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Research Paper

Understanding mechanisms and factors related to implant fixation; a model study of removal torque

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ABSTRACT

Osseointegration is a prerequisite for achieving a stable long-term fixation and load-bearing capacity of bone anchored implants. Removal torque measurements are often used experimentally to evaluate the fixation of osseointegrated screw-shaped implants. However, a detailed understanding of the way different factors influence the result of removal torque measurements is lacking. The present study aims to identify the main factors contributing to anchorage. Individual factors important for implant fixation were identified using a model system with an experimental design in which cylindrical or screw-shaped samples were embedded in thermosetting polymers, in order to eliminate biological variation. Within the limits of the present study, it is concluded that surface topography and the mechanical properties of the medium surrounding the implant affect the maximum removal torque. In addition to displaying effects individually, these factors demonstrate interplay between them. The rotational speed was found not to influence the removal torque measurements within the investigated range.

1. Introduction

Osseointegration and the importance of implant stability for clinical success are common denominators in the literature on dental implants. However, in a review of the way surface roughness influences implant fixation, Wennerberg and Albrektsson (2009) conclude that, in order to understand the complex interfacial mechanisms involved, further systematic

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studies and the standardization of techniques are needed. Despite the fact that clinical success rates for implants have been consistently high over the years, the osseointegration process is still a long way from being understood. Tolstunov (2007) describes implant failure in more challenging clinical situations and, according to Zarb and Schmitt (1990), the outcome of an implant can be attributed to local biology, local anatomy, implant and systemic or functional factors. Achieving a good initial primary stability at the implant insertion is also an important prerequisite.

The establishment of osseointegration, a direct contact between remodeled bone and implant, has been shown to dependent on several factors (Albrektsson et al., 1981) which have been subjected to investigations over the years, such as; surgical technique (Turkyilmaz et al., 2008; Shalabi et al., 2006), implant design (Dos Santos et al., 2009), surface properties (Wennerberg and Albrektsson, 2009; Mendonca et al., 2008), loading (Torcasio et al., 2008; De Smet et al., 2007) and the status of the surrounding bone (Degidi et al., 2009). In brief, it is important to obtain a primary stability in the host bone bed, thereby minimizing the micro-motions, in order to achieve a firm secondary fixation as a result of the osseointegration process.

A key to understanding the biomechanics and achieving functionality in the interface might be to control the extent of anticipated bone modeling and remodeling (Dunlop et al., 2009), by combining an optimal implant design with a thorough understanding of the way mechanical forces affect tissues (Stanford, 1999). All the authors Akca et al. (2006), Brånemark (1996) and Shalabi et al. (2006) report that mechanical measurements are often used to evaluate the fixation of experimental implants. According to a literature review by Shalabi et al. (2006), torque-based evaluation techniques might be most suitable whenever screw-shaped implants are to be evaluated biomechanically. However, due to the complexity of the measured system, the interpretation of these measurements in terms of what is actually happening at the interface and in the surrounding bone is very difficult. Understanding the way individual factors affect implant fixation therefore needs to be studied in more detail. Furthermore, some factors might demonstrate interplay or synergistic effects in specific conditions, thus adding to the complexity. However, experimental planning using statistical factorial designs has been shown to be a highly efficient tool for planning and evaluating multiple factors and interplays (Montgomery et al., 2009; Whelan et al., 2012). An increased understanding of the factors that influence implant stability could also provide a basis for developing standardized measurement procedures, which are presently lacking and are making interlaboratory comparisons difficult.

Polyurethane (PU) foams as testing materials simulating the mechanical properties of bone are being used more and more frequently in bone implant research. Compared with bone, PU foams exhibit a very low variance in physical properties and show good homogeneity (Tabassum et al., 2009). Their similarities in mechanical strength compared with that of bone have made them suitable as a testing material for simulation purposes (Calvert et al., 2010; Patel et al., 2008). Yerneni et al. (2012) conclude that using natural bone (pig rib) to analyze small variations in one specific factor yields a high dispersion of torque values, due to the heterogeneity of bone density and cortical thickness, and that this method is therefore inadequate for systematic measurements.

The objective of this experimental study was to obtain new insights into the mechanics controlling implant fixation by identifying the effect of individual factors on removal torque (RTQ) measurements. The parameters that were investigated were implant surface roughness, the mechanical properties of the medium surrounding the implant and the rotational speed during torque measurement. Thermosetting polymers were used as an embedding medium in order to eliminate the biological variation in this model study. Further, instead of using drilling and tapping as site preparation, an embedding approach was used to ensure that the surrounding material became integrated in the surface structures of the implant.

2. Materials and method

2.1. *Experimental implants and surface treatments*

The surface topography of machined turned, ultrasonically cleaned titanium (grade IV), screw-shaped implants, total length of 10 mm, threaded part 6 mm, Ø 3.75 mm, was modified by either electropolishing or acid etching, resulting in three different surface types; unmodified machined (M), electropolished (EP) and hydrofluoric acid etched (AE) (Lausmaa, 2001). Experimental titanium grade IV cylindrical samples, length 10 mm, Ø 3 mm, were identically cleaned, modified and additionally spin coated with a wax-based anti-adhesion coating (Release Spray, VOSSCHEMIE Gmbh, Germany), resulting in the modified surfaces; EP-S, M-S and AE-S.

2.2. *Polymeric embedding*

Polyurethane and epoxy-based thermosetting polymers, Multicast 30, EP 986 (Altropol Kunststoff GmbH, Germany) and solid rigid polyurethane foam (SRPF), with densities of 0.16, 0.24 and 0.32 g/cm^3 (Pacific Research Laboratories/Sawbones, Vashon Island, WA), were used as embedding materials. To minimize the trapping of air at the titanium surface, the Altropol resins were subjected to vacuum treatment during the embedding of the cylindrical samples. Positioning during molding was alternated according to a predetermined schedule, enabling maximum rotation of the samples. To ensure equal polymerization, the samples were conditioned in constant ambient conditions of 23 °C and relative humidity of 50% for one week prior to torque measurements. Embedding in SRPF was performed by Pacific Research Laboratories/Sawbones, according to their in-house processes.

2.3. *Model design*

A full factorial design of 3^3 with 2 replicas and a full factorial mixed model with 5 replicas were used for Sawbones and Altropol, respectively, in order to identify the effect of individual factors on RTQ experiments. The factors selected for study were surface roughness parameters of the titanium samples, the experimental RTQ measurement protocol and