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Fracture of ceramic heads in total hip replacement

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Abstract After introduction of ceramics in total hip replacement, there have been several studies on wear and fracture of the femoral head component. Though reports on fractures are few, we saw four fractures within 2 months. In all patients, a cementless hip prosthesis by four different surgeons was implanted between 3/2001 and 2/2004. In three patients, a ceramic-on-polyethylene pair and in one, a ceramic-on-ceramic pair was used. Only one patient suffered an adequate trauma. The mean survival of the ceramic head was 27 months (11–42). In two patients with polyethylene inlays, the inlay showed signs of wear out due to the fractured head. All four revision surgeries had a good outcome with satisfying results and no complications. Though we observe the postoperative development after implantation of ceramic components closely, we still believe that ceramics in total hip replacement in young and active patients are indicated with good long term results.

Keywords Total hip prosthesis · Ceramic head fracture

Introduction

Because of the increasing osteolysis which was induced by polyethylen components, Boutin in 1970 and Mittlemeir in 1974 began to implant alumina-on-alumina components in total hip prothesis [5, 21, 25]. The ceramics showed lower wear in comparison to metal-on-metal or metal-on-polyethylene articulation. The first ceramic bearing which was used by Boutin was actually a ceramic-on-ceramic bearing. Though the wear debris was low the problems lay in the risk of fracture and fixation.

The advantages of ceramics in total-hip-replacement are its sliding characteristics and its low wear debris generation. The sliding characteristic is assigned to the synophilic properties of the surface which leads to a low coefficient of friction [30]. Because of the ionic bonds, the ceramics are highly resistant to chemical and mechanical dissolution and are hard and strong but fragile. The synophilic properties are based upon a well-wetted surface with a low coefficient of friction and they are resistant to oxidation. In addition, the osteophilic surface of certain ceramics provides a good substrate for osteoblasts [18]. According to Sedel [24, 25]fracture toughness and wear are directly related to the properties of the material with high purity and density and low porosity and grain size.

Because of the problem of fracture in aluminia–ceramics, zirconia was introduced. Its advantage is the higher stability but it also has lower sliding properties and low thermal conductivity. The best mechanical properties are provided by yttrium-zirconia [11]. Nevertheless, there is an increasing number of reports on fracture of the zirconia heads.

Methods and patients

We report on four cases who presented at our outpatients' on 12/2004 and 01/2005 with a fracture of the

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ceramic head of the hip. The mean age of the three men and one woman was 59 years (56–66). In all patients, a cementless hip prosthesis by four different surgeons was implantated between 03/2001 and 02/2004. In three patients, a ceramic-on-polyethylen pair and in one, a ceramic-on-ceramic pair was used. When the patients presented, in only one patient an adequate trauma could be asked for. He fell on slippery ground right on the greater trochanter of the implanted hip prosthesis. One patient fell on his bottom on the opposite site of the implanted hip prosthesis and in two patients, the fracture occurred without any high impact trauma. The mean survival of the fractured ceramic ball was 27 months (11–42). In two patients with polyethylene inlays, the inlay showed signs of wear out due to the fractured head. Therefore, the ceramic head was replaced by a metal head combined with a replacement of the inlay. In one patient, the ceramic ball and the ceramic inlay were exchanged. In one other patient, the polyethylen inlay did not show any signs of wear and was therefore not exchanged. (See also Table 1) The femoral stem showed no signs of loosening due to wear debris or any other reasons in any of the patients. In none of the patients a foreign body reaction was seen. The revision surgery in all patients was without any complications. There was no need of blood transfusion. The mean hospital stay was 12 days (11–14) The postoperative mobilisation was satisfying and reached the same results as preoperatively (Figs. 1, 2).

Patient 1

Patient one presented himself in our outpatients' clinic and reported of a sudden pain without any trauma 4 days ago. Three years ago, a cementless hip prosthesis with a ceramic head and polyethylene cup was implanted. The x-ray showed a fracture of the femoral head. During the revision surgery the inlay of the acetabular cup did not show any signs of wear and scratches so that the surgeon decided not to change the inlay (see Fig. 3).

Patient 2

On the day of admission, patient two reported on ongoing pain for 4 months without any trauma. Three-and-a-half years ago, a cementless hip prosthesis with a ceramic head and polyethylene cup was implanted. The X-ray showed a fracture of the femoral head. The inlay showed clear signs of wear due to the fractured head so that it was exchanged along with the head.

Fig. 1 Zweymueller type stem and cementless cup

Fig. 2 Anatomical adapted stem and a cementless cup with a ceramic inlay. Typical signs of debris around the neck after fracture of the ceramic head

Table 1 Treatment of the patients with ceramic head fracture

Patient	1	2	3	4
Age on day of surgery	60	56	66	55
Weight in kg on day of surgery	80	94	81	85
Day of implantation	Jun 3 2001	Mar 19 2001	Feb 19 2004	Oct 29 2002
Femoral stem	Biomet PPF Size 5	Biomet PPF Size 5	PLUS Unischaft Size 7	Orthopedic Services CTX-S Size 5
Cone	12/14	12/14	12/14	12/14
Cemented stem	No	No	No	No
Acetabular cup	PPF-Screw cup Size 53	Duraloc Size 52	Duraloc Size 54	Plasmacup Size 54
Cemented cup	No	No	No	No
Femoral head	Ceramic Size 28	Ceramic Size 28	Ceramic Size 28	Ceramic Size 28
Femoral head manufactured by	Keramed Bionit 2	Keramed Bionit 2	CeramTec Biolox	Merete BioBall
Neck	Medium	Long	Medium	Long
Inlay	Polyethylene	Polyethylene	Polyehtylene	Ceramic
Activity	Normal	Normal	Normal	Normal
Day of fracture	Dec 23 2004	September 2004	Jan 25 2004	Feb 22 2005
Age on day of fracture	64	60	66	57
Weight on day of fracture	76	90	81	85
Trauma	No	No	No	Yes
Day of revision surgery	Dec 27 2004	Dec 10 2004	Feb 23 2005	Feb 23 2004
Revision of the head	Yes, metal	Yes, metal	Yes, metal	Yes, ceramic
Revision of the cup	No	No	No	No
Revision of the femoral stem	No	No	No	No
Revision of the inlay	No	Yes, polyethylene	Yes, polyethylene	Yes, ceramic

Fig. 3 PPF type stem

Patient 3

Almost a month after a fall on his left side, the third patient presented himself at our outpatients' clinic. He recalled that immediately after the fall there was no pain in his right hip which received a total cementless hip replacement a year ago. The pain started several days later. In this patient, the inlay of the acetabular cup was due to the scratches exchanged (see Fig. 1).

Patient 4

Two years after his total hip replacement, patient four fell on slippery ground on his left hip which was replaced 28 months ago. Though he did not feel any pain he heard and felt an ongoing crepitation in his operated hip while moving the lower left extremity. The X-ray and the CT-scan showed the fracture of the femoral head. Even though no signs of destruction and scratches were found intraoperatively, it was decided to change the inlay. Since all particles of the fractured ceramic head were sufficiently removed, the surgeon decided to implant a ceramic head and ceramic inlay (See Figs. 2, 4, 5, 6).

Discussion

Harms et al. [12]announced as on of the first the low cellular response of ceramic wear particles with minor fibrous scar tissue.They can be described as bioinert. According to Bohler the periprosthetic concentrations of particles in a ceramic-on-ceramic bearing is 2 to 22 times lower than in polyethylene and alumina/polyethylene wear pair. Bohler et al. [3] retrieved in their study the neocapsules and interfacial connective tissue membranes during revision surgery. Simon et al. saw a 10–50% reduction of wear rates of ceramic-on-polyethylene compared to metal-on-polyethylene for periods

Fig. 4 Signs of wear in a polyethylen-inlay after fracture of the head

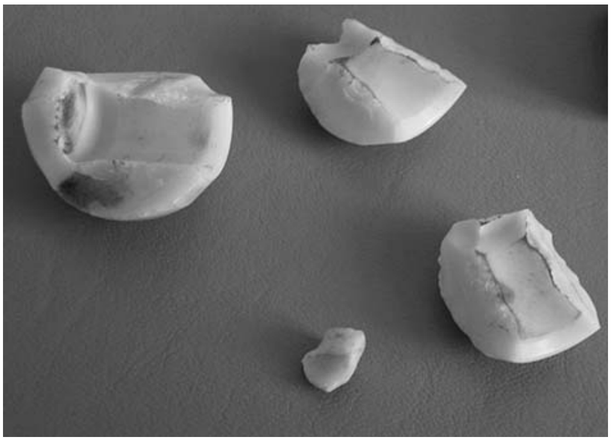

Fig. 5 Fractured ceramic head

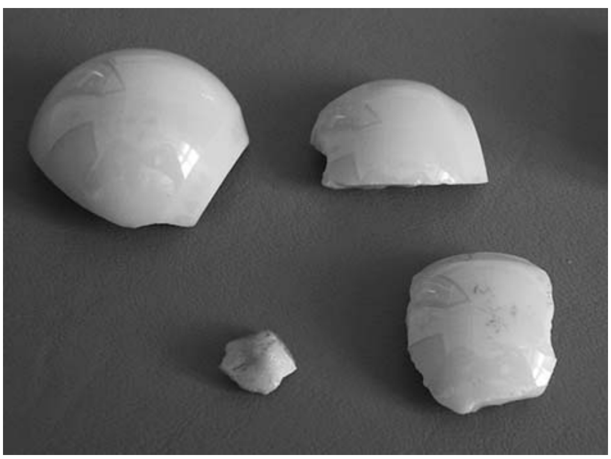

Fig. 6 Fractured ceramic head

exceeding 10 years, which was confirmed by an in-vivo study of Zichner and Willert who saw a 50% reduction of wear in ceramic-on-polyethylene compared to metal-on-polyethylene [26, 36]. They could further see a high rate of wear in the first 6 months (0.5 mm) with a decrease to 0.1 mm (ceramic) respectively 0.2 mm (metal) after 5 years [37]. According to Skinner [27] ceramic-on-ceramic wear rates are in the range of 0.003 mm/year, ten times less than ceramic-on- polyethylene and 50 to 100 times lower than metal-on-polyethylene. According to Hannouche et al. [11] the alumina-on-alumina combination is being recognized as one of the best answers to wear debris-induced osteolysis.

Wrobleski et al. [34]reported on a series of loosening in patients with zirkonia femoral heads in which he found histological areas of osteolysis and revealed zirconia particles. Norton et al. [22] saw a loosening rate of 67% in their population with zircona-ceramic-on-polyethylene (Hylamer). They implanted 29 hips in 26 patients. In all of the failed hips they saw an aseptic loosening with progressive osteolysis. To avoid massive bone loss they suggested early revision surgery. Allain et al. [1] saw a loosening rate of 47% in 100 consecutive hips with zirconia-ceramic-on-polyethylene bearing with a revision rate of 63% in 8 years. Their results made them return to a metal-on-polyethylene bearing.

As shown above, there are some reports on massive osteolysis though ceramic particles are described as bioinert with low foreign body reaction. Wirganowicz and Thomas [32] reported on a pathological periprosthetic fracture in a woman with a total hip replacement and a ceramic-on-ceramic bearing. The material curetted from the femoral medullary canal in the area of the osteolysis contained extensive amounts of histiocytes and foreign body debris.

A similar case was reported by Wirganowicz and Thomas [33] who saw a massive foreign body reaction in revision surgery of a total hip replacement with ceramic-on-ceramic bearing. The histochemical studies in the areas of osteolysis showed debris products from the ceramic implants.

There are also reports of loosening in ceramic-on-ceramic bearing. Already [4] Borsson et al. published a case report on a patient who was suffering from rheumatoid arthritis with ceramic-on-ceramic bearing with an extensive, rapidly evolving osteolysis around the prosthetic stem. Five years after the implantation of the total hip prosthesis, a periprosthetic fracture was seen. Yoon et al. reported on 103 hips with ceramic-on-ceramic bearing in which they saw a loosening rate of 22% after a mean follow up of 92 months. They could demonstrate by histological and ultrastructural studies a severe foreign body reaction to ceramic particles. Radiographically, signs of loosening were seen [35].

Ultra-high molecular-weight polyethylene (UHM-WPE) is seen as the standard counterface to zirconia heads [19]. As shown above, most reports are on the wear of the polyethylene and not on fractures of the ceramic head.

The wear may be influenced by the position of the acetabular cup, material and design. In a ceramic-on-polyethylen simulation, Schwägerl et al. [23] saw an increase of 100% in wear in a cup with 5% more inclination.

Though ceramics are resistant to mechanical and chemical properties and they are considered to be strong, there are reports on fractures in the literature. Dawihl et al. [7, 8] came to the conclusion that ceramic heads may carry a load of 50-times of the human body weight.

In 1998 Willmann reported on a fracture rate of 0.02% in 1.5 million heads since 1974 and Heck reported on 22 fractures in 10,000 patients[29, 13, 14]. In a later review of the literature, Willmann reported on a failure rate of ceramics up to 13.4 % manufactured before 1990 and a failure rate of 0.004% to 0.015% for ceramics manufactured after 1990. Especially for the Biolox femoral head Willmann [31] saw a fracture rate of 0.026% for first generation alumina, 0.014% for second generation alumina, and 0.004% for femoral heads manufactured after 1994.

Fritsch and Sedel saw a fracture risk of one in 2000 patients [10, 24]. Fritsch et al. analyzed over a period from 1974 to 1998, 4,341 alumina ceramic heads articulating with 2,693 alumina ceramic and 1,464 poleyethylene cups. They saw one fracture of a ceramic head in a ceramic-on-polyethylen and seven fractures in ceramic-on-ceramic whereas four fractures were related to direct trauma, two fractures were related to recurrent neck impingement and one was due to material fatigue. In a mushroom shaped head with ceramic neck which was used in 1,096 cases the fracture rate was\ 0.4% whereas the fracture rate in a ball type head was 0.06% (1,763 patients). They saw an improvement in using the ball type neckless heads with a fracture rate of almost 0% [24].

Heisel [15] reported on two traumatic fractures of ceramic heads. By reviewing the literature they came to the conclusion that a fracture of the ceramic head may be prevented by using a ceramic-on-polyethylene combination. In polyethylene they saw a damping behavior. Furthermore, they saw fractures of the ceramic head after chronic recurring below threshold trauma.

Kern et al. [17] reported on one ceramic head fracture in 500 implanted ceramic heads which occurred 2 years after implantation. Michaud et al. [20] reported on a spontaneous fracture of the ceramic head in a ceramic-on-polyethylen combination.Their review of the literature made overweight of the patient, high levels of activity or injury responsible for ceramic head fractures.

Because of two fractured zirconia-ceramic heads Hummer et al. [16] returned to metal-on-polyethylene.

Heck et al. [14] send a survey to the membership of the American Association of Hip and Knee Surgeons to determine their experience with total hip arthroplasty (THA) device-related failures over a period of 5 years. Forty-seven percent returned the survey. Although the use of ceramic femoral heads was low (5,023 hip arthroplasties compared to 65,000 hip arthroplasties overall), 11 fractures were reported which accords for a failure rate of 22/10,000. In contrast, a complete polyethylene failure was seen in 172 metal-backed sockets (failure rate of 29/10,000) and 77 of all-polyethylene sockets had complete a polyethylene failure (failure rate of 239/10,100) (see Table 2).**

Maccauro et al. [19] saw the cause of failure in the processing of the femoral head when he reported on a

Table 2 Reports on ceramic head fractures in the literature

Reports on series		
Author	Fracture rate	Annotation
Willmann [29]	0.02%	Insufficient material properties, careless handling and mismatch
Heck [13, 14]	0.22	
Willmann [30, 31]	13.4%	Manufactured heads before 1990
Willmann [30, 31]	0.004%	Manufactured heads after 1990
Fritsch and Sedel [10, 24]	0.5 %	Improve in using the ball type neckless heads
Kern [17]	1 in 500	Ceramtec Biolox
Case reports		
Author	Fractures	
Heisel [15]	2	Prevention is possible by using a ceramic-on-polyethylene combination
Michaud [20]		Risks: overweight, high levels of activity, injury
Maccauro et al. [19]	1	Failure due to the processing of the Y-TZP-femoral head

spontaneous fracture of a Y-TZP ceramic femoral head. This head belonged to a batch of ceramic heads in which fractures in 42% of the cases were reported until the manufacturer drew back the product from the market. First subcritical cracks resulted in the release of abundant debris of inert material in the joint space. The head in itself showed that a closed porosity was not achieved and high-pressure gas may have entered the core of the material. This may have led to micro-cracks during manufacture [19].

Ceramics have excellent compression and limited bending strength. Nevertheless, its fracture toughness is low because it does not have any possibility to deform without breakage. Reasons for breakage can be inhomogeneties in the poros, scratches and little notches on the surface. Small irregularities can grow until a sudden fracture without adequate trauma occurs [11].

Barrack et al. [2] accused the vertical positioning of the acetabular cup, impingement of the femoral head and the femoral head separation for failure of the ceramic ball. In the fabrication of ceramics the temperature applied and the quality and purity of the basic material are liable for the quality of the product. Depending on the abovementioned qualities, the porosity, grain size and grain distribution can be influenced [11].

This is concordant with the opinion of Willmann [31] who saw the reasons for a fracture of the ceramic heads in insufficient material properties, careless handling and mismatch between the metal taper and the bore in the ceramic head which leads to a high stress onthe head. Furthermore, a precise cleaning process and a smooth introduction without hammering was emphasized to prevent a failure of the ceramic component [11].

Barrack et al. came to the conclusion that revision surgery in femoral head fractures can be extensive. A ceramic head fracture may result in the generation of debris from modular interfaces, neck damage and debris generation from impingement, inability to use a ceramic head a second time on a metal trunnion and the dramatic loss of head and liner options intraoperatively [2].

The revision surgery of the fractured ceramic head must include a sufficient removal of all fractured particles around the articulation since the smallest particle may lead to a new wear of the components. Though one surgeon did not exchange the inlay of the cup in our series, the recommendation is to have at least a close look and perform a revision at an early stage to avoid an unnecessary revision surgery due to wear of the inlay. Irregularities on the surface of the inlay may lead to further wear debris which may also lead to an early loosening of the femoral stem or the acetabular cup. Though the recommendation is to change a fractured ceramic head into a metal head, since left particles of the ceramic may reinduce scratches and microcraques which may also result in a refracture of the revised head, we implanted a ceramic-on-ceramic bearing in patient 4. After removal of the fractured components and extensive lavage of the wound there were no particles left.The femoral stem and the acetabular cup did not show any signs of loosening either intraoperatively or radiographically. The patient himself was young, active and absolutely reliable as well as well informed about the advantages and disadvantages so that we decided to change in consent with the patient to a ceramic-on-ceramic bearing again.

Further reports will show if the fracture rate in ceramic heads increases and may result in avoidance of the ceramic components. Even though we enumerated several cases with fractured heads from the literature we have had good experience with ceramic-on-polyethylene and ceramic-on-ceramic bearing since this combination did show the fewest signs of wear and loosening. Compared to the numbers of implanted ceramic heads the fracture rate is, as demonstrated above, still low. Despite that, the use of ceramic heads with or without ceramic inlays leads to a significant reduction of wear debris and loosening rate in total hip replacement. This has to be opposed to the fracture rate. Nevertheless, each surgeon must confront his own experience with the results in the literature in order to decide which combination of components is the best for his patients.

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