – there were no signs of reactivation of the old infection and his operative wound was completely healed with no signs of infection in his both recent and old scars (Fig. 7).

There was one patient in whom dislocation occurred in a case of SLE. Reduction was performed on the second day under general anesthesia. She was on bed rest in an abduction brace for 2 weeks, and then became stable, with no history of redislocation till the last follow-up, with no restriction of her range of motion in any direction. In this case, a 28 ml head was used (Fig. 8).

No cases of fractures occurred either to the head or the rim of the ceramic liner till the last follow-up.

Hamadouche and colleagues recently reported on a previous study of ceramic on ceramic that was performed by the French surgeon Pierre Boutin. This was a consecutive series of 118 arthroplasties (106 patients) performed in 1979 and 1980. In all cases, a 32 mm alumina head was combined with an all-alumina socket. At the 20-year follow-up, it was found that 45 patients with 51 arthroplasties were alive and had not undergone revision. Twenty-five hips in 25 patients had been revised. Twenty-seven patients (30 hips) had died and nine patients (12 hips) were lost to follow-up. More importantly, no component fractures were reported. Wear of the components was not radiographically detectable, and only three of 118 hips showed evidence of osteolysis. The authors believed that the low incidence of osteolysis was related to the low rates of wear.

Recently, this same group of French surgeons reported the results of total hip arthroplasty in a group of young patients, younger than 55 years of age, with ceramic-on-ceramic bearings. All patients had undergone hybrid total

hip arthroplasty with cemented femoral stems and uncemented titanium sockets.

With a 9-year minimum follow-up, there was 93% component survival with no revision for any cause. There were only two mild cases of osteolysis, no radiographically measured wear, and no component fractures in this series [14].

The ceramic-on-ceramic articulation was matched to a control group of patients who had a metal-on-polyethylene articulation. In terms of pain relief and function, both groups were equivalent, with HHS scores averaging 97. Importantly, at this midterm follow-up, proximal femoral osteolysis was present in 0.6% of the patients in the ceramic-on-ceramic group. Conversely, 22.1% of the patients in the metal-on-polyethylene subgroup had radiographically identifiable osteolysis. Only 1.8% of patients in the ceramic-on-ceramic group underwent revision, as opposed to 7.4% of patients in the metal-on-polyethylene subgroup. There were nine insertional ceramic-on-ceramic chip fractures, but no catastrophic ceramic failures. Because of the insertional chip fracture problem, Stryker Orthopaedics later added a titanium sleeve to the ceramic acetabular insert. This seems to have alleviated the problem of chip, but the effects of impingement on the metal sleeve and metallosis and its relation to noise or other problems have not been determined [15].

The catastrophic fracture rate in this series was 0.2%, with three liners and one head fracture. As opposed to any other choice of bearing surfaces, ceramic-on-ceramic arthroplasty minimizes wear to the point at which osteolysis may be eliminated. Catastrophic fracture of the component is a devastating complication necessitating emergency revision surgery [15].

The results with more modern implants are excellent in terms of both pain relief and long-lasting durability.

Figure 7

Completely healed scar in the patient with old osteomylitis of the femur. Case (Fig. 1c) postinfection.

Figure 8

(a) Dislocated ceramic head, (b) after reduction. Case (Fig. 1b) systemic lupus erythematosis (SLE).

The risk of ceramic fracture is currently very low and much less than the risk of other implant-related problems.

Surveying the latest ceramic total hip arthroplasty series reported in recent journal articles or presented at the 6th World Biomaterials Congress, there were 11 studies representing more than 35 000 cases. From the Paris group, Hannouche *et al*. [16] who reported on 5500 cases followed for 25 years, found eight head fractures and five cup fractures.

Bizot *et al*. [17], presenting various developments in ceramic implants, found no fractures in their selected series followed for 20 years. From the FDA multicenter studies carried out recently in the USA, Garino [18] reported on 333 cases followed for 3 years (no fractures). Delaunay *et al*. [19] from France reviewed 133 cases followed for 5 to 10 years (no fractures). From Japan, the Kyocera group [20] presented 27 738 cases (nine head fractures, 0.032%). In the USA, Urban *et al*. [21] reported on 64 cases followed for a minimum of 17 years (no fractures). Also in the USA, D'Antonio *et al*. [22] and Bierbaum *et al*. [23] reported on 345 and 514 cases followed for 3 and 4 years, respectively (no fractures in each series). Thus, in this recent international set of presentations involving more than 35 000 cases with follow-up periods ranging from 3 to more than 20 years, there were 24 fractures.

In this study, one patient noticed a noisy sound in his hip joint and it was explained to him that this is common in patients with ceramic-on-ceramic hips. Squeaking (hip noise) is a specific issue in total hip replacement with hard-on-hard bearing surfaces. In an Australian study reporting 0.7% squeaking ceramic on ceramic hips, the authors reported that the squeak phenomenon occurred in patients who were taller, heavier, and younger [24]. The Australian study also reported a higher variance in acetabular anteversion and inclination in the hips that squeaked. A study from the Netherlands reported a 20.9% incidence of squeaking in 43 noncemented ceramic on ceramic hips [25]. That study reported no difference in patient characteristics or acetabular placement between squeaking and nonsqueaking hips, but found short necks on the implants in hips that squeaked. In three studies, squeaking reportedly developed an average of 14 to 26 months after surgery. Although the long-term clinical implications of squeak are unknown, the squeak phenomenon can have a psychological impact on patients, sometimes leading to decreased satisfaction or revision. The occurrence of squeak has been reported to range from 0.7% to as high as 20.9% [24,25].

Conclusion

The results were very satisfactory and significantly in favor of the use of this bearing combination, with the advantages of both the hard, wear-resistant ceramic heads and the cementless modular acetabular components with ceramic liners and additional fixation screws. This choice also broadens the spectrum of candidates for total hip replacement including young active women of child-bearing age, men with renal impairment, and any patient with less accepted bone quality or minimal acetabular defect. I think the future is for ceramic-on-ceramic bearing surfaces, and after the introduction of large ceramic heads with diameters of 36 and 40 mm, there will be better ROM and much more stability, adding to the advantages and benefits of these bearing surfaces in total hip replacement. Ceramic-on-ceramic is an excellent alternative bearing surface for total hip arthroplasty in young, high-demand patients with end-stage arthritis of the hip.

Acknowledgements

Conflicts of interest

There are no conflicts of interest.

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