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REVIEW ARTICLE

Ceramic bearings fracture: a literature review on risk factors, diagnosis, and treatment

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Abstract

Ceramic surfaces are commonly used in total hip arthroplasty (THA) in young patients due to their good tribological properties. Nonetheless, the fracture of ceramic components is among the most demanding complications of total hip arthroplasty.

Ceramic failure is a matter of emergency and needs urgent revision arthroplasty. In this regard, the present study aimed to better understand how to diagnose a ceramic component fracture, identify the major risk factors for the fracture of ceramic components, and analyze the different techniques used in revision arthroplasty for ceramic bearing failure.

The literature search was performed on PubMed, MEDLINE-Ovid, and Cochrane Reviews. The search keywords included ceramic fracture, ceramic failure, and ceramic arthroplasty revision surgery. A number of 47 articles were selected out of 126 articles found in the initial research. X-ray and computed tomography (CT) scan must be utilized on suspicion of ceramic component fracture. The most relevant risk factor for head fracture is short neck and 28-mm head combination. Moreover, acetabular cup malpositioning and liner misalignment during insertion are the two major risk factors for liner fracture. There is no consensus on the best revision treatment strategy. Nonetheless, it is necessary to perform a complete synovectomy and an accurate cleaning of the hip joint before the implant of the new components. Stability, integrity, and positioning of both femoral and acetabular components must be evaluated during surgery. If damaged, even well-fixed components should be removed. New ceramic bearing surface is the best option, whereas metal is not recommended for revision surgery.

Key words: Arthroplasty, Ceramic fracture, Hip, Replacement

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Introduction

Ceramic-on-ceramic (CoC) total hip arthroplasty (THA) has gained popularity owing to its tribological advantages, as compared to other bearing materials. Excellent biocompatibility, minimal osteolysis, low wear rate, corrosion resistance, and favourable lubrification are its noteworthy features, especially for young and active patients with high functional request (1, 2). Ceramic bearings have the lowest rate of wear, osteolysis, and aseptic implant loosening (3), as compared to

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Metal on Metal (MOM) or Metal on Polietilene (MOP) bearings. In fact, ceramic wear particles are bioinert due to the minimum risk of ionization which results in periprosthetic osteolysis. Nevertheless, ceramic is characterized by high elastic modulus and high intrinsic brittleness that do not allow plastic deformation. Consequently, ceramic components are very prone to chipping and breakage (4). Ceramic Fracture is a catastrophic event which is nowadays the most important issue in CoC THA, followed by chipping on insertion and squeaking. Several causes have been identified for ceramic fracture, such as weight-bearing stress, component malpositioning, femoral neck impingement, manufacturing defects, and trauma (5-7).

The fracture rate for the first generation of ceramics, alumina oxide (Al2O3) introduced by Boutin in France (8) in the 1970s, was high with reported fractures rate of up to 13.4%. (9) A major accomplishments in ceramic evolution was the introduction of third-generation ceramics under the trade name of *Biolox forte*. The fracture rate which was reported for this type of ceramic was substantially lower, as compared to the previous ones but still not negligible. In order to achieve even higher mechanical load-bearing capability, increase crack resistance, and then reduce fracture rate, zirconium oxide was added to alumina oxide. This combination which is called *Biolox Delta* is the fourth-generation and has been proven to have twice the strength of *Biolox forte* and lower wear rate even under the adverse conditions of microseparation (10, 11). Furthermore, the fracture rate is reported to be as low as 0.002% (12, 13) although the phenomenon seems to be underestimated.

Ceramic failure is a matter of emergency and needs urgent revision arthroplasty; nonetheless, it assumes importance due to the high frequency of complications arising from this fracture (14). In fact, the dissemination of sharp ceramic fragments retained in the joint space leads to abrasive wear of femoral stem taper and acetabular cup which results in catastrophic wear and the failure of the implant.

With this background in mind, the present review aimed to better understand how to diagnose ceramic fractures, assess the risk factors, and analyze the different techniques used in revision arthroplasty for ceramic bearing failure.

Methods

PubMed, MEDLINE-Ovid, and Cochrane Reviews databases, and Google Scholar were used to perform our research. A number of 126 articles were found using ceramic fracture, ceramic failure, and ceramic arthroplasty revision surgery as search words. The quality of evidence was checked in terms of bias, methodology, and study limitations. Examination and discussion were performed among all the co-authors. On a final note, only 47 articles were identified as relevant and then included into the current review study.

Diagnosis

Clinical examination is the first step in the diagnosis of ceramic fractures. In the event of components displacement, patients typically report clicking or grating noises, tight and groin pain, as well as the impairment of hip function. In the case of non-displaced components, the patients are regarded as asymptomatic (15).

Hip synovial fluid microanalysis allows the early diagnose of ceramic fractures. Some studies have indicated that ceramic fragments larger then 5μm are strongly associated with the presence of liner fracture (15, 16). Hip joint aspiration must be performed under sterile conditions and using ultrasound guide. The measurement of particles is performed using electron microscopy which is often available only in referral centre.

Radiologic assessment is essential in the diagnostic flowchart. In the event of femoral head fractures, the displaced fragments are often easily detectable on standard radiographs, especially in comparison to the previous ones (17, 18). Ceramic liner fractures might be also visible on standard radiographs only in case of fragment dislocation. Sometimes liner fractures are not displaced and not detectable by standard radiographs (19, 20).

CT imaging is recommended when plain radiographs are not diagnostic or patients presented with pain and/or squeaking following CoC THA. CT scan is often performed to confirm a displaced fracture that was already detected by plain radiographs. Furthermore, acetabular version, malpositioned cups, and periprosthetic bone quality can be also evaluated. In the event of displaced fragments, CT imaging provides a precise estimation of fragment size and body position in order to plan a proper revision (15, 21).

Risk factors for ceramic head or liner fracture

Revision surgery for fractured ceramic components should be performed with great care to reduce the risk of ceramic failure. It is essential to ensure that no damage has occurred to articular

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surface during the insertion of the liner and line has been correctly placed into the acetabular cup. To prevent intraoperative damage to the taper, it is important to remove the protective cover immediately before femoral head insertion. Finally, to avoid damage to the articulating surface, extreme attention is needed during hip reduction.

The literature reported that ceramic fracture cases and rates often refer to alumina ceramic rather than alumina matrix composites, such as *Biolox Delta.* These resistant composites are more frequently employed these days, as compared to the past 10 years. Ceramic fractures, as previously mentioned, may involve ceramic head or liner more frequently alone than together.

Regarding ceramic head fractures, the most mentioned postoperative cause is trauma and its association with hip dislocation increases the risk of fracture. Nevertheless, spontaneous atraumatic fractures are not uncommon and mainly occur during normal daily activities (22-25). Other risk factors for ceramic head fractures include a high level of activity and obesity. Howard et al. reported a 2.3 times increased fracture ratio for 10 units in BMI (26); moreover, a study conducted by Migaud et al. demonstrated a direct correlation between obesity and ceramic head fracture (27). Among intraoperative causes of ceramic head fracture, the association between small femoral heads (28mm) and short neck size has been suggested in literature to be more related to fracture (4, 28, 29). Koo et al. found five head fractures, a 1.4 % fracture rate in 367 CoC THA using third-generation 28-mm heads in association with short neck size. The fracture involved the circumferential portion of the head near the edge of the head bore (30). In those cases, the head bore corner was very close to the outer ceramic head surface and the distance component was excessively limited, in comparison with the medium and long neck combinations promoting the propagation of fracture. A recent study performed by Lim et al. suggested the use of larger heads in association with longer neck size. They reported 98% survivorship of 301 patients treated with 32-mm ceramic heads, titanium sleeves, and variable neck length during a 9-year follow-up with only one reported case of head rupture (31). As evidenced by the available literature, the only confirmed risk factor associated with the ceramic head fracture is the use of 28-mm head and shorter neck for alumina ceramic. Future studies will better evaluate fracture risks factor even for *Biolox Delta* heads that are linked to a lower failure rate, as compared to previous ceramic products.

Ceramic liner fracture is not directly related to a major traumatic episode; however, it occurs more frequently during trivial movements, such as squatting, hyperflexion, or wide hip abduction; moreover, high BMI score and obesity seem to be also involved in liner fracture (32, 33). Ceramic liner fracture is often a sub-clinic event with a reported occurrence of less than 1% (34, 35). Even in this case, the failure rate with the introduction of newer ceramic materials should be better investigated.

Ceramic liner fracture mechanisms are distinct from those associated with ceramic head fractures the most common of which are thought to be component malposition, increased cup inclination, and impingement (7, 15, 34, 36).

Traina et al. assessed 26 cases of ceramic liner fractures in a case-control study and demonstrated that ceramic component ruptures were undoubtedly associated with cup malposition which is principally linked to excessive anteversion. CT scan revealed a greater number of cups placed outside the optimal range of cup anteversion (15˚+/-10˚) in the failure group in association with an audible noise in 80.7% of cases (36).

As previously demonstrated by Traina et al., YC Ha et al. observed five cases of liner fracture in 157 THA with a sandwich-type acetabular component which were all characterized by an excessive cup anteversion (7).

Sandwich-type liners in which a polyethylene layer is interposed between ceramic liner and metal back are not recommended. In fact, literature has clearly warned about the use of such hybrid devices due to the cyclic impingement between acetabular components and femoral neck (33, 37-39). This component association frequently induces head subluxation increasing the risk of liner fracture or liner dissociation due to the enhanced load on the liner edge rim (40).

Another suggested cause of ceramic liner rupture is misalignment during insertion and impaction that could lead to chipping and subsequent implant failure (34). Using a laboratory model, McAuley et al. proved that the risk of acetabular liner fracture would be higher if it was misaligned during impaction into the acetabular cup (41).

Treatment Strategy

Before surgery, non-weight-bearing and rest are mandatory for patients with ceramic fracture, physical activity. The maximum range of motion must be avoided in order to reduce ceramic particles spreading and limit the potential abrasive damage to the prosthetic components, such as femoral stem taper and acetabular liner.

Ceramic fracture revision surgery is considered an urgent procedure. Nowadays there is no

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consensus on the best strategy to address this problematic surgery, and it might be troublesome and associated with low results.

Literature has suggested that bulky fragments be removed from hip joint after an extensive surgical approach and pseudocapsulotomy. Moreover, an accurate synovectomy and plentiful irrigation of the articular space are necessary to reach hidden joint parts until the complete elimination of ceramic fragments (42, 43).

In fact, small sharp ceramic fragments could act as abrasive paste inside the hip joint wearing out the new articular components. Allain et al. observed that only 19% of patients required repeated revision, as compared to those who received partial synovectomy (14). Accordingly, they concluded that total synovectomy and irrigation are crucial surgical steps.

Extended trochanteric osteotomy is sometimes necessary to access the femoral stem if its revision is required. This procedure also improves the exposure of the acetabular components and helps to remove the retained ceramic fragments and achieve complete synovectomy. After joint cleaning, the integrity and stability of implant components must be checked. In fact, acetabular components positioning and orientation must be assessed. In most of the cases, at least one component may need to be altered and sometimes the surgeon should remove the well-fixed components.

There is no consensus on the implantation of a new ceramic head on a previously used femoral stem taper when the femoral stem is retained. It is especially due to the fact that a routinely explantation of well-fixed stems can be very laborious. During intraoperative inspection, it is crucial to assess any damage to the taper. Femoral stem revision is required in case of critical and extensive trunnion damage,whereas the explant and the consequent reimplantation of the femoral stem are not mandatory at the event of slight damages.

Before the introduction of alumina matrix products, the authors recommended stem revision in an effort to avoid the fracture of the new ceramic head due to fretting corrosion (44). Shortly thereafter, Hannouche et al. evaluated the results of revision surgery of fractured ceramic heads and found no fracture among 61 ceramic heads that were re-implanted on a non-revised titanium morse taper at a mean of a 6-year follow-up (45).

In case of tapers with minimal damage, the best current option is the use of an integrated titanium alloy sleeve (BIOLOX option) to cover the stem taper imperfections which create a flat surface where the new ceramic head is placed (43).

Literature concurs that acetabular component revision must be performed after ceramic liner fracture. In addition, modern explant systems allow for the safer removal of well-fixed acetabular components (low risk of massive transfusion, prolonged operation time, and damage to the remaining bone stock). Acetabular component revision must be accomplished if the locking mechanism is damaged or the component is deformed due to the risk of compromising the new liner placement. Ceramic liners rely on a morse taper; therefore, any damage to them, such as erosion, requires revision. Furthermore, in case of excessive anteversion or vertical positioning of the acetabular component, revision is the best choice to prevent impingement and/or hip dislocation which would compromise the new hip arthroplasty.

Choice of bearing surface

From a tribological viewpoint, CoC, followed by ceramic on polyethylene (CoP) bearings, represents the best treatment options after ceramic fracture. Despite its brittleness, the use of ceramic reduces the possibility of metallosis and third-body wear even if associated with ultra-high-molecular-weight polyethylene (UHMWPE) reducing the risk of osteolysis and consequent implant loosening (21, 46, 47).

The use of MoP bearings, especially in CoC revision surgery, is discouraged due to the high risk of metallosis and polyethylene wear. Traina reported neither osteolysis nor implant loosening during a 3.3-year follow-up in ceramic fractured THA that underwent CoC revision. On the other hand, all patients with MoP bearings showed radiographic signs of osteolysis due to polyethylene wear. Moreover, one out of eight patients needed a second time revision surgery due to polyethylene wear-related implant loosening (43).

Conclusions

Since ceramic fracture is a rare but catastrophic event, revision surgery is a matter of urgency that must be carried out at the earliest possible time. Based on available literature, short neck and 28-mm head combination is recognized as the most relevant risk factor for ceramic head fracture. On the other hand, acetabular cup malpositioning and liner misalignment during insertion are recognized as the two major risk factors for liner fracture. If the ceramic fracture is highly suspected, X-rays and CT scan are required to better characterize the integrity of the components and assess their positions and relationship.

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Revision THA for fractured ceramic bearings is a difficult operation with high rates of failure and repeat revision surgery. No consensus has been achieved on the best treatment strategy; nonetheless, extensive synovectomy and thorough irrigation are mandatory during revision surgery. Implant components, including integrity, stability, and orientation should always be checked. There still exist serious concerns over the revision of well-fixed implants, especially for femoral stem due to technical difficulties and potential damages to the remaining bone stock. In conclusion, CoC or CoP bearing components are both considered good options to reduce the risk of third body wear of revised implants, while MoP bearings should be avoided.

Limitations

Every study has some limitations which should be addressed in the paper. The main limitation of the current systematic literature search was the paucity of high quality studies. For instance, synovial fluid microanalysis was supported only by few studies. Risk factors for ceramic head or liner fracture have been extensively studied; however, the obtained results are scattered and a definitive conclusion may not be drawn. Furthermore, no evidence-based protocol has been published for revision after ceramic fracture.

Author's contribution

Alessandro Aprato was involved in the conception and design of the study and provided quality assurance on all study output. Alessandro Aprato and Glauco Loddo contributed to the conception and design of the study and drafted the manuscript. Stefano Giaretta, Paolo Di Benedetto, and Alessandro Massè collected articles and assisted in revising the manuscript. All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that they have no conflict of interest regarding the publication of this article.

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