Ceramic Hip Replacements: Wear Behavior Affects the Outcome – A Tribological and Clinical Approach

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3.1 Introduction

Recently, the endoprosthetic treatment of younger and more active patients has increased and got into focus of the orthopedic community. This patient group wants to live an active life, posing increasing demands on the mechanical and tribological properties of artificial hip implants. In addition, life expectancy and activity levels of older patients have been increasing [52, 81, 82, 89]. As a consequence, also the virtual picture of the old, less active patient has to be revised. In a clinical study, Wollmerstedt et al. [52, 81, 82] have measured the mean daily movement of patients (mean age 70 years) with total hip arthroplasty. They observed a mean number of two million load cycles per year which is double than those being the basis for simulator studies (one million cycles per year). On the other hand, an increased level of activity should not increase the risk of a wear induced osteolysis. The authors conclude that the bearing material plays an even more important role than has been acknowledged up to now.

The wear induced aseptic loosening is still one of the main indications for a revision surgery in THA [75, 78, 83–86]. Facing the problems being created by wear particles in metal or polyethylene bearings has to be the first aim to minimize the creation of wear debris and to avoid the resulting complications. Polyethylene particles are responsible for a large number of periprosthetic osteolyses in total joint arthroplasty [34, 83–85, 90]. Considering

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shells and inserts made of polyethylene, influencing factors are, among others, the size of the femoral ball head [91–93] and the activity level of the patient [15, 76]. It is common consensus that large bearing diameters due to their enhanced range of motion (ROM) are preventing subluxation, dislocation, and impingement, and are positively influencing joint stability. Postoperative dislocation rates of up to 10% [87, 88] visualize that the dislocation problem is still a major concern, and that implant stability together with a sufficient ROM is an important success factor in THA [51]. Nevertheless, a larger diameter of the bearing couple in connection with polyethylene inserts leads to an increased wear volume [91–93].

For ceramic bearing couples, the problem of wear volume is more or less solved. Clinical experience states that they show the lowest particle emission and osteolytic potential of all bearing materials in use. As a consequence, ceramic implants are well suited for risk patients, e.g., in the case of metal allergy [65]. Furthermore, ceramic bearing couples show no increase of wear volume with increased bearing diameter [94]. The above mentioned problems have lead to a more widespread use of ceramic bearing couples.

The first applications of ceramic bearing couples in orthopedics were made of pure alumina (Al_2O_3) [1, 3, 17, 32]. Since 1971, they are used in this area, and more than five million components have been implanted [16, 33, 42]. Enhancements regarding the microstructure and the reliability of ceramic materials have been reached mainly by improving the production process, leading to a significant increase in mechanical strength. Composite ceramics with even more improved mechanical properties offer new areas of application such as larger bearing couples for better range of motion and joint stability. In the following, the main characteristics as well as the mechanical behavior of a special ceramic composite material are analyzed. Its clinical potential is assessed as being very promising [19].

3.2
Ceramic Selection for Bearing Couples

Pure alumina ceramics have been the standard for more than 40 years for hip arthroplasty due to their superior wear performance and biocompatibility. While at the beginning of the use of alumina components the fracture rate was comparatively high, improvements in ceramic technology, quality management and design optimization has led to highly reliable application of alumina and very low fracture rate (today ~ 0.02%). Today, the material properties which are in a physically realistic expectation for alumina are almost reached.

There are mainly three aspects in the current state of the art in arthroplasty which push the need for a higher performance material than can be provided by pure alumina:

- A strong tendency to use larger wear couples for improved range of motion and comfort for the patient
- Higher reliability in the case of unforeseen severe impact on the ceramic components, including disadvantageous wear conditions
- Increasing need for the use of ceramics for other artificial joints like knee and spine, particularly of interest to consequently avoid any possible implication of metal debris

The ceramic material providing the highest strength is *zirconia* due to the unique transformation toughening effect (as explained later). High performance yttria stabilized zirconia (Y-TZP) can provide more than double the strength in comparison to pure alumina.

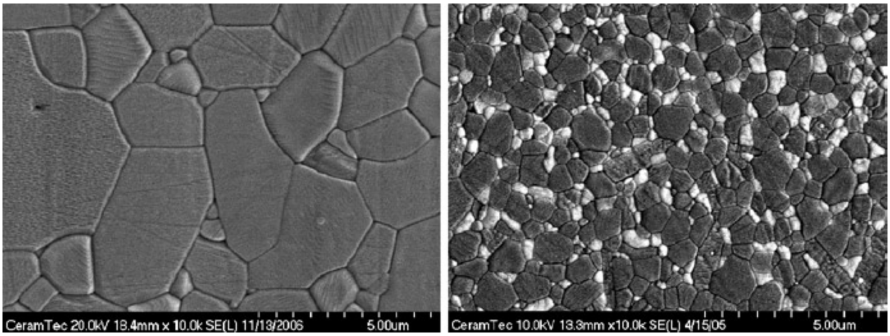


Fig. 3.1 Microstructure of pure alumina BIOLOX®*forte* and ZTA BIOLOX®*delta*. Note that the magnification in both figures is identical. Alumina appears gray, zirconia white. Zirconia content in BIOLOX®*delta* is 17vol.%

However, the use of Y-TZP for wear applications has almost disappeared in Europe and USA due to the particular problem of hydrothermal aging, i.e., undesired phase transformation in human body environment with adverse impact on the surface integrity of the component. Moreover, zirconia shows a significantly lower hardness and thermal conductivity than alumina which is also considered a disadvantage for Y-TZP.

An ideal ceramic material for arthroplasty should combine the advantages of zirconia and alumina (BIOLOX®*forte*, CeramTec GmbH, Plochingen, Germany), i.e., the high strength and toughness on the one hand, and high hardness and inertness on the other hand. This concept can be achieved using a composite of these ingredients, i.e., zirconia toughened alumina (ZTA). Such a material is available in the market since 2002, under the trade name BIOLOX®*delta* (CeramTec GmbH, Plochingen, Germany). It was just in the year 2009 that the total number of hip components produced with ZTA almost balanced the number of those with the established pure alumina. It is expected that ZTA will dominate the near future of bioceramics for arthroplasty.

Figure 3.1 shows a comparison of the microstructures of alumina and ZTA as they represent the current state of the art.

3.3
Benefit of the Phase Transformation of Zirconia

The benefit in crack resistance which is obtained from incorporating zirconia into an alumina matrix as shown in Fig. 3.2 is well known in the science of high performance ceramics.

Figure 3.2 represents a realistic part of the microstructure. The gray particles refer to the alumina matrix, yellow to tetragonal zirconia. The phase transformation of zirconia is indicated by the change to red color. In the case of severe overloading, crack initiation and crack extension will occur. High tensile stresses in the vicinity of the crack tip trigger the tetragonal to monoclinic phase transformation of the zirconia particles. The accompanied volume expansion of approx. 4% leads to the formation of compressive stresses which are efficient for blocking the crack extension [18, 21].

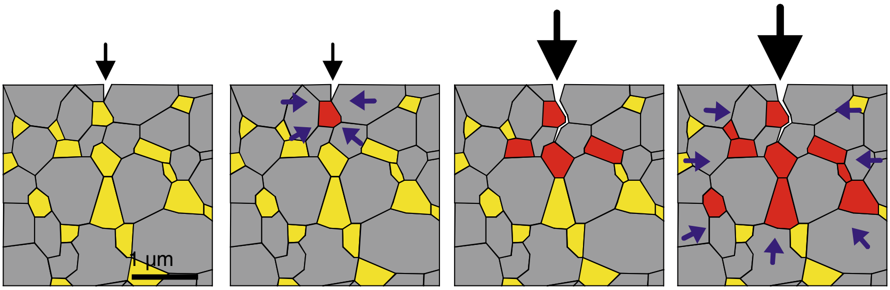


Fig. 3.2 Reinforcing mechanism in BIOLOX®delta at crack initiation and propagation. Yellow particles represent tetragonal zirconia. Color change to red indicates monoclinic phase transformation. Arrows show the region of compressive stresses due to phase transformation

As it is demonstrated in Fig. 3.2, this reinforcing mechanism is fully activated within a region of a few micrometers. For the macroscopic performance of the material it is very important that immediately at the beginning of crack initiation the reinforcing mechanisms are also activated. Regarding this mechanism, one should keep in mind that the average distance between the reinforcing zirconia particles is approx. 0.3 µm, i.e., similar to the grain size. Thus, the reinforcement is activated immediately when any microcrack is initiated. This is of particular interest for the significant advantage of ZTA (BIOLOX®*delta*) under severe wear conditions.

3.4

Simulation of Severe Wear Conditions

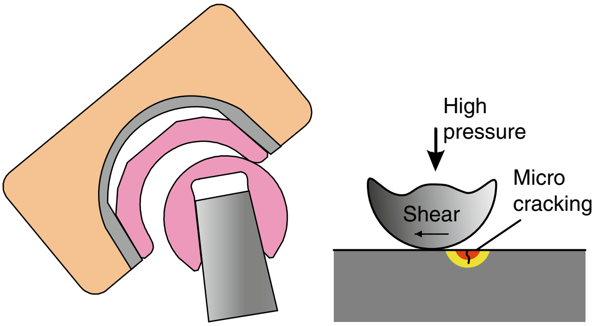
Under normal conditions, the wear of ceramic surfaces during the life time of a patient is almost negligible. The amount of wear debris in comparison to other materials is reduced by orders of magnitude. Moreover, zirconia and alumina are bioinert, thus no detrimental effects are expected from the debris.

However, under adverse circumstances the wear conditions can be disturbed. In particular, it is possible that the ball head leaves the ideal position inside the insert due to impingement or microseparation. In this case, the wear conditions shift from surface contact to point contact which lead to highly located compressive stresses. Such a situation is the main reason for stripe wear, i.e., a clearly distinguished area with significantly higher surface erosion.

In order to show the performance of ZTA vs. pure alumina at high impact wear, several experiments have been performed [79, 80]. In Fig. 3.3 (*left*), the configuration of a microseparation test as performed by Stewart et al. [80] is shown.

It is well known, that in the vicinity of highly located contact the surface can be damaged due to microcracking, as schematically depicted in Fig. 3.3 (*right*). This is most likely the reason for increased surface erosion under stripe wear conditions. On the other hand, as it was discussed under Fig. 3.2, it should be expected that a material with an efficient toughening mechanism in the micron-scale shows an improved performance under stripe wear conditions. This expectation is convincingly shown from the experiments performed by Stewart et al. [80], see Fig. 3.4.

Fig. 3.3 *Left*: Simulation of stripe wear conditions, ball head leaves center position *Right*: Schematic description of surface microcracking in vicinity of high contact load



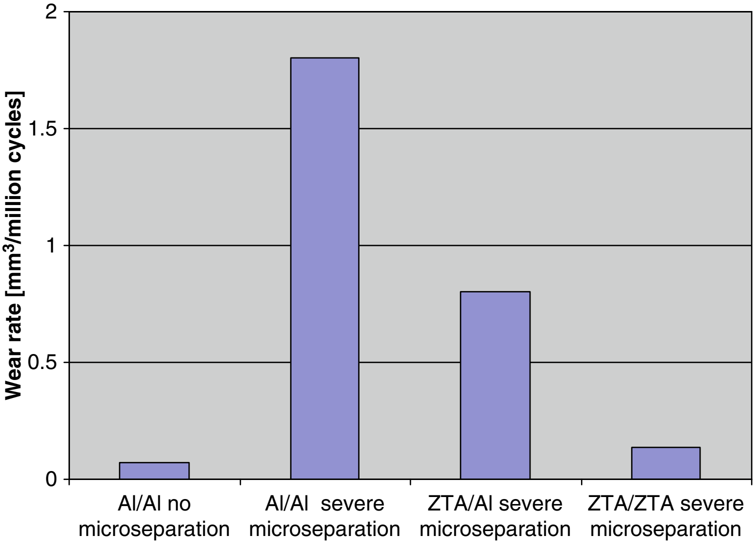


Fig. 3.4 Results of microseparation tests after [*Stewart*], average of five million cycles

In this experiment, three different couples of ceramics are used: (1 and 2) pure alumina vs. alumina, (3) ZTA vs. alumina and (4) ZTA vs. ZTA. As a reference, the pure alumina couple was also tested without microseparation. As expected, the standard wear test without microseparation revealed extremely low wear rate of <0.1 mm^3/million cycles. The same couple, tested under extreme conditions of five million cycles microseparation, shows more than one order of magnitude higher wear rate due to contact load damage. It should be considered that these testing conditions are unrealistically severe. As the most important result of this experiment, the ZTA couple (4) performs excellent even after five million cycles of microseparation. The total wear is only marginally higher than the wear of the pure alumina under optimal conditions. This result supports the hypothesis that ZTA materials provide higher reliability under disadvantageous wear conditions. The performance is clearly correlated to the intrinsic reinforcement of the zirconia which efficiently prevents microcracking.

3.5
Tribological Aspects of Ceramic Bearings

Ceramic-on-ceramic bearings made of pure alumina have a long clinical history [42, 43]. The performance in the early years was sometimes not satisfying which was due to material, design, and surgical related factors. Over the years, the improvements in materials and manufacturing as well as the adaptation of design and surgical technique have led to a variety of safe and successful designs. Nevertheless, the potential of ceramic-on-ceramic bearing couples to reduce the risk of osteolysis is based on their excellent wear behavior [14, 16] as well as their high degree of biocompatibility which is caused by the minimal risk of ionization of ceramic particles [6]. The long-term in-vitro volumetric wear rate for well-functioning ceramic-on-ceramic bearings made of pure alumina has been measured as varying from 0.02 mm^3/mc [35] to 0.04 mm^3/mc [13], whereas the linear wear rate for well-functioning in-vivo pairings has been reported between 0.025 µm to 5 µm [28, 38, 45].

The request for larger bearings arising from the increased patient demands has led to bearing diameters that require special attention with respect to frictional moments and wear [10]. In [36], the wear behavior of ceramic bearing couples up to 44 mm is compared to that of the clinically well-functioning 28 mm made of pure alumina. It could be shown that even large deviations in clearance and roundness do not lead to excessive wear but to a steady-state wear rate in the same range as the 28 mm pure alumina bearing. In [2], the friction moments for different hard-on-hard bearings and bearing diameters have been investigated. It could be shown that assuming same diameters by linear scaling of the resulting friction moments, the ceramic-on-ceramic bearing exhibited the lowest friction moment, therefore, promising the best wear behavior in clinical use compared to metal-on-metal or ceramic-on-metal.

Stripe wear is a phenomenon known from hard-on-hard bearings [8, 49]. The occurrence of stripe wear in vivo may depend on implant design, orientation in the hip joint, patient activities and implant duration [31, 49]. Although only anecdotal reports exist for a correlation between ceramic wear debris and osteolysis [48], the phenomenon and its reproduction in-vitro has been studied. In [9], the shape and surface roughness of in-vitro created stripe wear in the ZTA ceramic BIOLOX®*delta* has been compared with the stripe wear of retrieved parts of the same material. The reasons for revision were non wear-related. Results show that the artificially reproduced stripe wear shows good correlation with that from the explanted parts.

3.6
Clinical Performance and Their Relation to the Material of the Bearing Couple

Wear and its consequences are limiting factors of total hip arthroplasty in young and active populations. Aseptic loosening due to polyethylene wear remains the most common case of implant failure [83–86, 90]. In the Swedish National Hip Register, aseptic loosening accounts for 75% of all hip revisions [78]. The Finnish Arthroplasty Register suggested that the limiting factors for survival of total hip arthroplasty for patients younger than 55 years old was polyethylene wear [75]. Schmalzried et al. [76] demonstrated that polyethylene wear was related to activity and activity was related to younger patients' age. The life expectancy and activity demands are increased. This results in up to a tenfold increase in the tribological demands of hip implants [77].

It is clear from the literature that current orthopedic surgical practice is in need of further alternatives in order to complement the metal against ultra high molecular weight or highly crossed linked polyethylene wear couple for a category of patients defined as younger and more active.

Several reports demonstrated that the use of ceramic implants may contribute to a large extent to diminishing wear debris and, hence, to a significant reduction of the revision rate in THA. The use of ceramic-on-polyethylene bearing couples has enabled a two to fivefold reduction in the revision rate compared to metal on polyethylene bearing couples [7, 53, 59, 69, 70].

Alumina ceramic on ceramic bearings have shown a 100-fold decrease in wear compared to highly cross-linked polyethylene materials [54].

Cell culture studies demonstrated that ceramic wear particles are more biocompatible and have the lowest functional biological activity and osteolytic potential compared to other bearing materials [54]. Baldini et al. [55] investigated alumina ceramic-on-ceramic hip replacements (BIOLOX® 32 mm, BIOLOX®*forte* 28 mm). The average service life of the explants had been 8 (1–17) years. The investigation showed extraordinarily minimal wear rates and no negative biological reactions to the released ceramic particles. Wear debris particles were largely absent. In the few cases particles were observed, however their volume was minimal. No evidence of foreign body reaction or inflammation was observed. No cases of extensive osteolysis or cytotoxic effects were found. These results offer additional confirmation of results obtained from earlier investigations conducted by various work groups.

Extremely low wear has also been recorded in hip simulator studies and in vivo for alumina ceramic on ceramic bearings. These results are reflected in clinical results where there has been a very low incidence of osteolysis.

3.6.1
North American Experience

D'Antonio and Capello [56] presented a review of the 52,000 ceramic-on-ceramic hips implanted since the 2003 FDA approval of Stryker ceramic hip arthroplasty products. They reported that a total of four insert fractures (0.008%) and nine femoral head fractures (0.017%) were seen in the group. Further data comparing metal-on-polyethylene and ceramic-on-ceramic couples at greater than 7 years follow-up found a 7.5% revision rate in the control group (metal-on-polyethylene) versus a 2.7% revision rate for ceramic-on-ceramic. There were no fractures in the ceramic cohort, while the control group experienced osteolysis and revisions attributable to wear [99]. Capello et al. [56] reported on 475 hips at an average 8 years of follow-up. Cortical erosions were seen less in the ceramic-on-ceramic hips (1.4%) than in the metal-on-polyethylene group (30.5%), and there was no aseptic loosening in the ceramic group. Overall, there was less than 1% requiring revision in the ceramic-on-ceramic hips.

Murphy et al. [57], in a report on the Wright MT IDE trials, included 1,709 hips in 1,484 patients across 12 centers. At an average 8-year follow up, there were four ceramic liner fractures including intraoperative chips (0.27%) and two re-operations for instability. While regulatory approvals have historically forced ceramics to introduce new sizes at a slower pace than metal components with respect to head size, Murphy concluded that the relative lack of neck and liner options did not impede safe surgery with these components.

In another study, Murphy et al. [30] treated 360 patients (mean age of 51.7 ± 12.3 years) with 418 ceramic-on-ceramic bearing couples. 41 of these cases (11%) were revisions. No case of osteolysis could be observed. The authors concluded that the results of these studies are very promising due to the young age of the patients and the high incidence of revision cases.

Mesko et al. [58] reported on a comparison of alumina ceramic-on-ceramic (BIOLOX®*forte*) and metal-on-polyethylene bearing couples in patients whose activity levels are well above average. The 10-year survival rate was 96.8% for the ceramic-on-ceramic group and only 92% for the metal-on-polyethylene group. Mesko concluded that the long-term safety of ceramic-on-ceramic bearings is demonstrated by the low incidence of revision in comparison to metal-on-polyethylene.

Steppacher et al. [46] reported on first results of a prospective study in which 123 dysplastic hips (Crowe type I and II) in 108 patients (mean age of 47.6 ± 12.7 years) have been treated with a ceramic-on-ceramic bearing couple (alumina, BIOLOX®*forte*, 28 mm, 32 mm). No cases of osteolysis or dislocation have been observed. The authors conclude that these results are very promising in young patients with dysplasia after 2–10 years follow-up.

Lewis et al. [25] reported on first results of a prospective, randomized medium- to long-term study in which ceramic-on-ceramic and ceramic-on-polyethylene bearing couples were compared in a follow-up time of up to 10 years. 55 active patients with a mean age of 42.2 years received 56 cementless components. 30 implantations were made with the hard-on-hard bearing couple, 26 with the hard-on-soft bearing couple. In all hips, 28 mm femoral ball heads were used. Signs of wear debris were identified in 25 of the 26 ceramic-on-polyethylene hips, but only in 12 of the 23 ceramic-on-ceramic hips. The linear wear rate per year was significantly lower for the ceramic-on-ceramic group (0.02 mm) than for the ceramic-on-polyethylene group (0.11 mm). The authors concluded that the ceramic bearing couple is a safe long-term option avoiding possible risks that might arise through the use of polyethylene or metal components.

The review of the experience in the American environment clearly shows that there is a significant reduction in wear achieved when the ceramic on ceramic articulation is used in a challenging patient group, the younger and more active patient. The use of this articulation in large numbers in the USA is now approaching the 10 year level with very significant reductions in osteolysis.

3.6.2

European Experience

The reported long-term clinical and radiographic results with alumina ceramic-on-polyethylene and ceramic-on-ceramic demonstrated the value of ceramics as a femoral bearing surface in THA.

Ihle et al. [59] reported on significantly lower wear rate and debris in ceramic-on-polyethylene bearing couple, less osteolysis and revisions when compared to metal-on-polyethylene bearing couple after 20 years in vivo. The mean age of the patients was 52 years. They observed no ceramic fractures. The average annual wear rate was 0.107 mm for the ceramic femoral ball head group and 0.190 mm for the metal femoral ball head group. At 13.8%, the revision rate for the ceramic femoral ball head group was significantly lower than the 46.2% revision rate for the metal femoral ball head group.

Zichner et al. [53] reported that the revision rate in hard-on-soft bearing couples after 10 years was five times higher with metal femoral ball heads than with ceramic femoral ball heads. In this study, the same THA systems using the same surgical technique were implanted. This result was supported in newer investigations by Kusaba et al. [22] and Dahl et al. [5].

In a prospective study, Dahl et al. [5] reported a significantly increased wear with metal femoral ball heads (CoCr, 28 mm) compared to ceramic femoral ball heads (alumina, BIOLOX®*forte*, 28 mm). The wear rates of the control group correlated with values from the literature. The linear wear rate of cemented polyethylene inserts which have been implanted together with ceramic femoral ball heads in 47 cases and with metal femoral ball heads in 40 cases has been investigated. All patients have been operated by one surgeon using the same surgery technique. Using radiostereometric analysis (RSA), it was observed that the linear wear in the group of the metal femoral ball heads was more than double compared to the linear wear in the group of the ceramic femoral ball heads (0.93 mm compared to 0.43 mm, $p=0.001$).

Descamps et al. [60] presented the 15-year results of a prospective, randomized study in which the wear rates of 37 alumina ceramic-on-polyethylene THA and 37 metal-on-polyethylene THA were compared. A 28 mm femoral ball head (BIOLOX® *forte*) was used. The wear rate for ceramic-on-polyethylene (0.058 mm/year linear, 35.7 mm^3/year volumetric) was significantly lower than those for metal-on-polyethylene (0.102 mm/year linear, 62.8 mm^3/year volumetric). This corresponds to a reduction in head penetration of 44%. Descamps concluded that these results are comparable to results obtained in earlier studies of ceramic-on-polyethylene and metal-on-polyethylene at a follow-up of more than 10 years.

The reported European experience with an alumina-on-alumina combination showed a mean wear rate of 0.025 μm/year and limited osteolysis up to 10 years after arthroplasty [61–63]. When comparing 28 bilateral arthroplasties (one alumina ceramic-on-ceramic and the contralateral alumina ceramic-on-polyethylene) at 20-year revision-free follow-up, Hernigou et al. [64] saw more wear and osteolysis in the ceramic-on-polyethylene hip than the ceramic-on-ceramic hip.

Toni et al. [48] has compiled data on 7005 CoCr bearing couples (BIOLOX®, BIOLOX®*forte*, BIOLOX®*delta*). During the period from 2006 to 2008, 686 ceramic-on-ceramic bearing couples (BIOLOX®*delta*) were implanted. The 17-year follow-up investigation of 147 patients treated consecutively with a 32 mm alumina ceramic-on-ceramic bearing couple between 1990 and 1991 revealed no cases of osteolysis, not even among those patients whose replacements showed increased wear as a result of suboptimal positioning. Toni suggested that these results support the claim that the use of ceramic-on-ceramic couples will help to minimize the risk of osteolysis. There were no cases of noise development or fracture. He called attention to the problem of false osteolysis positives, pointing out that it is necessary to first examine the preoperative X-rays to avoid mistaking older bone defects for cases of postoperative osteolysis.

Raman et al. [66] showed that the use of large femoral ball head diameters (36 mm, 40 mm) in ceramic-on-ceramic THA (BIOLOX®*delta*) can help to lower the risk for dislocation and secure a large range of motion. He also applies it to patients older than 60 with insufficient muscular stability. A total of 319 consecutive primary THAs in 302 patients with an average age of 65 (11–82) years were clinically and radiologically examined at a follow-up of 12 months. No dislocations and no cases of aseptic cup loosening were observed.

3.6.3
Asian Experience

Recently published clinical results from Asia show that modern ceramic-on-ceramic bearing couples have low risk of osteolysis and revision rates. This is especially valid for younger and more active patients, patients with a high incidence of previous hip surgeries and patients with dysplasia. Those patient groups are in general associated with an increased risk of complication and revision due to wear induced osteolysis and instability.

Kusaba et al. [22] described hip dysplasia as one of the most common indications for hip arthroplasty in Japan. Between July 1998 and October 2008, 1078 dysplastic hips were treated with a cementless alumina ceramic-on-ceramic bearing couple (BIOLOX®*forte*). 86 hips in 79 patients (mean age of 53 years) have been followed (completed follow-up time 5 years). No dislocations or revisions were observed.

In another study Kusaba et al. [23] analyzed the surface structure of 36 explanted metal femoral ball heads (CoCr, 32 mm, average 9 years in vivo) and 56 ceramic femoral ball heads (alumina, BIOLOX®*forte*, 32 mm, average 8.5 years in vivo). The linear wear rate per year of the polyethylene inserts were lower with the ceramic femoral ball heads (0.13 mm ± 0.05 mm) than with the metal ones (0.21 mm ± 0.09 mm). The polyethylene wear was directly related to the roughness (Ra) of the femoral ball heads ($p < 0.05$). The average Ra value of the ceramic femoral ball heads (0.011 µm ± 0.003) was lower than that of the metal femoral ball heads (0.032 µm ± 0.015). Here, the roughness of the explanted ceramic femoral ball heads was comparable to that of new metal femoral ball heads. The revision rates were significantly lower with the ceramic-on-polyethylene bearing couple than with the metal-on-polyethylene bearing couple.

Kim et al. [67] evaluated alumina ceramic-on-ceramic (BIOLOX®*forte*) in 93 consecutive cementless THA. The average age at the time of surgery was 38.2 (24–45) years. No ceramic fractures were seen. Radiographs and computerized tomographic scans demonstrated no acetabular or femoral osteolysis. The survival rate with aseptic loosening as the endpoint was 100% at 11.1 years.

In another study, Kim [68] reviewed clinical and radiological results of 601 hips with alumina ceramic-on-ceramic cementless THA in 471 patients with an average age of 52.7 years at the time of surgery. The mean follow-up was 8.8 (5–12) years. No THA required revision of any component for aseptic loosening. No ceramic fractures, acetabular or femoral osteolysis were observed. Kaplan-Meier survival analysis, with aseptic loosening as the endpoint for failure, revealed a 10-year rate of survival of 100% for the acetabular and femoral component.

3.6.4
Australian Experience

Walter [98] reviewed a large series of 2503 alumina ceramic-on-ceramic THA which was performed from July 1997 to September 2004. None of these hips has required revision for osteolysis. He reported that ceramic fracture has not been a major problem with one patient requiring revision due to fracture of a ceramic insert.

Lusty et al. [26] proved in a prospective study a survival rate of 99% after 7 years. In 283 patients (mean age of 58 years), 301 hips have been treated with alumina ceramic hard-on-hard bearings (BIOLOX®*forte*). All implantations were performed in one center with identical surgical methods and identical implants. 251 patients were followed-up clinically and radiologically. Nine revisions have been performed due to periprosthetic fractures, psoas tendinitis, and femoral shortening osteotomy. Using aseptic loosening and osteolysis as the endpoint, the survival rate was 99%. The explanted inserts exhibited a low volumetric wear of 0.2 mm^3.

Lusty concluded that these results are consistent with those in other studies of alumina ceramic-on-ceramic bearings.

3.7
Current Situation on Articulation Noise

The issue of noise generation by the components implanted in total hip replacements has recently received a great deal of attention.

There are several types of noises or sounds that can be emanated from the operated hip area. These noises can be transient particularly in the early rehabilitation period as the muscles and tissues around the implants heal. In addition, there are reports of longer lasting component generated noises such as squeaking. Noises are reported from all kinds of bearings [4, 19, 37, 44] even though they are more common in hard-on-hard bearings. The percentage of noises varies greatly, from 0.6% reported by Walter [50] up to 21% published by Keurentjes [20]. This is mainly due to the different definitions of the squeaking noise given by the authors. Restrepo [39] describes it as a “high-pitched noise” whereas in [20] different types of noises are summarized, defined as a reproducible sound of squeaking, clicking, or grating, as squeaking. Toni [47] described noises as being grinding sounds likely due to third particle wear. Therefore, it is important to differentiate between the types of noises that emanate from a hip in order to examine the responsible mechanisms. Additionally, to assess the main influencing factors of the different noise types may facilitate prevention and/or treatment.

A thorough review of the case studies presented in the literature reveal a variety of complications that could cause noise generation in the so-called squeaking hips. According to [50], the occurrence of squeaking was related to a very thick anterior capsule that folded into the joint gap causing slight subluxation of the bearing. Rosneck [41] reported the possibility of femoral head edge loading on the acetabular ceramic due to high cup inclination which is also the main reason given by Lusty [27]. Although this correlation is questioned in [39], careful investigation of the herewith published data reveals that almost all hips are placed far outside the so-called Lewinnek zone [24]. Back [1] suggested a disruption of the fluid film as being the reason for squeaking in metal-on-metal resurfacing. Morlock [29] reported on a mismatch of the bearing diameter as being the cause for squeaking, whereas Eickmann [12] found metal debris in a squeaking ceramic-on-ceramic bearing couple. As can be stated from the above, all the above mentioned factors imply a frictional cause for the squeaking. Ecker [11] states that in their study all squeaking cases of ceramic-on-ceramic bearings occurred with liners with an elevated titanium alloy rim and metal contamination of the bearing. According to the findings described there, squeaking is mainly due to the materials and designs of the hip implant system including stem and shell [40] as well as component placement.

3.8
Conclusion

Medium- and long-term clinical experience with ceramic hip implants clearly states a significant reduction of revisions due to wear-related osteolysis and its complications. The use of a ceramic-on-ceramic bearing is a safe and durable option in the young and active patient avoiding the concerns of active metal ions and osteolytic polyethylene debris. In hip endoprosthetics, the new ZTA ceramic (BIOLOX®*delta*) offers the possibility of using larger femoral ball heads (larger than 36 mm) and inserts with a thinner wall thickness.

Dislocation is the second-most reason for revision in hip arthroplasty [78]. Several authors report that the risk of impingement and dislocation has been strongly reduced due to the use of 32 mm and 36 mm articulation diameters in ceramic bearing couples [71–74]. No additional wear is produced compared to a 28 mm ceramic bearing couple. In revision endoprosthetics, a special ceramic femoral ball head system (BIOLOX®OPTION) made of the mentioned ZTA-ceramic (BIOLOX®*delta*) has been developed which consists of a thin-walled ceramic femoral ball head and a metal sleeve. This system provides a secure possibility of replacing a ceramic femoral ball head in a revision surgery without the need of replacing the stem. The ball head system offers a safe solution for the rare case of ceramic component fracture and expanded applications for primary surgery [95–97].

Ongoing studies will provide further evidence of long-term outcomes and patient activity levels for ZTA-ceramic (BIOLOX®*delta*) implants.

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