Multiscale Topography Analysis of Microtextured Titanium: Importance of Lateral Spatial Resolution

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Introduction: Peri-implant tissue formation can be modulated by surface morphology. For example, a variety of cementless implants exist that utilize a complex random topography for osseointegration. These 'microtextured surfaces' are generally described by R_a, or root-mean-square (RMS) roughness, which commonly ranges from 1 to 6 µm. There is now growing evidence that other hybrid and spatial parameters associated with surface topography also influence implant performance.

In practice, the measurement of these spatial and hybrid surface parameters is strongly influenced by the choice of measurement method and the associated spatial resolution. The **purpose** of this study is to demonstrate the critical importance of multiscale topography analysis in order to obtain an accurate representation of surface characteristics. Specifically, two commonly used methods –*White Light Interferometry* (WLI) and *Atomic Force Microscopy* (AFM) – with significantly different lateral resolutions are shown to lead to vastly different representations of microtextured titanium implant surfaces.

Methods: Commercially pure titanium discs (22mm diameter x 3mm thick) were prepared with 4 different surfaces: *fine grit blasted* (FGB), *fine grit blasted and acid etched* (FAE), *reactive ion etched* in $N_2/F_2/Cl_2$ plasma for 4 minutes (RIE4) and 8 minutes (RIE8). Scanning electron microscope images of the surfaces were obtained with Hitachi S3000 VP-SEM. Twenty one representative surface images were obtained per group. Interferometer surface measurements were obtained with a VEECO NT8000 WLI (Veeco Metrology Inc, Tucson, AZ) at 100x magnification. WLI images were 64µm x 48µm (640x480 pixels), at a lateral resolution of ~400 nm. AFM images were acquired in semi-contact mode with MicroMasch NSC15/AlBS tips (MicroMasch, Wilsonville, OR) on a Solver PRO AFM (NT MDT, Moscow, Russia). The specified tip radius was less than 10nm with a full cone angle less than 30^0. The AFM height range was 5µm. AFM images were acquired at 25µm x 25µm (256 x 256 pixels) for FGB and FGB+AE. RIE4 and RIE8 surfaces images were 1.5µm x 1.5µm (512 x 512 pixels). The lateral resolution of the AFM ranged from 10 to 100nm. Interferometer and AFM, 3D data was exported to MATLAB as ASCII and 8bit TIFF files. The images were processed in a custom program to calculate 14 topography parameters.

Results: Distinct sub-micron morphological differences were visible when comparing the SEM images of Group 1 (FGB and FAE) and Group 2 (RIE4 and RIE8) surfaces. Tables 1 and 2 list a selected subset of different surface parameters for these surfaces obtained using WLI and AFM. It is evident that the two methods lead to vastly different topographical parameters and surface representations. For instance, in the case of FGB and FAE, interferometer images showed a 26% decrease in developed area but AFM measurements indicated a 110% increase due to acid etching. These surfaces are dominated by critical features at length scales less than 400 nm, which is a regime that cannot be accessed using WLI. In contrast, the higher spatial resolution of the AFM clearly shows the effect of sub-micron features and their consequence on peak density and developed area. Figure 1 provides a qualitative visual indication: the AFM surface topography is similar to the SEM images, but both images differ sharply from the one acquired using WLI.

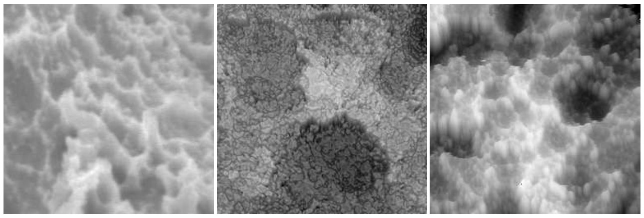

Figure 1 - FGB+AE surface as imaged by SEM (left), WLI (center), AFM (right). All images are 25µm x 25µm

Table 1.Comparison of selected values for Group 1 surfaces (%Δ based on FGB values). For brevity, only one height, spatial and hybrid parameter is presented in the tables

	WLI			**AFM**		
Surface	FGB	FAE	%Δ	FGB	FAE	% Δ
RMS Height (nm)	3387	2871	-13%	757	926	22%
Peak density (100 μm^{-2})	0.72	0.78	10%	4.08	4.04	-1
Developed Interfacial Area Ratio	2.01	1.48	-26%	0.27	0.57	110%

Table 2. Comparison of selected values for Group 2 surfaces (%Δ based on RIE4 values)

	WLI			**AFM**		
Surface	RIE4	RIE8	% Δ	RIE4	RIE8	% Δ
RMS Height (nm)	19	89	356%	40	40	0%
Peak density (100 μm^{-2})	0.28	0.45	57%	7895	2003	-67%
Developed Interfacial Area Ratio	0.002	0.007	394%	0.88	0.52	-41%

Conclusions: The critical features associated with surface topography occur over multiple lateral length scales ranging from nanometers to millimeters. In evaluating the topographical parameters of a surface, it is essential to probe the surface over this wide range of length scales. In practice, this leads to a trade-off because techniques with fine resolution are usually limited to scanning over smaller surface areas. Thus, it is imperative that topography be measured over multiple length scales using a combination of experimental techniques. The use of any single method alone runs the risk of significant errors (as in the case of the WLI parameters in our study) and, subsequently, to erroneous correlations with the bioperformance of the implant. In the course of this study, we also identified gaps in measurement technology, especially in characterizing surfaces with large roughness amplitudes (RMS > 4µm) at 10-100nm lateral resolution.