Chemical Mechanical Polishing Implementation on Dental Implants

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***Abstract*-These instructions give you basic guidelines for preparing papers for conference proceedings. In this study, Chemical Mechanical Polishing (CMP) technique is introduced as a new alternative to generate controlled nano/micro scale roughness on the titanium implant surfaces. It is known that micro scale patterns induced on biomaterial surfaces promote bio-compatibility by increasing the capability of cell attachment. However, current developments on biomaterials highlight the impact of nano-scale roughness in promoting the biocompatibility on the metallic implant surfaces. CMP process brings the advantage of inducing smoothness or controlled nano-structures on the bio-implant material surfaces. Here, we focus particularly on the dental implant applications to change the surface roughness and the resulting bioactivity in a control manner.**
Keywords: CMP, Titanium dental implants, biomaterials

I. INTRODUCTION

Surface properties of metallic implants play an important role in their biocompatibility and therefore, various surface treatment approaches have been employed to tune the surface texture, energy and chemistry of implants at atomic level. Among the various surface treatments, chemical mechanical polishing (CMP) is introduced here as a promising technique to synergistically promote corrosion resistance and biocompatibility of the dental implant materials. In CMP process, the top surface of the titanium metal is exposed to the chemicals in the polishing slurry. This interaction forms a chemically altered top film that is removed by the mechanical action of the slurry abrasive particles. The chemically altered top film has to be a protective oxide to enable planarization by stopping chemical corrosion on the recessed metal surfaces while the elevated structures are polished [1]. It has been suggested by an earlier study that the application of CMP on Ti films can create a continuous titanium oxide film on the surface that has the potential in promoting bioactivity [2]. Furthermore, alteration of the surface topographical structure and chemical composition on the titanium implant samples has been shown to influence cell orientation through surfaces guidance at the contact [3]. These enhancements in the surface properties such as the oxidation of Ti surface, surface structuring, as well the use of biomimetic hydroxyapatite coatings have been shown to help improve biocompatibility in the literature [4, 5].

The present study focuses on the implementation of CMP process to induce nano-smoothness and controlled nano/micro-roughness on the titanium dental implant surfaces. We have demonstrated earlier on the titanium plates that through inducing nano and micro patterns by CMP the cell growth capability of the titanium implants can be altered [6,7,8]. Our purpose in this paper is to create engineered Ti based bio implants with self-protective oxide surfaces to minimize chemical and bacterial reactivity, while promoting their biocompatibility through surface enhancing at a 3-dimensional application.

II. EXPERIMENTAL DETAILS

CMP and analyses were conducted on titanium foils with 1 mm thickness and 99.6% purity (TI000430) obtained from Goodfellow Cambridge Limited. The original sample surface considered as baseline for the experimentation was annealed. In order to compare to the properties of the original surface against the surfaces prepared through CMP, polishing was conducted by using a desktop Tegrapol- 31 polisher and 5% weight alumina (Al_2O_3) slurry with 50nm particle size. CMP tests were conducted at 70 N down force which is equivalent to a 7.88 psi pressure on the used sample size. Initial samples were polished using a Suba IV subpad stacked under a polytex buff pad to obtain a very smooth surface. In addition, two sizes of sand paper (silicon carbide 150C and P320) were used in place of the polishing pad to create the micro structures through CMP. All CMP testing except for the first sample were conducted by using H_2O_2 as oxidizer. Samples that were ran with the polymeric CMP pads and abrasive papers were polished for 2 minutes with ~3% oxidizer addition to promote chemical activity. Material removal rates were calculated through weighing the samples pre and post polish by a high precision balance.

In order to adopt the CMP at 3D level, the same experimental conditions were followed for titanium dental implant samples obtained from Mode Medical Limited. These commercial dental implants have different surface finishing implemented as machined surfaces as shown in Fig. 1.

Fig. 1. Machined implant surface microscopic images(x100)

Fig. 2. 3D CMP design with robotic arm and general 2DCMP tool with implant that holding on different polymeric pad.

These implants were processed with CMP as detailed above with the suggested appropriate process that design and tools given at the Fig.2 and compared to etch through dipping in H_2O_2 at various concentrations. Material removal rates were calculated through weighing the samples pre and post polish and weight difference divided to total volume of the corresponding implant sample.

All the implant samples were characterized for wettability through contact angle measurements with simulated body fluid (SBF) by using a KSV ATTENSION Theta Lite Optic Contact Angle Goniometer using the sessile drop method. Five drops were measured on each sample. The drop image was stored by a camera and an image analysis system calculated the contact angle (Θ) from the shape of the drop. The microstructures of specimens were examined using a Nanomagnetics Atomic Force Microscope (AFM) with contact mode and the surface roughness values were recorded on 10 x10 μm scan area.

Biocompatibility of the CMP conditions applied Ti plate samples evaluated via cell attachment test and L929 fibroblast cells used for the proliferation of soft tissue cells on the sample.

III. DISCUSSION

Fig. 3 illustrates the CMP results obtained on the titanium plates after the implementation of CMP with four different conditions in addition to the baseline. It can be seen that the material removal rates on the samples polished on the polymeric pads were low and particularly the CMP test conducted without an oxidizer resulted in negligible material removal rates. On the other hand, the use of the abrasive papers increased the removal rates significantly. Contact angle values reflecting on the wettability of the surfaces and hence signaling on the biocompatibility of the samples were also detected to be different. The high contact angle value on the untreated sample can be attributed to the different nature of the baseline sample surface since the original sample was anodized creating a very porous and thick oxide layer. On the CMP induced samples, however, the contact angles increased

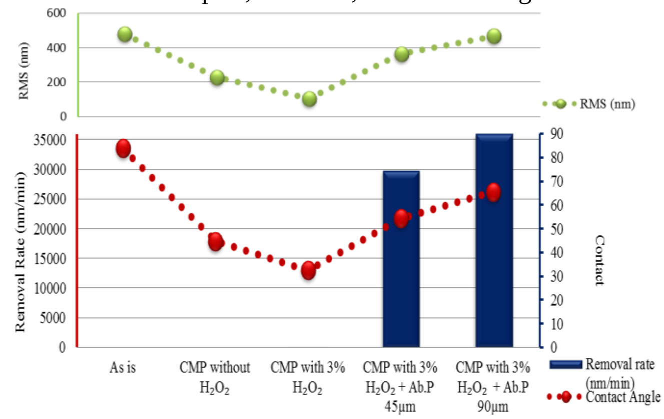

Fig. 3.Wettability, removal rate and RMS results as a function of applied CMP conditions on Ti plate surface

as the surface roughness was increased through induced roughness level. It was also observed that the removal of the surface oxide layer of the original sample by only using DI-water during CMP also changed the contact angle which can be explained based on the fact that the surface energy of the freshly exposed titanium metal is higher leading to elevated wettability response on the surface.

The same experimental conditions were also applied to 3-D dental implant samples. Fig. 4 shows the wettability and removal rate evaluations on the dental implant samples with machined surfaces as a function of applied CMP conditions. Surfaces with an expected smoother finish, such as in the case of CMP application in the presence of oxidizer resulted in higher wettability and hence a lower contact angle while the surfaces with the induced micro roughness resulted in a higher contact angle. In order to evaluate the effect of the oxide formation on the wettability response, the samples were also dipped into the oxidizer solution without CMP implementation for the implant surfaces which were prepared by only machining surface treatment and wettability results given at the Table I.

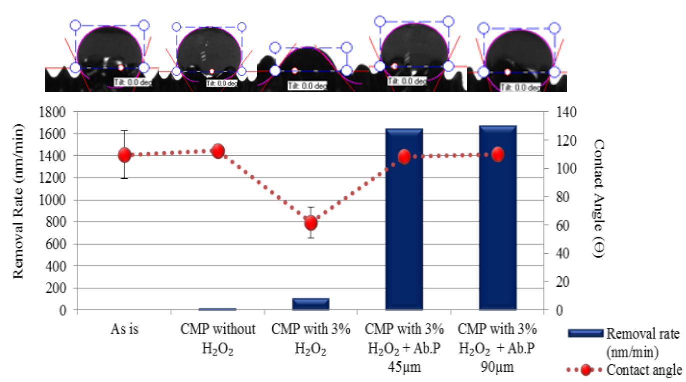

Fig. 4. Wettability and removal rate results as a function of applied CMP conditions on machined Ti dental implant with contact angle droplet image above respectively.

TABLE I
Wettability and Removal rate results as a function of applied CMP conditions on machined surface Ti dental implant

Samples Conditions	Removal Rate (nm/min)	Contact Angle (Θ)
1-Baseline	0	83.99
2-Dipping 3% H_2O_2	103.90	62.19
3-Dipping 30% H_2O_2	181.82	66.08
4-CMP with 3% H_2O_2	251.08	very low*
5- CMP with 3% H_2O_2 + Dipping 3% H_2O_2	303.03	32.88
6- CMP with 3% H_2O_2 + Dipping 30% H_2O_2	363.64	64.03

*Altered surface has very hydrophilic surface properties that water based droplet slipped over the surface immediately, that did not permit the take contact angle measurement on the surface.

In the presence of oxidizer applied CMP sample showed highest wettability performance against to the other samples. Dipping into the oxidizer also increased the wettability properties of surface but there is a reverse correlation between the concentration of the oxidizer and wettability. Furthermore in the presence of oxidizer CMP applied samples also dipped into the oxidizer solution and similar result obtained. CMP reduced surface contact angle value and with the increased oxidizer concentration the wettability performance increased.
Altered surface properties desired to show good biocompatibility and to evaluate that cell attachment test were applied to Ti plates which given at Fig. 5.

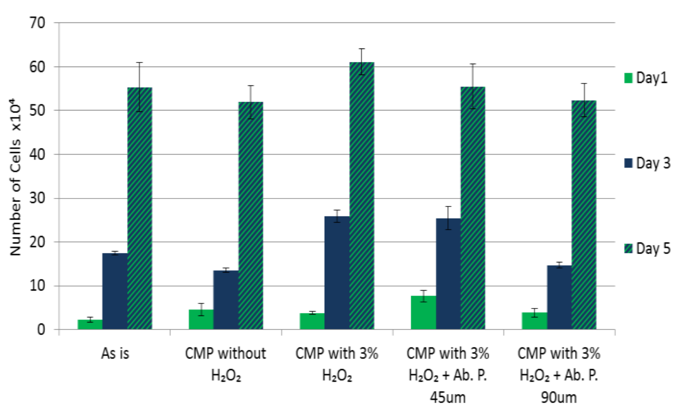

Fig. 4. Cell attachment test on CMP applied Ti plates with L929 fibroblast cell with evaluation time as 1,3 and 7 day.

In the presence of oxidizer CMP applied samples showed highest cell attachment amount during the test period. But increased surface roughness decreased linearly cell attachment capability of the surface.

IV. Conclusion

It is known that the increased surface microstructure and surface oxidation can promote the adhesion of the biological species on the implant surfaces. In this study, CMP process is proposed as an alternative technique to induce microstructure or smoothness to the titanium surfaces to enable more biocompatible surfaces by simultaneously forming a protective oxide layer. Wettability analyses through contact angle measurements were shown to be a valid and easy approach to detect the surface roughness that affects surface properties.
Biocompatibility test also showed us that the oxidizer used samples have a better cell attachment and CMP process enable to control of surface roughness. 3-D Dental implant samples will be evaluated with cell attachment test as a part of this study.

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