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Tribological Analysis of 3D Printed Small Joint Replacements

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Additive manufacturing seems to be a promising way to produce customized small human joint implants with good biocompatibility and with longevity that can compete with conventionally machined parts. Titanium alloy printed by the Selective Laser Melting technology coated with a diamond like carbon (DLC) layer was investigated using a pin on plate apparatus and the results were compared with the conventionally machined CoCrMo material. The surface durability of the machined CoCrMo pins and the 3D printed Ti6Al4V coated with DLC pins was assessed using coefficient of friction (CoF) measurements. Model synovial fluid lubricant was observed in the contact area for both types of the pins. Behavior of two lubricant proteins, albumin and γ-globuline was studied using the fluorescent microscopy.

Keywords: tribology, 3D print, friction, small joint, film formation

1. Introduction

The first metatarsophalangeal joint (MTP) is a crucial joint of the human forefoot during gait. It plays an important role in human stability and it can be subject to number of diseases leading to its replacement with an artificial joint. The small size of the joint and the complexity of its shape open the possibility to use the additive technology of metal printing to produce the joint implants with minimum number of components. Tribological assessment of the articulating surfaces can help to evaluate the longevity of such implants. The aim of this study is to analyse the CoF, wear and film formation in the contact area between the pin and the plate [1].

2. Materials and Methods

The machined CoCrMo on polyethylene is a convenient material used for articulating surfaces in small implants as it reports low friction and low wear. However, titanium alloy (Ti6Al4V) seems to be a more promising material due to its biocompatibility and due to possibility to print an osteointegrative porous structures that are suitable for non-cemented implants. As the number of particles released from titanium is higher than those released from CoCrMo, the machined Ti6Al4V articulating surface was coated with a DCL layer. The contact area of the CoCrMo and Ti6Al4V against an ultra-high molecular weight polyethylene and against a transparent polymethyl methacrylate (PMMA) was investigated under conditions simulating the MTP joint. The geometry was tested in a pin on plate configuration with reciprocating motion.

Table 1: Material properties and measurement conditions

	Pin		Plate	
Materials	CoCrMo	Ti6Al4V	UHMW PE	PMMA
Young's modulus	230 GPa	114 GPa	0.8 GPa	3.35 GPa
Poisson's ratio	0.28	0.34	0.46	0.36
Contact pressure	9 – 35 MPa			
Lubricant	Model synovial fluid (Albumine, γ-globuline, Hyaluronic acid and Phospholipids)			
Velocity	10 mm/s			
Total distance	1200 mm			

3. Results

An analysis of the friction for CoCrMo and Ti6Al4V coated with DLC pin articulating against the UHMWPE was developed.

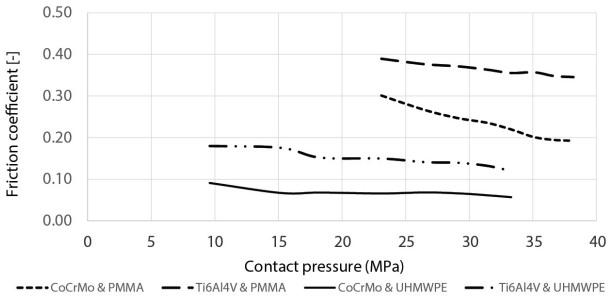

Figure 1: CoF analysis for articulating materials.

4. Discussion

Observation of the tribological properties for the MTP implants led to several conclusions. The CoF was higher for the printed titanium alloy material with the DLC coating. The surface analysis showed a porous structure with roughness up to 50 nm of the DLC layer what played an important role in the lubrication film formation and affected the protein aggregation in the contact area. The manufactured CoCrMo pin showed roughness under 20 nm and a lower friction. There were also differences between the load levels. However, no polyethylene transfer to the counterface occurred, indicating that the boundary lubrication with proteins was active. The protein aggregation in the contact area was observed using the fluorescent microscopy under the conditions adjusted to the transparent articulating material. These results will help us to evaluate the durability of the 3D printed surfaces for purposes of the small joint arthroplasty and help us to improve the design of the articulating parts.

5. References

[1] T.J. Joyce, Calculation of theoretical lubrication regimes in two-piece first metatarsophalangeal prostheses, Bio-Medical Materials & Engineering 18(1) (2008) 45-51.