CLINICAL ORAL IMPLANTS RESEARCH

Short Communication

Evaluation of surface roughness as a function of multiple blasting processing variables

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Abstract

Objectives: This study evaluated the effect of implant surface blasting variables, such as blasting media size, velocity, and surface coverage and their two- and three-way interaction in surface roughness parameters.

Material and methods: Machined, grade IV titanium-alloy implants (n = 180) had their surfaces treated by a combination of 36 different blasting protocols according to the following variables: aluminum oxide blasting media particle size (50, 100, and 150 μm); velocity (75, 100, 125, and 150 m/s), and surface coverage (5, 15, 25 g/in.^{2}) (n = 5 per blasting protocol). A single 0.46 inch nozzle of the blaster was pointed at the threaded area and spaced 0.050 inches away. Surface topography (n = 5 measurements per implant) was assessed by scanning electron microscopy. Roughness parameters Sa, Sq, Sdr, and Sds were evaluated by optical interferometry. A GLM statistical model evaluated the effects of blasting variables on the surface parameters, and their two- and three-way interaction ($P < 0.05$). Statistical inferences for Sa and Sq were performed after a $\log_{10}$ transformation to correct for data skewness.

Results: Prior to the $\log_{10}$ transformation, Sa and Sq values for all processing groups ranged from ~0.5 to ~2.6 μm and from ~0.75 to 4 μm, respectively. Statistical inferences showed that Sa, Sq, and Sdr values were significantly dependent on blasting media, velocity, and surface coverage (all $P < 0.001$). Media × velocity, media × coverage, and media × velocity × coverage also significantly affected Sa, Sq, and Sdr values ($P < 0.002$). The highest levels were obtained with 100 μm blasting media, coverage for 5 g/in.^{2}, and velocity of 100 m/s. No significant differences were observed for Sds ($P > 0.15$).

Conclusions: The blasting variables produced different surface topography features and knowledge of their interaction could be used to tailor a desired implant surface configuration.

An extensive literature has reviewed the influence of the topography regarding surface roughness on bone healing on a micrometer as well as on a nanometer level (Albrektsson et al. 2008; Albrektsson & Wennerberg 2004a,b; Coelho et al. 2009a,b, 2011, 2009c; Coelho & Lemons 2009; Coelho & Suzuki 2005; Coelho et al. 2010; Cooper 2000; Dohan Ehrenfest et al. 2010; Granato et al. 2009; Marin et al. 2008; Mendes et al. 2007, 2009; Wennerberg & Albrektsson 2009a,b). However, while some evidences point out to a direct relationship between surface roughness and overall implant stability gain at early implantation times *in vivo*, the influence of the multiple surface roughness parameters is still to be determined (Javed et al. 2011). In this regard, titanium implant surfaces have been modified by a varied of additive and subtractive methods to increase the surface area, alter its topography, texture (Klokkevold et al. 2001) and consequently, its chemistry and physics.

Moderately rough implant surfaces (Sa = 1–2 μm) are currently the most clinically used (Wennerberg & Albrektsson 2010). While studies have considered different surface roughness parameters in animal studies, these suggest that a Sa of approximately 1.5 μm and an Sdr of about 50% promotes the strongest bone response (Wennerberg et al. 1996a,b,c).

It has been suggested that implant topography description should ideally include spatial, hybrid or functional parameters, preferably in three-dimensions (i.e., Sdr and Sds) (Wennerberg

& Albrektsson 2000). Although these implant design parameters have been extensively investigated, the amount of published work concerning the effect of different blast parameters that could create favorable surface characteristics in measurable roughness parameters is still sparse in the literature. As a consequence, no informed design platform has been established with respect to which combination of blast processing parameters most affect surface texture.

Therefore, this study evaluated the effect of variables, such as blasting media, velocity, and surface coverage during blasting procedures over implant surfaces and their two- and three-way interaction in surface roughness parameters, such as Sa, Sq, Sdr, and Sds.

Material and methods

Machined, external hexagon, grade IV titanium-alloy implants (Tryon Cylindrical, SIN – Sistema de Implante, Sao Paulo, Brazil) were used in this study. A special fixture was fabricated to attach implants to a mandrel, leaving the threaded part exposed for blasting procedures and assuring reproducible positioning. A LA3250 lathe running an AF10 AccuFlo blaster (Comco, Burbank, CA, USA), using a single 0.46 inch nozzle was pointed straight down at the threaded part and spaced 0.050 inches away. A 36 combination matrix considering different blast protocols were run according to the following variables: Al_2O_3 (aluminum oxide) blasting media particle size (50, 100, and 150 μm), velocity (75, 100, 125, and 150 m/s), and surface coverage (5, 15, and 25 g/in.^{2}) on 180 different implants (five implants for each blasting procedure).

The inter-relationship between blaster pressure (velocity) and powder stream density (quantity) of the blaster made possible the creation of a pure velocity × coverage chart. Powder output was measured and held constant for each specific abrasive size and velocity. The step-over distance was kept constant for all parts resulting in identical blast patterns for each implant. With the powder output empirically determined and the step-over distance fixed, the different coverages for a given velocity were achieved by adjusting the nozzle speed. The coverage is given in the equation below:

$$\textit{Coverage}\ (C) = \textit{powder output}\ (B)/\textit{nozzle speed}\ (N) \times \textit{step over distance}\ (S).$$

The velocity was selected as the independent control across the different types of abrasives. For this reason, the powder output was established by the blaster settings, required to achieve the desired velocity. An abrasive velocity meter (Comco, Burbank, CA, USA) was used to determine the blaster settings that corresponded to 75, 100, 125, and 150 m/s for each powder. After an appropriate orifice size was selected, the pressure was adjusted until the powder attained the desired velocity at a distance of 0.05 inches from the nozzle. Once the configurations for the desired powder velocities were known, trap tests were performed for each setting to determine the powder output (B) in grams per second.

Each test was performed five times and the average value for each velocity setting was used for all calculations. The step-over distance was set at $S = 0.011$ in/rev. With the 0.046 inch nozzle placed 0.05 inches away from the part, the diameter of the blast on the part was 0.058 inches, meaning that each area of the part was blasted 0.058/0.011 = 5.3 times as it is rotated under the nozzle.

The distance between the nozzle and the part was chosen to give a sharp delineation between the blasted and unblasted areas. The appropriate nozzle speed was calculated for each coverage and blaster setting, and from that value, the appropriate settings for the lathe were determined.

All implants were handled with gloves and were taken straight from their packages and installed into the blast tooling ($n = 5$ implants per blasting configuration). After blasting, the implants had their surfaces evaluated at the flat region of the cutting edges ($n = 5$ measurements per implant). The surface topography was assessed by scanning electron microscopy (SEM) (Philips XL 30, Eindhoven, the Netherlands) at 3000× magnification and an acceleration voltage of 20 kV ($n = 3$ per surface). Roughness parameters Sa (average surface roughness) and Sq (mean root square of the surface), Sdr (increment of the interfacial surface area relative to a flat plane baseline), and Sds (density of summits, i.e., the number of peaks per area) were evaluated by optical interferometry (IFM) (Phase View 2.5, Palaiseau, France) over 100 μm × 100 μm spot size. Five implants of each surface were evaluated at the flat region of the implant cutting edges (three measurements per implant) and to separate roughness from waviness and shape for digital 3D measurements, a high-pass Gaussian filter was utilized.

A GLM statistical model was employed to evaluate the effects of blasting media, velocity, and surface coverage on the four different parameters evaluated, as well as their two- and three-way interaction. Statistical significance was set to 95%. All statistical inferences for Sa and Sq were performed after a $\log_{10}$ transformation to correct for data skewness.

Results

SEM and IFM evaluation showed that surface texturing was achieved for all the different processing parameter combinations (Fig. 1). Prior to the $\log_{10}$ transformation utilized to correct for data skewness, Sa and Sq values within all processing groups ranged from ~0.5 to ~2.6 μm and from ~0.75 to 4 μm, respectively.

Statistical inferences showed that Sa, Sq, and Sdr values were significantly dependent on blasting media, velocity, and surface coverage (all $P < 0.001$). Media × velocity, media × coverage, and media × velocity × coverage also significantly affected Sa, Sq, and Sdr values, with all presenting $P < 0.002$. Since identical trends were observed for Sa and Sq parameters, only Sa is depicted in Fig. 2. Sdr results are presented in Fig. 3.

In general, for all the three parameters, the highest levels were obtained when blasting media of 100 μm was utilized, followed by 150 μm and 50 μm media, respectively (Figs 2a and 3a). When coverage was considered, significantly higher levels were obtained for the 5 g/in^2 compared to the 10 g/in^2 and 15 g/in^2 (Figs 2b and 3b). When velocity was concerned, the highest values were obtained for the 100 m/s, followed by the 75 m/s, 125 m/s, and 150 m/s (Figs 2c and 3c). The overall values for all 36 parameter combination evaluated are presented in Figs 2(d) and 3(d). No significant differences were observed for Sds (P values > 0.15).

Discussion

Modification of the implant surface has significantly enhanced both the rate and quality of osseointegration. From a clinical perspective, this leads to a shortened treatment period with further increased success rates (Akoglu et al. 2011; Ellingsen et al. 2004; Vroom et al. 2009). Currently, modification in the nano-level has attracted significant attention, since studies presented enhanced osteogenic responses when nanotopography was applied (Bjursten et al. 2010; Jimbo et al. 2011a,b).

Although nanometer modification has been and is of great interest, the importance of microtopography will never be precluded since it has been shown to be an essential factor for the biomechanical and biological aspect of osseointegration (Ronold & Elling-

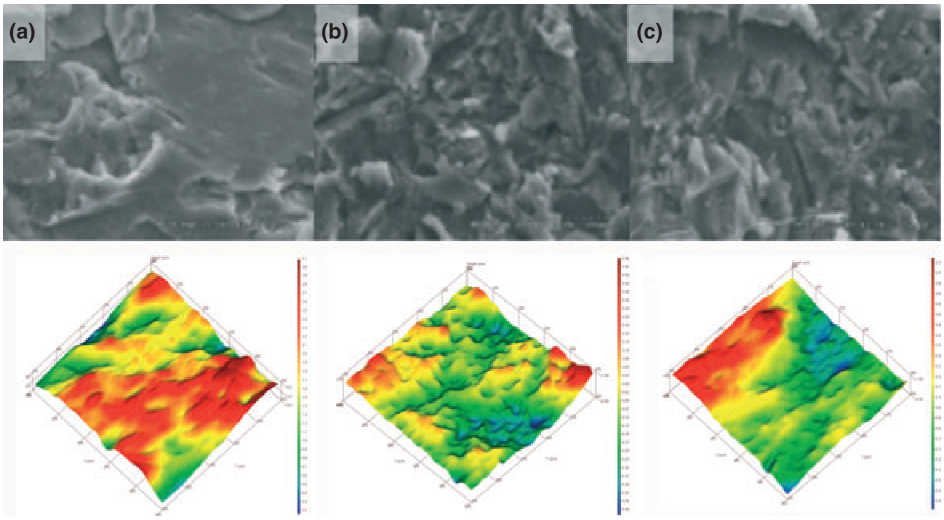

Fig. 1. Representative scanning electron microscopy (SEM) and interferometry (IFM) for (a) 50 μm blasting, (b) 100 μm blasting, and (c) 150 μm blasting (original magnification 3000×).

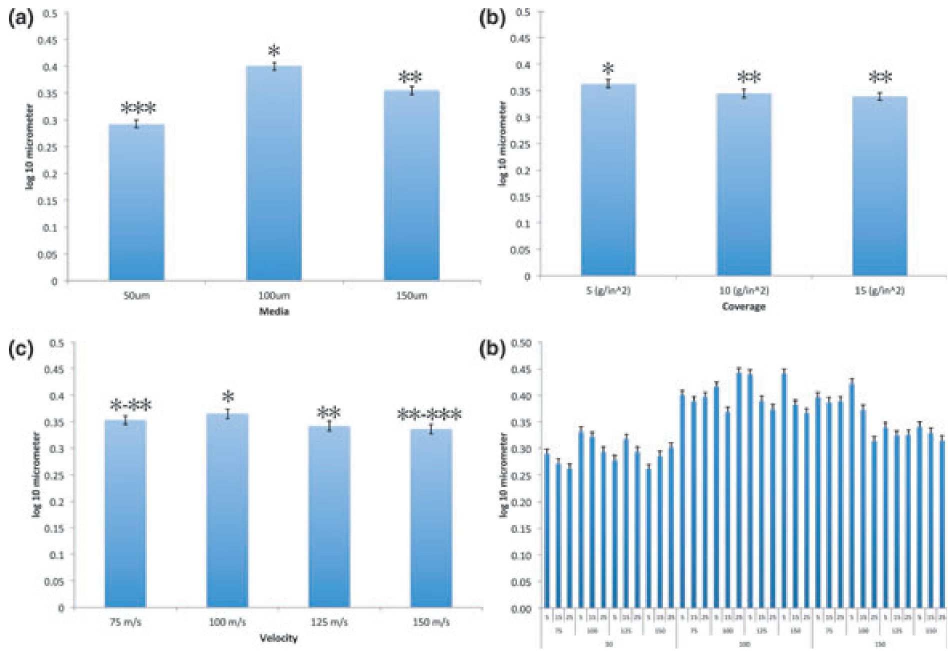

Fig. 2. Log_{10} Sa (mean ± 95% confidence interval) values for the different blasting parameters utilized. (a) Sa as a function of blasting media diameter, (b) Sa as a function of coverage parameter, (c) Sa as a function of velocity, and (d) Sa for all 36 blasting configurations (three blasting levels at the bottom, four velocity levels in the middle, and three coverage levels at the top of *x*-axis). Statistically homogenous groups for (a), (b), and (c) are depicted by the number of asterisks. Statistically different groups in (d) are present when no overlap in value range exist between any two given groups.

sen 2002). It has been reported that, due to enhanced interlocking, the retention between implant and bone is significantly increased by micro topography (Hansson & Norton 1999). In addition, a recent study by Browaeys et al. (2011) reported that there were no histological differences between smooth implants with or without nanostructures under immediately loaded conditions, where both implant surfaces were encapsulated by soft tissue (Browaeys et al. 2011). It was suggested that the lack of micro roughness might have lead to the failure of osseointegration under dynamic loading conditions, and the importance of micro roughness was emphasized.

The results of the current factorial analysis presented that a wide variety of microtopography could be prepared by regulating the variable factors during blasting procedure ranging from minimally rough surfaces to excessively rough surfaces. By changing the combination of the blasting media, velocity, and surface coverage as conducted in this study, surface topography could be altered significantly in a well-controlled manner. It is an indication that manufacturers can strategically design their surface topography from numerous topographical aspects such as height (roughness), degree of symmetry (skewness), and surface area (spatial intricacy and summit density). For instance, there is a possibility to design a surface possessing the suggested Sa and Sdr values, while altering other parameters. It would be of great interest to observe the biological responses to

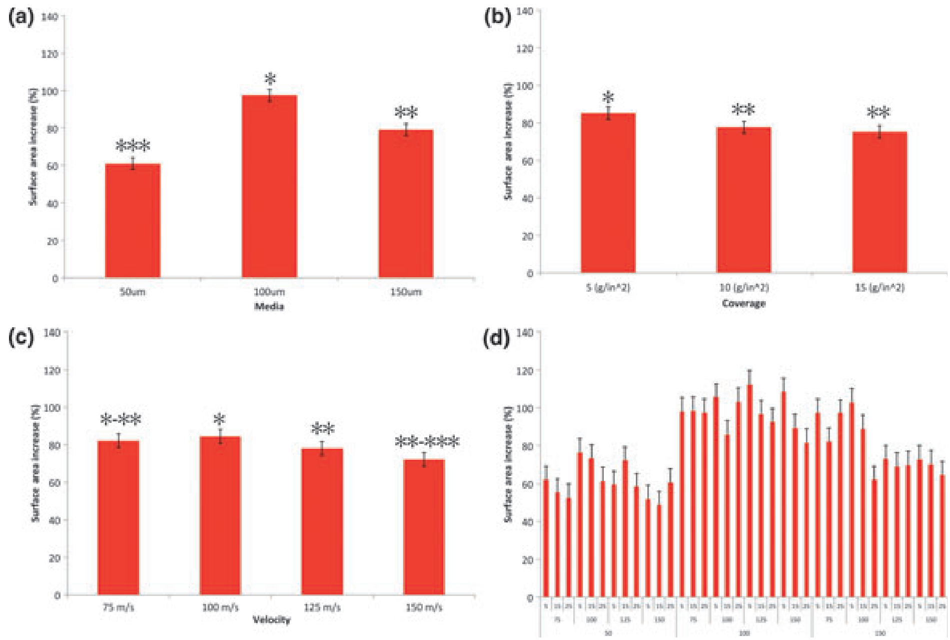

Fig. 3. Sdr (mean ± 95% confidence interval) values for the different blasting parameters utilized. (a) Sdr as a function of blasting media diameter, (b) Sdr as a function fo coverage parameter, (c) Sdr as a function of velocity, and (d) Sdr for all 36 blasting configurations (three blasting levels at the bottom, four velocity levels in the middle, and three coverage levels at the top of *x*-axis). Statistically homogenous groups for (a), (b), and (c) are depicted by the number of asterisks. Statistically different groups in (d) are present when no overlap in value range exist between any two given groups.

such surfaces both *in vitro* and *in vivo*, since the modification may further enhance osseointegration within the moderately roughened surface range.

A further parameter to consider in the future is the type of the base material in which the blasting will be performed to. Due to a demand for a further biocompatible and esthetic implant material, materials such as zirconium dioxide (ZrO_2) or polyether ether ketone has recently been tested for these purposes (Koch et al. 2010; Sennerby et al. 2005). Since the Vickers hardness for these materials are different from the currently tested grade IV Ti, it is extremely difficult to apply the same topographical features to such newly introduced materials. Hence, it would be worthwhile to investigate the optimal settings for these newly introduced materials.

As a whole, the results of this study may be a valuable index for determining the setup conditions to achieve the desired surface topography after blasting.

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