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Failure analysis of sandwich-type ceramic-on-ceramic hip joints: A spectroscopic investigation into the role of the polyethylene shell component

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ABSTRACT

The mechanisms leading to systematic failure in modular acetabular components with a sandwich insertion (alumina/polyethylene/titanium) have been reconsidered in light of the newly collected Raman spectroscopic results. Raman assessments were conducted on the polyethylene shells, which belonged to a series of six failed sandwich implants with *in vivo* lifetimes ranging between 2 and 9 yr. With only one exception, all implants commonly showed dislodgment of the polyethylene shell during radiographic analyses prior to revision surgery. The polyethylene shell slipped out of the backing titanium shell, while always remaining integer to the ceramic liner. Four implants fractured at the ceramic liners, but their fractures occurred according to distinctly different patterns, which could be rationalized and classified. The insertion of the polyethylene layer, originally conceived to reduce the rigidity of the ceramic-on-ceramic bearing and to prevent impingement between the ceramic liner rim and the femoral neck, played a role in implant failure with its initial (asymmetric) thickness reduction due to creep deformation (eventually followed by cup rotation and backside wear). The results of the present spectroscopic investigation suggest that a simplistic failure classification of the sandwich-type implant as a "ceramic fracture failure" could be misleading and might represent a confounding factor in judging about the reliability of modern ceramic implants.

1. Introduction

Through the relatively long history of alumina ceramic-on-ceramic hip bearings, the cases of fracture reported with relatively high rates could systematically be associated to design failures (Tateiwa et al., 2008). French statistics from the early seventies (Hamadouche et al., 2002; Hannouche et al., 2003; Sedel, 2000) reported a 2% fracture rate for alumina-on-alumina implants due to an unreliable fixation method adopted on the cup side. In Germany, an early design with a skirted head mated with a bulky monoblock screw cup (i.e., also referred to as the Mittelmeier design) led to fracture incidences up to 0.8% (Cameron, 1991; Huo et al., 1996; Peiro, 1991) and was abandoned by the maker in 1991. More recently, in Japan, a high fracture incidence rate in alumina ceramic-on-ceramic implants has been found for a particular "sandwich" design, which included the insertion of an adaptive layer of ultra-high molecular weight polyethylene

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(UHMWPE) between the ceramic liner and the metal shell (Oonishi, 1992). In the period between 1998 and 2001 (after which the maker interrupted the supply), about 5500 implants using this hip system were replaced. Since then, several authors (Amino, 2002; Ha et al., 2006; Hasegawa et al., 2003; Kitajima and Hotokebuchi, 2003; Park et al., 2006; Suzuki, 2003) reported about catastrophic fractures at the alumina-bearing surface (ABS) of the implants from the cup side for the same sandwich-type hip implant. Owing to the phenomenological aspects of the described cases, all the failures of sandwich-type implants have commonly been referred to in the published literature as “ceramic failures” (Ha et al., 2006; Hasegawa et al., 2003; Park et al., 2006; Suzuki, 2003). Suzuki et al. (2003) mainly described problems of fracture and dislocation with the ceramic liner for the same implant studied in this paper (i.e., the ABS of the sandwich implant), while Amino (2002) reported on 5500 cases of ABS cup (January 1998–July 2000) with 16 fractures by January 2002. Kitajima and Hotokebuchi (2003) also reported more than 60 fractures by January 2003 for the ABS of the sandwich implant. These studies, reporting about a large percent of failures in sandwich-type hip implants, investigated the same implant object of the present investigation. Similarly, fractures of modular ceramic acetabular components with a sandwich polyethylene insertion (from a different maker) were recently also reported by German surgeons (Kircher et al., 2009).

While fracture of the ceramic liner component certainly represents the most evident and catastrophic phenomenon observed in a sandwich-type implant retrieved after failure, there are two important details suggesting that the actual origin of the implant failure might not necessarily reside in a poor structural behavior of the ceramic cup component. Despite the improved quality of recent ceramic implants as compared to their previous generations, it is obviously impossible to completely eliminate the risk of fracture in brittle ceramic components such as hip heads and liners. However, thoroughly compiled data reviews (excluding sandwich-type implants) indeed show that the fracture rate of third-generation alumina-bearing couples occurs at extremely low levels (Kircher et al., 2009; Tateiwa et al., 2008). On the other hand, ceramic cups usually possess by far more load-bearing capacity than the mating ceramic heads, not only because cups are mainly loaded in compression but also because, unlike balls that necessarily contain taper edges, the cup morphology can be accurately designed in order to conspicuously avoid stress intensification. Accordingly, among the sporadic events of fracture reported in the literature (Krikler, 1997; Maccauro and Piconi, 2000; McLean et al., 2002; Piconi et al., 1999; Pulliam and Trousdale, 1997; Suzuki, 2003), a large majority of cases are concerned with fractured ceramic heads rather than with ceramic liners. It follows that, if the poor strength (or brittleness) of alumina ceramic would actually have been the main cause of failure in sandwich-type implants, one could hardly explain why fracture systematically occurred on the less-stressed liner side, as reported in the majority of sandwich-type failures (Hasegawa et al., 2003; Amino, 2002), instead of hitting the most stressed regions at the corners of the head taper, which is made of the same material.

The so-called sandwich cup configuration, with its ceramic liner locked into an adaptive layer of polyethylene, was originally conceived in order to reduce the rigidity of the ceramic-on-ceramic coupling and to prevent impingement between the rim of the ceramic liner and the metal neck of the femoral stem. Various surgeons, who reported about the sandwich implant failures, observed that the liner had rotated during gait by about 90° inside the metal shell and the ball head has been displaced in superolateral direction (Hasegawa et al., 2003; Yamamoto et al., 2004). The ball head eventually entered into contact with the metal shell in the superolateral area and in a number of cases the ceramic liner fractured. In one case, fracture and fragmentation of the ceramic cup were reported (Hasegawa et al., 2003), while in another report the liner was found yet unfractured despite the implant having undergone liner rotation (Yamamoto et al., 2004). In reviewing the published literature, one might intuitively feel consensus toward authors hinting that the fault of sandwich implant failure arises from brittleness of the ceramic components (Ha et al., 2006; Park et al., 2006). The squatting attitude of Asian patients was also suggested as becoming an exacerbating factor in the fracture process (Ha et al., 2006). However, a clear and final explanation of the implant failure mechanism(s) is still missing in the literature.

We revisit here several cases of sandwich-type implant failure by focusing on the specific role played by the polyethylene shell component in the overall process of implant failure. Our opinion is that the published descriptions of ceramic liner fracture in sandwich-type implants are indeed phenomenologically correct. However, we shall also attempt to provide some clear experimental proofs supporting the thesis that the structural inadequacy of the alumina components was not the principal factor originating failure in

Table 1 – Clinical details of the six cases of sandwich-type implant failure examined in this study.

Case	Gender	Follow-up	Cause	Pristine PE thickness [μm]	Side	Inclination [deg.]	Anteversion [deg.]
I	Female	4 yr 8 months	Dislodgement fracture	3000	Left	42	−5
II	Female	9 yr 3 months	Dislodgement	5000	Right	43	16
III	Female	9 yr 8 months	Dislodgement	5000	Right	50	24
IV	Female	2 yr 11 months	No-dislodgement destruction	2000	Left	59	41
V	Female	4 yr 11 months	Dislodgement fracture	2000	right	45	25
VI	Female	9 yr	Dislodgement fracture	3000	left	51	51