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Influence of thread shape and inclination on the biomechanical behaviour of plateau implant systems

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ABSTRACT

Objective. To assess the influence of implant thread shape and inclination on the mechanical behaviour of bone-implant systems. The study assesses which factors influence the initial and full osseointegration stages.

Methods. Point clouds of the original implant were created using a non-contact reverse engineering technique. A 3D tessellated surface was created using Geomagic Studio® software. From cross-section curves, generated by intersecting the tessellated model and cutting-planes, a 3D parametric CAD model was created using SolidWorks® 2017. By the permutation of three thread shapes (rectangular, 30° trapezoidal, 45° trapezoidal) and three thread inclinations (0°, 3° or 6°), nine geometric configurations were obtained. Two different osseointegration stages were analysed: the initial osseointegration and a full osseointegration. In total, 18 different FE models were analysed and two load conditions were applied to each model. The mechanical behaviour of the models was analysed by Finite Element (FE) Analysis using ANSYS® v. 17.0. Static linear analyses were also carried out.

Results. ANOVA was used to assess the influence of each factor. Models with a rectangular thread and 6° inclination provided the best results and reduced displacement in the initial osseointegration stages up to 4.58%. This configuration also reduced equivalent VM stress peaks up to 54%. The same effect was confirmed for the full osseointegration stage, where 6° inclination reduced stress peaks by up to 62%.

Significance. The FE analysis confirmed the beneficial effect of thread inclination, reducing the displacement in immediate post-operative conditions and equivalent VM stress peaks. Thread shape does not significantly influence the mechanical behaviour of bone-implant

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systems but contributes to reducing stress peaks in the trabecular bone in both the initial and full osseointegration stages.
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1. Introduction

There are many dental implants and materials used to create restorations such as abutments and crowns. For this reason, dentists have a variety of options to find the best implant treatment for the specific needs of their patients.

The most commonly used dental implants are the endosteal ones that are surgically implanted directly into the jaw bone representing an alternative to bridges or detachable dentures. They come in several types including screw/threaded, cylinder/smooth and plateau implants.

The development of dental implant systems benefited from titanium's biocompatibility and osteoinductive properties that can lead to an optimal implant osseointegration [1]. This phenomenon is responsible for the high level of treatment success reached by endosteal dental implants in current times. Reaching a good osseointegration level depends on a variety of factors and their inadequate control affects the stable anchorage of the implant to the bone tissue.

Some authors emphasised the role of surface treatment for long-term stability of implants [2]. This seems to be closely related to a continuous and adequate remodelling regarding the implants, with bone restructuring having an important role in the anchoring of the implant [3].

The success of the implant treatment generally depends on the good primary stability (which is a mechanical phenomenon) and secondary stability (which is a biological phenomenon called osseointegration). Factors playing a major role in achieving a good primary stability of dental implants have been reported [4]. Some authors measured the stability of dental implants using resonance frequency analysis [5]; other authors instead have experimentally measured *in vivo* the load distribution in mandibular implant-retained overdentures [6].

Among various kinds of endosteal dental implants, plateau implants have been originally produced by two manufacturers (i.e. Bicon and Tatum Surgical Inc.) and have been implanted since 1985.

Bicon SHORT® implants are highly recommended for patients with limited bone height. The short lengths (<8 mm) allow clinicians to avoid vital structures, such as the inferior alveolar nerve, and can eliminate the need for grafting or sinus lifting procedures. These implants are characterised by multiple parallel circular-shaped threads, commonly known as plateau or fins. Plateau design offers a larger surface area than a screw implant of the same dimensions and allows for the callus formation between the fins of the implant. Furthermore, the larger surface area of bone-implant contact facilitates stress reduction due to load transfer along the bone-implant interface.

Recent studies on the behaviour of short implants were carried out to assess the relationship between implant factors, such as length and macrostructure [7,8]. Moreover, the bone healing response to different implant root shape designs and cumulative survival rates of short implants were investigated [9–11]. Improved designs of plateau root forms [12–14] have increased the cumulative survival rate to above 90% [15] and optimised the biological responses of early endosseous peri-implant healing [16].

The implant design is one of the primary factors that determine the resultant stress at the interface for a given load condition. Excessive stress on the bone may cause bone resorption and hamper a good long-term stability of the implant [17–19]. An implant with less than 1 mm of bone loss during the first year and 2 mm thereafter can be considered successful. In relation to the aforementioned issues, plateau implants provide a very good performance. Their peculiarity is that they leave hollow spaces between the implant and bone, called 'healing chambers' [18] that are progressively filled by new bone apposition.

The mechanical response of the implant–bone system can be investigated *in silico* by means of three-dimensional finite element analysis (FEA) [20–27]. Modern CAD–FEM (Computer Aided Design and Finite Element Method) methodologies play an essential role in biomedical investigations [28], in particular in dentistry [29,30]. These represent a powerful tool used by several authors to investigate the stress distributions in bone-implant systems [31,32] as well as in endodontically treated teeth [33,34] and crown restorations [35–38], considering different loading conditions.

However, apart from sparse clinical results, the influence of features determining plateau implant geometry has been studied with reference to bone remodelling patterns and clinical outcomes, while it needs to be clarified with reference to load transfer and implant stability.

The aim of the of the present investigation was to assess the influence of the implant thread shape and inclination on the mechanical behaviour of bone-implant systems by reference to the initial and full osseointegration stages.

2. Materials and methods

2.1. Generation of solid models

The original implant shape (4.5 × 6.0 mm Bicon SHORT® Dental Implant, Boston, USA) was digitised by a reverse engineering technique [39] with a laser scanner CAM2 Edge SCANARM HD — FARO (accuracy ±25 μm). Point clouds were imported into the Geomagic Studio® environment, where 3D tessellated surfaces were created. Feature detection algorithms, embedded into Geomagic Studio® software, were then adopted to extract sharp edges and cross section curves. Starting from cross-sections curves, the parametric 3D CAD model (Fig. 1, rectangular thread) was created using SolidWorks®

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