Surface characteristics of surface-engineered titanium implants: Surface chemistry, morphology, pore configuration, oxide thickness, crystal structure and roughness

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Purpose: Detailed surface characterization is a scientific base in order to advance our understanding of interfacial phenomena between the implant surface and tissue but also to develop the next generation of implant. The purpose of the present study was to characterize the surface properties of surface-engineered titanium implants

Materials and Methods: Screw-shaped titanium implants were divided into three groups accordingly the surface engineered methods: electrochemically oxidized Mg-incorporated implants (3.75 × 7 mm) in a mixture of magnesium-containing electrolytes, electrochemically oxidized TiUnite® (3.75 × 7 mm, Nobel Biocare, Göteborg, Sweden) in a mixture of phosphoric acid and sulfuric acid and a dual acid etched Osseotite® (3.75 × 8.5 mm, Implant Innovation, FL, USA) in HCl and H_2SO_4. Surface oxide properties of implants such as surface chemistry, oxide thickness, morphology/pore characteristics, crystal structures and roughness were characterized with various surface analytic techniques, involving X-ray Photoelectron Spectroscopy (XPS), Scanning Electron Microscopy (SEM) equipped with energy-dispersive spectrometer (EDS), X-ray diffractometry (XRD) and Optical Interferometry. Surface chemistry was more intensively investigated at as-received surfaces and Ar ions etched surfaces of screw implants since surface chemistry is known to play key roles for enhancement of osseointegration of titanium implants.[1-3]

Results/Discussion: *The surface chemistry* showed similar fingerprints of titanium oxide and contaminant C for all implants, but also revealed essential differences of the elements incorporated in the surface oxide layer such as about 9 at% Mg for the Mg implant, 11 at% P for TiUnite and about 12 at% Na for Osseotite. (Fig1-2, Table 1)

Figure 1

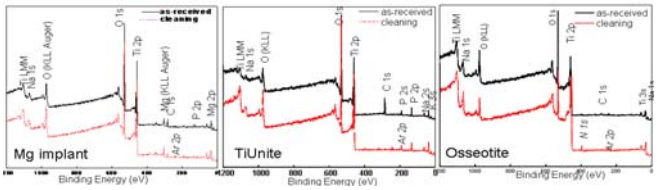


Figure 2

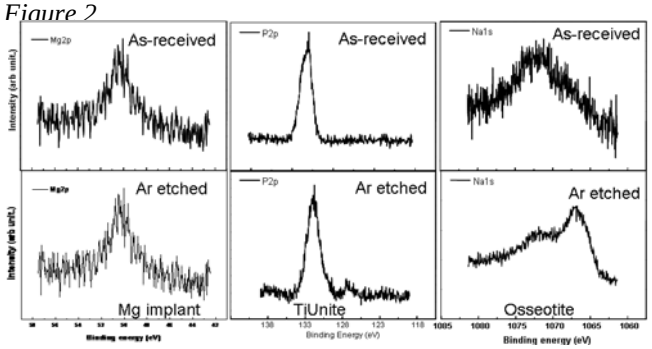


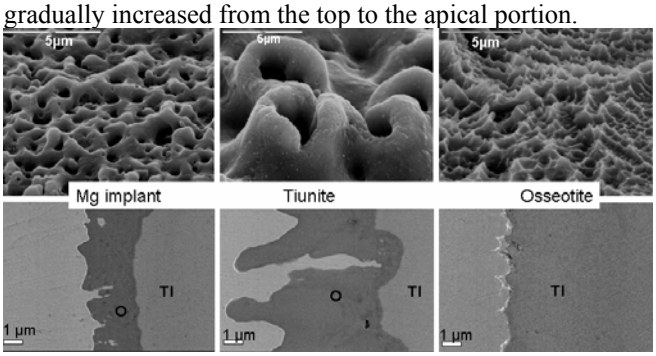
Table 1

Element composition	Mg implant As-received[1]	Mg implant After-cleaning[2]	Tiunite As-received[1]	Tiunite After-cleaning[2]	Osseotite As-received[1]	Osseotite After-cleaning[2]
Ti 2p	18.8	21.1	13.0	22.0	15.6	36.7
O 1s	53.4	57.3	50.5	56.4	48.4	40.7
C 1s	15.2	3.0	24.3	2.1	34.2	3.7
Mg 2p	7.6	9.3	-	-	-	-
P 2p	2.3	2.7	9.7	10.9	-	-
Na 1s	1	3	0.5	3.8	0.7	11.8
N 1s	0.5	0.5	0.6	1.5	1.0	4.8
S 1s	1.0	0.8	1.2	1	trace	trace
Ar		2.0		2.1		2.1

[1]the figures were given as detected at as-received surface
[2]the figures were given after 150 seconds of Ar+ sputter cleaning, corresponding 2 nm thick oxide.

The surface morphology of the Mg implants and TiUnite demonstrated a duplex oxide structure consisting of an inner barrier layer without pores and an outer porous layer with numerous pores while Osseotite revealed a crystallographically etched appearance with pits.

The diameter and depth of pores/pits were ≤ 2 µm and ≤ 1.5 µm for the Mg implant, ≤ 4 µm and ≤ 10 µm for the TiUnite and ≤ 2 µm and ≤ 1 µm for the Osseotite, respectively. *The oxide layer* revealed an homogeneous thickness, about 3.4 µm of all threads of the Mg implants and 5 nm of Osseotite. In contrast, the TiUnite showed heterogeneous oxide thickness, about 1 to 11 µm which gradually increased from the top to the apical portion.



The crystal structure showed a mixture of anatase and rutile phase for the Mg implants and TiUnite and amorphous for Osseotite. *The mean roughness, Sa values* were 0.69 µm for the Mg implant, 1.35 µm for TiUnite and 0.72 µm for Osseotite.

Conclusions: The present study indicates that detailed surface characterization is very necessary for the modified implant surfaces since various surface properties will be created in terms of surface chemistry, morphology, pores characteristics, oxide thickness, crystal structure and roughness.

References: 1.Sul YT. Biomaterials 2003: 24; 3893-3907. 2. Sul et al. Int J Oral Maxillofac Implants 2005;20:349-359. 3. Sul et al. Biomaterials 2005: 26; 6720-6730.

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