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Biomechanical evaluation of dental implants with three different designs: Removal torque and resonance frequency analysis in rabbits

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ABSTRACT

The objective of this study was to investigate the effect of implant design on stability and resistance to reverse torque in the tibia of rabbits. Three test groups were prepared using the different characteristics of each implant model: square threads with progressive depth to the apex, a cervical portion without threads and a self-tapping system that is quite pronounced and aggressive (Group 1); triangular threads with flat tips with increasing thread depth from the cervical portion to the apex and a small self-tapping portion with a short thread pitch (Group 2); long thread pitch, progressive thread depth, an apical area with a small self-tapping portion (Group 3). For the two last groups, a final single-use drill was provided for each implant. Nine rabbits received 54 conical implants with a same surface treatment. The resonance frequency was analysed four times (0, 6, 8 and 12 weeks), and removal torque values were measured at three time intervals after the implantations (6, 8 and 12 weeks). In comparing the implant stability quotient at the four time points, highly significant statistic differences were found ($p = 1.29^{-10}$). The reverse torque at the three time points was also significantly different among the groups ($p = 0.00015$). The implants of Group 2, with seemingly less aggressive design, more quickly reached high values of stability and removal torque. Under the limitations of this study, however, it is possible that in cases in which there may be low osseointegration response, the implant design should be evaluated.

1. Introduction

The process of osseointegration is affected by many factors, including the implant design, the implant surface treatment, the bone quality, the surgical technique and postoperative care (Chung et al., 2008). Among these factors, the thread design of an implant plays a relevant role and is one of the dominant factors. In addition, the design of the implant threads directly affects stress distribution and marginal bone restoration (Chun et al., 2002; Eraslan and Inan, 2010). Recent studies have focused on the influence and sensitivity of the implant features, such as thread-pitch, depth, width, helix angle. Understanding these factors and applying them appropriately to the design of dental implants can help reduce the potential for implant failure (Abuhussein et al., 2010).

The design of an implant plays a fundamental role in the osseointegration process (Chong et al., 2009; Wu et al., 2012; Jimbo et al., 2014), particularly in low-density bone. It has been proposed that design features that maximize the surface area available for contact may improve mechanical anchorage and primary stability in cancellous bone (Orsini et al., 2012), based on implants that showed that inadequate initial stability increases failure (Javed et al., 2013).

While different implant designs have shown similar initial stabilities in dense bone (Rompen et al., 2001), implant stability in soft low-density bone may be influenced by the implant design (O'Sullivan et al., 2000; Glauser et al., 2001). Furthermore, it has been suggested that a combination of microscopic surface topography and macroscopic levels of implant design (e.g., screw thread profiles) may be essential for creating a stable bone-implant interface in low density bone (Stanford, 1999). Threads have been incorporated into implants to improve initial stability (Brink et al., 2007; Chong et al., 2009), enlarge implant surface area, and distribute stress favorably (Chun et al., 2002; Eraslan and Inan, 2010).

The development of innovative dental implant materials, designs, and treatment techniques has not always produced expected or desired results. Additional studies are needed to optimize the relationship between artificial materials and the

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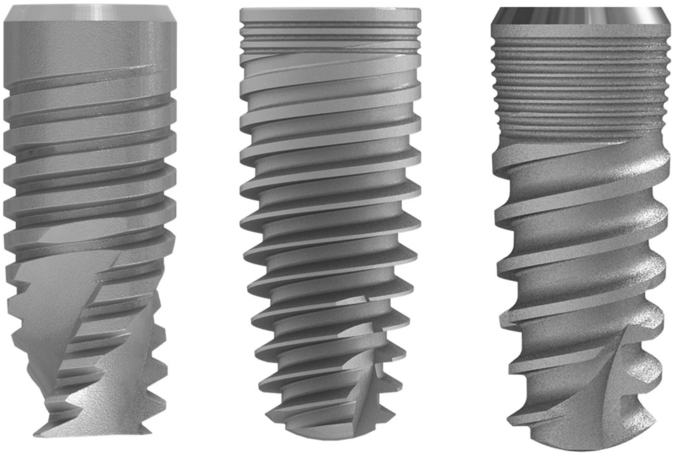

Fig. 1. Image shows the design of the implants used in the study. Models MF4, C1, MF7 are shown from left to right.

body's tissues. Therefore, the purpose of this study was to investigate the effect of variation in the threads type and characteristics of the apex court (self-tapping) of dental implants on the stability and removal torque after implantation using a rabbit tibia model.

2. Materials and methods

2.1. Implant characteristics

This study utilized 54 conical implants from the same manufacturer (MIS, BarLev Industrial Park, Israel), with the same type of surface (sand-blasted and acid etched), so that these factors presenting the same level of stimulation in all samples; the different details regarding the implant body conformation (Fig. 1) determined the formation of the groups:

Group 1: Conical implants with square threads, with a cervical portion without microthreads (1 mm) and plane threads with a progressive depth increase to the apex; apical portion plane and a self-tapping system that is quite pronounced and aggressive; and a short thread pitch with a dual thread design.
Group 2: Conical implants with triangular threads with flat tips that become increasingly acute, with increasing thread depth from the cervical portion to the apex; in the first millimetre, there are micro rings, and there is a dual thread design on the implant neck; in the apical area, there is a small self-tapping portion with a short thread pitch. For this model, a single-use final drill is provided with each implant.
Group 3: Semi-conical geometry with dual flat tip thread, long thread pitch, progressive thread depth, an apical area with a small self-tapping portion and a 3 mm portion with threads from the cervical portion. A stainless steel final drill is provided with each implant.

The implants underwent a sandblasted surface treatment with large-grit and acid-etching (SLA) throughout the body and internal hex connection. The implants measured 3.75 mm in diameter and 10 mm in length.

2.2. Animals and surgical procedure

Nine New Zealand white mature rabbits weighing approximately 4 kg were used in this study. This study was approved by the ethics committee of the Federal University of Santa Maria, Rio Grande do Sul, Brazil. The rabbit represents a frequently used test model system in Orthopedics, the reasons for which are probably more historical and economic (Wennerberg et al., 2003). This animal model was chosen because it provides ideal conditions for the investigation of bone regeneration and implant osseointegration (Lopes and König Júnior, 2002; Novaes et al., 2010). The rabbits were anesthetized by intramuscular injection of ketamine (35 mg/kg; Agener Pharmaceutica, Brazil). Then, a muscle relaxant (Rompum 5 mg/kg, Bayer, Brazil) and a tranquilizer (Acepran 0.75 mg/kg, Univet, Brazil) were injected intramuscularly. Additionally 1 ml of local anesthetic (3% Prilocaine-felypressin, Astra, Mexico) was injected subcutaneously at the site of surgery to improve analgesia and to control bleeding. A skin incision with a periosteal flap was used to expose the bone of both proximal tibias. The bone site was prepared with burs under copious saline irrigation. One implant from each group was inserted for into each tibia, totaling three implants per tibia. The implants were positioned at the same level with respect to the marginal border, that is, at bone level and, fixed bicortically. The tibia was chosen as the implant site because of the simplicity of the surgical access (Piattelli et al., 2003). As the implant location in the tibia may influence both osseointegration and removal torque due to different bone features from metaphysis to diaphysis, the position of implant insertion belonging to the three groups was changed so as to have equality in the distribution of implant locations in the tibia for each group. The insertion torque of the implants was monitored using a manual torquemeter and did not exceed 20 ± 3 N; the stability was then measured. The periosteum and fascia were sutured with catgut sutures and the skin with silk sutures. Postoperatively, a single dose of 600,000 IU Benzetacil was used. After surgery, the animals were placed in individual cages with 12-h cycles of light, controlled temperature (21 °C) and the ad libitum diet that is normally used by the laboratory. No complications or deaths occurred during the postoperative period. All animals were killed with an intravenous overdose of ketamine (2 ml) and xylazine (1 ml); three animals were killed for each time point: 6 weeks, 8 weeks and 12 weeks after the implantations. Both tibias were removed, placed in 10% formalin solution and immediately taken to the laboratory (Biotecnos, Santa Maria, Brazil) for analysis.

2.3. Resonance frequency analysis

All rabbits were used for resonance frequency analysis (RFA) to measure the implant stability. A Smartpeg^{TM} (Integration Diagnostics AB, Göteborg, Sweden) was screwed into each implant and tightened to approximately 5 N. The transducer probe was aimed at the small magnet at the top of the Smartpeg at a distance of 2 or 3 mm and held stable during the pulsing until the instrument beeped and displayed the ISQ value. For RFA, the implants were measured immediately after the installation and three times during removal: immediately after the implant installation; 6-weeks after the implant installation; 8-weeks after the implant installation; 12-weeks after the implant installation. The implant stability quotient (ISQ) values were measured by Osstell^{TM} Mentor (Integration Diagnostics AB, Göteborg, Sweden). The ISQ values were measured in two directions proximal to distal and lateral to medial, and an average of each sample was determined (Fig. 2). A mean value was calculated from the measurements performed parallel to the long axis of the tibiae.

2.4. Removal torque test

A total of 54 implants were retrieved. The biological specimens were processed immediately after removal of the tibiae. The samples were maintained in liquid solution (10% buffered formalin), and immediately evaluated (1 h after removal) thus before dehydration; a Torque Testing Machine—CME (Técnica Industrial Oswaldo Filizola, Guarulhos, Brazil), which is fully controlled by software DynaView Torque Standard/Pro M (Fig. 3), performing