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Short communication

Assessment of a chair-side argon-based non-thermal plasma treatment on the surface characteristics and integration of dental implants with textured surfaces

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ABSTRACT

The biomechanical effects of a non-thermal plasma (NTP) treatment, suitable for use in a dental office, on the surface character and integration of a textured dental implant surface in a beagle dog model were evaluated. The experiment compared a control treatment, which presented an alumina-blasted/acid-etched (AB/AE) surface, to two experimental treatments, in which the same AB/AE surface also received NTP treatment for a period of 20 or 60 s per implant quadrant (PLASMA 20′ and PLASMA 60′ groups, respectively). The surface of each specimen was characterized by electron microscopy and optical interferometry, and surface energy and surface chemistry were determined prior to and after plasma treatment. Two implants of each type were then placed at six bilateral locations in 6 dogs, and allowed to heal for 2 or 4 weeks. Following sacrifice, removal torque was evaluated as a function of animal, implant surface and time in vivo in a mixed model ANOVA. Compared to the CONTROL group, PLASMA 20′ and 60′ groups presented substantially higher surface energy levels, lower amounts of adsorbed C species and significantly higher torque levels ($p = .001$). Result indicated that the NTP treatment increased the surface energy and the biomechanical fixation of textured-surface dental implants at early times in vivo.

1. Introduction

The rationale for surface modification focuses on implant interaction with biofluids positively altering the cascade of events that leads to bone healing and intimate interaction with the device (Jimbo et al., 2007). Several reviews (Coelho et al., 2009; Dohan Ehrenfest et al., 2010) lead to a general consensus that both rough surfaces (over smooth turned

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surfaces) and surface chemistry (Ca–P based coatings over non-coated surfaces) favor the early host-to-implant response (Albrektsson and Wennerberg, 2004a,b; Coelho et al., 2009).

However, in most cases, combinations of texture and chemistry known to hasten osseointegration are proprietary processes and not available for the dental community. An economically viable, chair side, operator (dental surgeon) controlled surface treatment that enhances the host response to any implant surface would provide better treatment to more patients.

While prior attempts to modify surface characteristics with thermal or radio-frequency plasma devices were successful, they operated either at high temperatures or under low pressures. As well, because the equipment was expensive and unreliable, these processes fell from favor (Aronsson et al., 1997; Baier, 1986, 1987; Baier and Meyer, 1988). By contrast, non-thermal plasmas (NTPs) deploy most of their energy to drive "high-temperature" chemistry, allowing surface activation/modification while operating at room temperatures (Barker, 2005). Unlike previous radiofrequency technology that required low pressures (Liu et al., in press), recent innovation, has scaled microplasma NTP generators to dimensions that are small enough to allow safe and portable operation in the clinical setting at atmospheric pressure, while providing sufficient energy to generate meaningful increases in surface energy.

The incorporation of reactive species and surface cleaning may result in increased levels of surface reactivity and energy that could improve the integration of commercially available implant surfaces. The objective of the present investigation was to evaluate the biomechanical effects of an Ar-based NTP treatment, suitable for use in the dental office and applied immediately prior to implantation, on the surface character and integration of a dental implant with a textured surface, in a beagle dog model.

2. Materials and methods

This study utilized screw root form endosseous grade IV titanium alloy implants of 3.8 mm in diameter by 8.5 mm in length. The implants provided by the manufacturer presented an alumina-blasted and acid-etched (AB/AE) surface (Duo System, Signo Vinces, Brazil).

The control treatment used implant specimens as-supplied, while two experimental groups used these same implants and treated them with either 20 or 60 s of non-thermal plasma (NTP) per quadrant (PLASMA 20′, PLASMA 60′). The plasma was applied with a KinPen^{TM} device (INP-Greifswald, Germany). The plasma treatment was applied immediately prior to any characterization assessment and again prior to implantation in the in vivo component of this study.

SEM (Philips XL 30, Eindhoven, The Netherlands) was performed at various magnifications under an acceleration voltage of 15 kV. Surface roughness was evaluated in three control implants by optical interferometry (IFM) (Phase View 2.5, Palaiseau, France) at the flat region of the implant cutting edges (three measurements per implant). Sa (arithmetic average high deviation), Sq (root mean square), Sds (density of summits), and Sdr (developed surface ratio) parameters were determined. A filter size of 250 μm × 250 μm was utilized.

Surface energy (SE) was determined using the Owens–Wendt–Rabel–Kaelble (OWRK) method (Owens and Wendt, 1969). Briefly, 500 μl droplets of distilled water, ethylene glycol, and diiodomethane were deposited on the surface of each implant with a micro-pipette (OCA 30, Data Physics Instruments GmbH, Filderstadt, Germany). Images were captured and analyzed using SCA30 software (version 3.4.6 build 79). The relationship between the contact angle and SE was calculated as $\gamma_L = \gamma_L^D + \gamma_L^P$, where γ_L is the SE, γ_L^D is the disperse component and γ_L^P is the polar component.

Surface specific chemical assessment was performed by X-ray photoelectron spectroscopy (XPS). The implants ($n = 3$, each group) were inserted in a vacuum transfer chamber and degassed to 10^{-7} torr. The samples were then transferred under vacuum to a Kratos Axis 165 multitechnique XPS spectrometer (Kratos Analytical Inc., Chestnut Ridge, NY, USA). Spectra were obtained using a 165 mm mean radius concentric hemispherical analyzer operated at constant pass energy of 160 eV for survey and 80 eV for high resolution scans. The take off angle was 90° and a spot size of 150 μm × 150 μm was used. The implant surfaces were evaluated at various locations.

The *in vivo* study included 6 adult male beagle dogs, approximately 1.5 years of age. The experimental protocol received the approval of the École Nationale Vétérinaire d'Alfort (Maisons-Alfort, Val-de-Marne, France).

All surgical procedures were performed under general anesthesia. The pre-anesthetic procedure comprised an intra-muscular (IM) administration of atropine sulfate (0.044 mg/kg) and xylazine chlorate (8 mg/kg). General anesthesia was then obtained following an IM injection of ketamine chlorate (15 mg/kg). Following hair shaving, skin exposure, and antiseptic cleaning with iodine solution at the surgical and surrounding area, a 5 cm incision at the skin level was performed. Then, a flap was reflected and the radius diaphysis exposed.

The surgical region was the center of the radius diaphysis, where three implants (one of each treatment) were placed into each limb. The right and left limbs received implants that remained for periods of 2 and 4 weeks *in vivo* (two distinct surgical procedures were performed), respectively. The implants were alternately placed from proximal to distal at distances of 1 cm from each other along the central region of the bone, and the start surface site (CONTROL, PLASMA 20′, AND PLASMA 60′) was alternated between animals. The implant distribution resulted in an equal number of implants for the 2 and 4 weeks comparison for both surfaces.

Drilling started with a 2 mm diameter pilot drill at 1200 rpm and was followed with burs of 2.5 mm and 3.2 mm at 800 rpm, all under saline irrigation. The implants were then placed into the drilled sites by means of a torque wrench. Standard layered suture techniques were utilized for wound closure (4-0 vicryl—internal layers, 4-0 nylon—the skin). Post-surgical medication included antibiotics (penicillin, 20.000 UI/kg) and analgesics (ketoprophen, 1 ml/5 kg) for a period of 48 h post-operatively. The euthanasia was