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Wear tests in a hip joint simulator of different CoCrMo counterfaces on UHMWPE

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ABSTRACT

The objective in this work was to study the effect of different material counterfaces on the Ultra High Molecular Weight Polyethylene (UHMWPE) wear behavior. The materials used as counterfaces were based on CoCrMo: forged with hand polished and mass finished, CoCrMo coating applied on the forged CoCrMo alloy obtained by Physical Vapour Deposition (PVD). A hip joint simulator was designed and built for these studies. The worn surfaces were observed by optical and scanning electron microscopy. The results showed that the hand polished CoCrMo alloy caused the higher UHMWPE wear of the acetabular cups. The CoCrMo coating caused the least UHMWPE wear, while the mass finished CoCrMo alloy caused an intermediate UHMWPE wear. It is shown that the wear rates obtained in this work are closer to clinical studies than to similar hip joints simulator studies.

1. Introduction

When the natural joint has to be replacing with artificial materials, there is a change in the tribological situation due to the inability of the actual materials used to produce an artificial permanent lubricating film. Therefore, the materials used to articulating components in an artificial joint are always subject to wear. Furthermore, there is no ideal bearing material currently fulfils all the requirement of total joint replacement design. Nowadays, the penetration rates of the femoral heads into the acetabular cups are so low that there should not be any problem associated with the design or functionality of the implant. However, the wear particles, especially from UHMWPE debris, cause osteolysis due to a particle-initiated foreign body reaction (leading to aseptic loosening of the stem or acetabular cup) and finally make a revision operation necessary [1,2].

Joint simulators were developed for predicting the in vivo wear rates of total joint replacements by means of laboratory tests. In these tests the motion, load, lubrication, environment and geometries of the articulation are more similar to those found clinically than in screening wear test devices [3,4]. The objective of this work was to study the effect of different material counterfaces on the UHMWPE wear behavior by means of a hip joint simulator (HJS).

2. Materials and methods

The HJS used in this study is a three-station machine that operates with a type of motion termed biaxial rocking motion (BRM). As a simulator device, the geometric configuration of the components resembles exactly those of the hip joint replacements. The acetabular components (cups) and the femoral components (heads) are mounted in the so-called anatomical position [1–3] that is, with the cups sliding over the heads, as is the case of the natural joint. Fig. 1 shows a schematic representation of the HJS motion/loading configuration.

In the HJS, a biaxial rocking motion is applied to the femoral heads via a rotating inclined block (angle of inclination of ±23°) mounted below the femoral head. The BRM provides a practical-engineering implementation of the walking cycle *in vitro*. The BRM includes flexion-extension and abduction–adduction motion, both with a sinusoidal excursion of ±23° but with a phase difference of $\pi/2$. The excursion of the abduction–adduction motion is four times higher than the true abduction–adduction motion of the human hip joint when walking. Thus, BRM provides exaggerated walking kinematics. However, the HJS has been designed to provide a practical imitation of the motions and loads seen by the hip joint during a typical walking cycle [4–6].

In the HJS, the motion can be synchronized to physiological loading profiles [7–10] describing a double-peak load waveform, that results in a closer reproduction of the true dynamic load of the hip joint when walking, as performed by Mejia [1], Wang [5] and Clarke [3]. However, Saikko [4] has used constant load, hypothesizing that since the BRM is not a close reproduction of the true situation the load need not be, either. The constant load applied (1000 N) corresponds to the average load of the Paul load cycle [2]. The tests in the following described were also performed under a constant load, based on the results by Saikko [4], which addressed the possibility that static load in conjunction with BRM can be sufficient to produce realistic wear simulation for UHMWPE in hip joint replacements [11–14]. Additionally, static or constant load simplifies the wear test device as well as the method. All the before mentioned studies involving BRM joint simulators have been proven as a realistic and practical wear test method.

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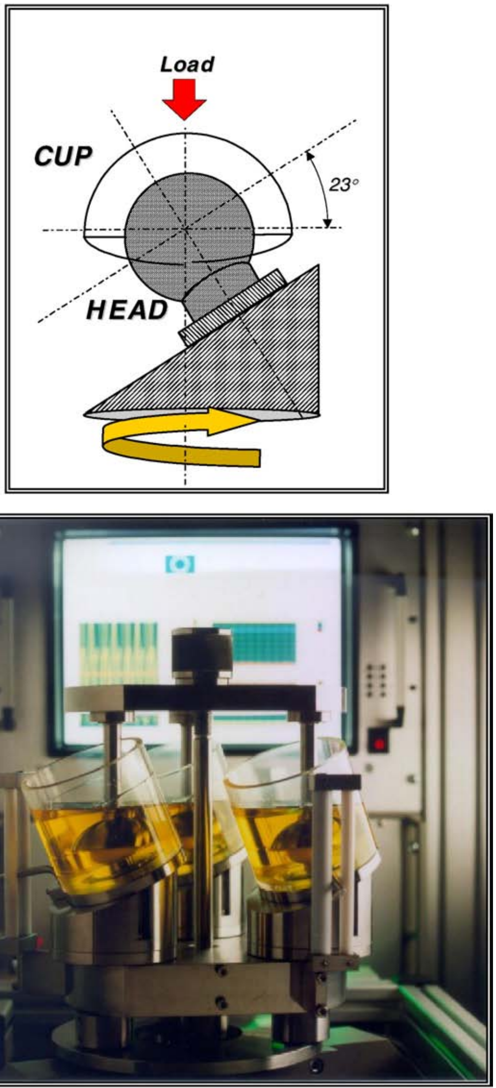

Fig. 1. Motion/loading configuration of the HJS wear test machine.

The tests on the HJS wear machine were performed as follows. The acetabular cups were mounted on a home-made metal back support to transmit the load to each of the three stations. The cups were then pressed against the femoral heads. While the cups remain static, the heads slide according to the biaxial rocking motion. A constant load of 1000 N (102 kg) per station was applied during the test. The frequency of the motion was 1.23 Hz (810 ms/cycle) [18–20]. In the HJS a cycle is considered as completion of one rotation of the head. The wear of the UHMWPE cups was determined by weight loss measurements every 333,333 cycles up to a total test length of 3 million cycles. The test lubricant was replaced with fresh solution after every weighing stop and distilled water was added during the test for compensating water evaporation. Each station has an environmental test chamber made of a transparent polycarbonate wall. Each chamber was filled with 350 ml of lubricant. As test lubricant, a solution consisting of bovine serum and distilled water was used with a total protein concentration of 30 mg/ml. The lubricant includes sodium azide (0.1 mg/l) as antibacterial agent. The serum was purchased at Sigma-Aldrich SrI (Calf serum, bovine donor; product No. C9676). The soak adsorption of the UHMWPE cups was determined using an additional control cup. The cleaning and drying of the UHMWPE cups were performed according to the ASTM 1715 standard. Weighing was carried out with a Mettler Toledo AT261DeltaRange® microbalance with an accuracy of ±10 μg.

Table 1
Chemical composition of the forged CoCrMo alloy (%)

Element	Cr	Mo	Mn	Ni	Si	Fe	C	N
Balance	26–30	5–7	max 1	max 1	max 1	max 0.7	max 0.35	max 0.25

Table 2
Roughness and hardness of each material tested

Material	Roughness Ra (μm)	Hardness (HVN)
Hand polished	0.03 ± 0.01	673 ± 21
Mass finished	0.05 ± 0.01	840 ± 62
CoCrMo coating	0.10 ± 0.01	884 ± 28

All specimens were observed in an optical microscope Olympus and a JEOL 6400 scanning electron microscope at an electron beam voltage of 20 kV. This equipment has a microanalysis EDS.

Acetabular cups made of UHMWPE GUR1020 and previously sterilized with 25 KGy (2.5 Mrad) gamma radiation were used. The cups were supplied by SAMO S.p.A. The density was 0.9737 g/cm^3. The cups are designed to be used with a metal back component and in conjunction with 28 mm femoral heads. The articulating counterfaces were therefore 28 mm femoral heads. Three different femoral head materials were studied; listed below the standard material in this study was a hot-forged CoCrMo alloy. Table 1 shows the chemical composition of this material.

The microhardness was made on the 18 samples obtaining 10 measurements in each sample. A Leitz Miniload 2 instrument was used applying a 490.3 mN load on a pyramidal diamond indenter. The surface roughness measurements were made using a profilometer (Mitutoyo Surftest SV-512; Mitutoyo, IL, USA) with a 5 nm resolution and assisted with appropriate software (Surfpack, v 3.0, Mitutoyo, Japan). Before evaluation, a Gaussian filter was used to remove errors of form and waviness. For each specimen five different lengths (sampling length 0.8 mm, and transversing length 2.5 mm) were analyzed following the ISO/JIS B0601. Ra was used to give a numerical characterization of the surface roughness. Ra is the arithmetical mean deviation of the profile and is calculated as the arithmetical mean of the absolute values of the profile deviations from the mean line. Table 2 the hardness and roughness of each material.

- CoCrMo forged (hand polished)
- CoCrMo forged (mass finished)

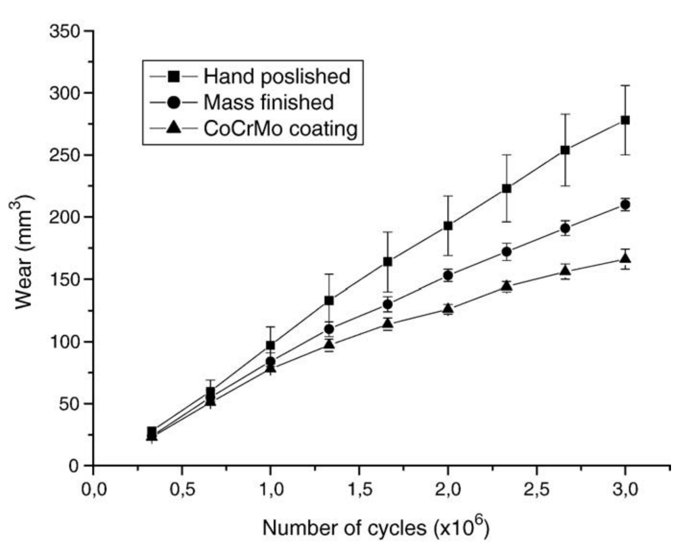

Fig. 2. Average wear losses of the UHMWPE cups in the HJS wear tests.