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# Retrospective lifetime estimation of failed and explanted diamond-like carbon coated hip joint balls

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ABSTRACT

Diamond-like carbon (DLC) coatings are known to have extremely low wear in many technical applications. The application of DLC as a coating has aimed at lowering wear and to preventing wear particle-induced osteolysis in artificial hip joints. In a medical study femoral heads coated with diamond-like amorphous carbon, a subgroup of DLC, articulating against polyethylene cups were implanted between 1993 and 1995. Within 8.5 years about half of the hip joints had to be revised due to aseptic loosening. The explanted femoral heads showed many spots of local coating delamination. Several of these explanted coated TiAlV femoral heads have been analyzed to investigate the reason for this failure. Raman analysis and X-ray photoelectron spectroscopy (XPS) depth profiling showed that the coating consists of diamond-like amorphous carbon, several Si-doped layers and an adhesion-promoting Si interlayer. Focused ion beam (FIB) transverse cuts revealed that the delamination of the coatings is caused by in vivo corrosion of the Si interlayer. Using a delamination test set-up dissolution of the silicon adhesion-promoting interlayer at a speed of more than 100 μm $year^{-1}$ was measured in vitro in solutions containing proteins. Although proteins are not directly involved in the corrosion reactions, they can block existing small cracks and crevices under the coating, hindering the exchange of liquid. This results in a build-up of crevice corrosion conditions in the crack, causing a slow dissolution of the Si interlayer.


## 1. Introduction

Aseptic loosening of load bearing articulating hip joints due to particle generation, one of the major complications in total hip arthroplasty, may be reduced by using diamond-like carbon (DLC) coatings. DLC coatings are biocompatible and provide excellent low wear properties in many different tribological applications [1]. Additionally, different tribological experiments on DLC sliding against polyethylene (PE) have shown very promising results. These promising low wear values were mainly obtained when testing was carried out in water or NaCl solution. Later it became apparent that when tested in a joint simulator using serum as the lubricant no large reduction in wear of the PE counterpart could be obtained. Details of these studies can be found in two review articles published in 2003 and 2007 [2,3]. Due to these low wear results for DLC and diamond-like amorphous carbon sliding against PE, mainly published towards the end of the last century, attempts have been made to use the superior low wear properties of DLC in medical applications on articulating joints. While DLC includes an abundance of different hard carbon-based coatings, the expression diamond-like amorphous carbon describes a subgroup of amorphous carbon-based coatings. Over the period 1993–1995 a series of diamond-like amorphous carbon-coated TiAlV femoral hip joint heads, articulating against PE counterparts were implanted. In a clinical follow-up study, the coated implants showed only a 54% survival rate after 8.5 years. The surfaces of the explanted diamond-like amorphous carbon-coated heads showed damage, including numerous pits and delamination of the coatings, which caused excessive wear of the PE counterpart. For comparison, 101 hip joint prostheses consisting of ceramic alumina femoral heads articulating against PE cups were implanted by the same surgeon. After 8.5 years the implant survival rate for patients with the uncoated ceramic heads was 88.2%. Both type of implants were based on the same type of cementless hip joint prosthesis. All patient details, such as age distribution, body weight, and gender, as well as the different indications for revision, can be found in the medical follow-up study published in 2003 by Taeger et al. [4].

Some of this local delamination on a diamond-like amorphous carbon-coated and explanted hip joint head are displayed in

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