Journal of Applied Biomaterials & Biomechanics 2009; Vol. 7 no. 1: 23-28 ORIGINAL ARTICLE

Mechanical characterization of an innovative dental implant system

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ABSTRACT: Purpose: *The research presented is aimed at the characterization of the mechanical resistance of an innovative system of an abutment-fixture connection in dental implants. This innovative connection system is composed of a triangular prismatic connection designed to improve the anti-rotational properties of the implant, and to seal any gap between the abutment and the fixture.*
Methods: *The mechanical performances of the dental implant system were investigated by means of static mechanical strength tests, which allowed the identification of the bending, torque and compression resistance of the system, and fatigue testing, according to the practice standard - ISO 14801. Surface finishing was also analyzed by scanning electron microscopy (SEM) observations and laser profilometry tests.*
Results: *The analyzed implant exhibited good mechanical characteristics, both in static and in fatigue tests. Moreover, the gap between the fixture and the abutment detected by SEM analyses was restricted, both before and after fatigue tests, being approximately 4 μm in the worst case observed: this is representative of optimal sealing against fluid infiltration.*
Conclusions: *The modification of traditional dental implants with the introduction of a triangular prismatic connection system not only allowed the implant rotational stability and sealing performances to increase, but also conferred optimal mechanical resistance to the implant. (Journal of Applied Biomaterials & Biomechanics 2009; 7: 23-8)*

KEY WORDS: *Titanium, Dental implant, Mechanical resistance, Roughness*

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INTRODUCTION

Dental implants are usually composed of two independent elements, ie a fixture and an abutment, connected by various devices. The fixture component is actually inserted into the osseous tissue, while the abutment acts as the support where the crown, or ceramic part, of the prosthesis is mounted. The two elements are usually connected by a screw; in some cases a tapered joint can be used, either alone or with the support of a differently shaped insert (for example, pentagonal, hexagonal or octagonal), whose purpose is to fix the abutment orientation (1-3).

It is well-recognized that the environment has a strong influence on the implant service life, with particular reference to bacteria infiltration and consequent infections: this issue can be faced by applying surface treatments that enhance the implant resistance to bacteria colonization, or by adopting a proper implant design of the sealing system (4-8).

BTLock SrL proposed an innovative connection system composed by fixture of an abutment and a connection screw; the abutment-fixture connection is obtained by a triangular prismatic connection on three different levels. The resistance to bending loads applied to the abutment is provided by the high insertion depth of the abutment into the fixture: the prismatic connection acts on different levels, i.e. through the triangular connection, and at a deeper level through a cylindrical sliding connection. The two connections, together with the screw, are designed to provide high stability to angulated loads applied through the abutment, and consequently induced flexural stress.

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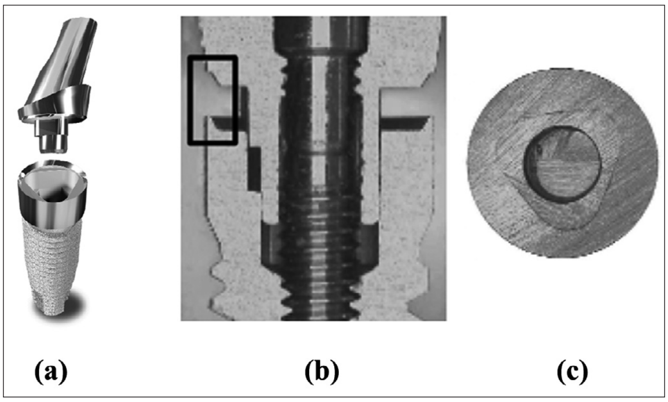

Fig. 1 - ***Fixture-abutment connection system.***

The fixture, manufactured in commercial purity grade 4 titanium, is characterized by a cylindrical design in proximal position, which becomes conical in the apical position. The traditional threads on the fixture are coupled with micro-threads on the implant neck, aimed at increasing the osseointegration of the implant in the cortical proximal area, while the screw threads geometry and dimensions are designed to improve integration with spongious bone, and consequently load transfer and implant stability.

The abutment-fixture system is designed to permit platform switching (9, 10): since the abutment has a reduced diameter compared to the fixture diameter, the fixture-abutment rim can be shifted towards the center of the implant axis, resulting in an improved implant success probability, due to a safer tissue positioning and lower infiltration possibility. The plastic deformation of the conical termination of the external part of the platform is responsible for the effective seal to the infiltration of fluids and microbial agents. Moreover, the implant design allows a thicker gum pad; therefore, increasing the abutment biological sealing.

Longitudinal machining marks, which extend over the fixture tip up to the neck, are intended to facilitate both the implant insertion in the drilled site and to release the tensile stresses generated by the screwing insertion. The six marks have a mirror-like symmetry: the three clockwise oriented marks are designed to facilitate the fixture screwing insertion, while the three anticlockwise oriented marks are intended to enforce the anti-rotational stability following osseointegration and the new bone apposition. The smooth end of the neck, with an extension of 0.3 mm, is designed to avoid the infiltration of germs and bacteria.

These implants are designed to achieve an enhanced rotational stability and resistance to fluid infiltration; although the mechanical performances of the device still need to be tested, in order to assess the effective suitability of the proposed connection system. Dental implants undergo various stress situations, mainly due to mastication, which must be withstood by the system without demonstrating failure or damage. Mastication loads involve different components, in particular, compression forces and fatigue stresses. In the former case, the maximum value was estimated to vary from 880 N in the molar section to 220 N in the incisors, while the mean value is remarkably lower (approximately 200 N). Conversely, tangential loads, which can also be dangerous, never exceed 100 N (11-13).

In this study, the mechanical resistance conferred by a triangular prismatic connection of the fixture and the abutment to a dental implant was characterized; static and fatigue tests were performed. The sealing effectiveness of the connection was also considered.

MATERIALS AND METHODS

Tested implant systems

As mentioned above, the dental implant system investigated is composed of a fixture, an abutment and a connection screw. Its peculiarity is related to a patented abutment-fixture connection obtained by a triangular prismatic connection on three different levels (Fig. 1). The triangular connection ensures an effective rotational stability, while the conical axial connection, matching the abutment design (Fig. 1b, rectangular box), prevents fluid infiltration inside the implant, and consequent bacteria proliferation and colonization issues. This connection system allows an enhanced rotational stability, compared to traditional hexagonal or octagonal anti-rotational connections.

Two different types of surface finishing were applied, labeled as DMA and BT-Tite. The former is obtained by combined physical-mechanical processing, i.e. sandblasting with controlled powders granulometry, and subsequent chemical processing (double acidic etching followed by time-controlled passivation). The surface finishing obtained produces a highly microporous surface, which should combine with a deep screw thread to give improved osseointegration and increased primary stability. The BT-Tite surface finishing was obtained by directly applying a chemical etching treatment on the machined surface.

Mechanical tests were performed on the dental implant systems, according to the practice standard ISO 14801 (14). The worst case testing principle was applied, and the tested dental implants described represent the worst case situation in terms of size and fixture core diameter.

Bending, torque and compression static tests and fatigue tests were performed on the following finished devices:

- Fixture: diameter 3.75 mm, length 11.5 mm, titanium (grade 4, ISO 5832-2 (15)).
- Abutment: diameter 3.75 mm, length 11 mm, titanium alloy (grade 5, ISO 5832-3(15)).
- Connection screw: thread diameter 1.8 mm, titanium alloy (grade 5, ISO 5832-3 (15)).

This system is identified as S-T.

Before static and fatigue testing, each fixture was connected to the abutment using its connection screw and applying a torque of 30 N cm through a specific dynamometric wrench.

Static tests were also performed on implant systems characterized by shorter threads and a larger core, labeled S-S. Finally, additional static tests were performed on 25° angled abutment systems (S-A).

Testing procedure

Static and fatigue tests were performed using two Instron machines: an electromechanical one for static tests, and a servo-hydraulic machine for dynamic fatigue tests, both equipped with a 50 kN load cell. The servo-hydraulic testing machine allowed the application of the desired cyclic load with frequencies up to 12 Hz; the error did not exceed ± 5% of the maximum applied load.

In all mechanical tests, loading geometry was chosen according to the ISO 14801:2007 standard; the load was applied to the abutment through a 10 mm diameter stainless steel hemisphere, positioned on the hollow tip of the abutment by an internal pin. The implant was cemented inside a stainless steel hollow cylinder, using cold-curing acrylic resin. The fixture was retracted 3 mm above the hollow cylinder level, in order to consider the worst case of bone resorption. The implant was positioned at 30° with respect to the vertical axis of the loading system. The load was applied to the hemisphere through the flat surface of a stainless steel rod base.

To evaluate the torque resistance of the implant, fixtures were screwed into a true 10 mm diameter stainless steel rod, which was positioned inside the inferior hydraulic clamp of an 858 Mini Bionix MTS machine. A stainless steel pin was inserted in the hollow abutment, in order to pinch the abutment with a true high load. In addition, the abutment was clamped to the upper hydraulic clamp of the MTS machine. Four tests were performed with a constant rotation rate of 25°/min.

Finally, the surface characteristics of all analyzed systems were investigated by scanning electron microscope (SEM) observations and laser profilometric measurements.

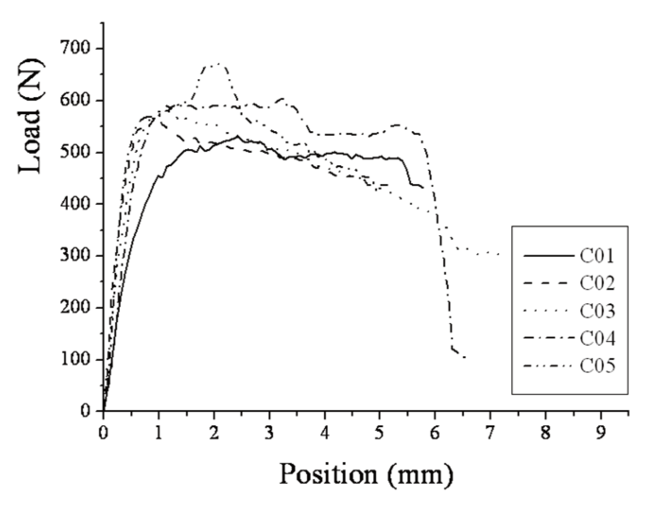

Fig. 2 - ***Bending tests: load vs. position curves for five specimens of dental system S-T.***

RESULTS AND DISCUSSION

Mechanical tests

Static tests were performed by applying a 0.03 mm/sec ramp and measuring the resistant load. Tests were performed on five identical specimens; the test was concluded when failure or plastic bending deformation higher than 5 mm occurred. Figure 2 shows results obtained on the dental implant S-T.

The maximum bending moment was calculated as follows:

$$M = 0.5 \cdot F \cdot L \qquad \text{[Eq. 1]}$$

F being the applied load and L being the distance of the clamping plane from the loading center. Considering that the hemisphere has a radius of 5 mm and that it protrudes 2.8 mm from the abutment, the loading center is located 2.2 mm below the measure length L.

The calculated maximum average load was 591 ± 52 N; the maximum bending moment, calculated as an average over the five tested specimens, was 220 ± 11 N cm.

Static tests were also performed on specimens S-S and S-A: in the latter case, load orientation was angled at 30° with respect to the fixture, which corresponded to an angle of 55° with respect to the abutment axis. The calculated average maximum loads were 774 ± 67 N (S-S) and 393 ± 47 N (S-A), while the average maximum bending moments were 337 ± 20 N cm (S-S) and 213 ± 28 N cm (S-A).

In fatigue tests, a sinusoidal cyclic unidirectional load was applied. The minimum load of the sinusoidal cy-

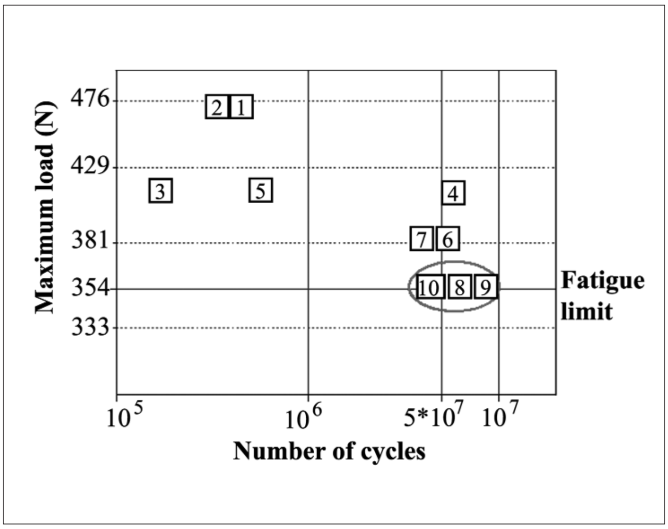

Fig. 3 - ***Fatigue test: load vs. cycle diagram for 10 specimens of dental system S-T.***

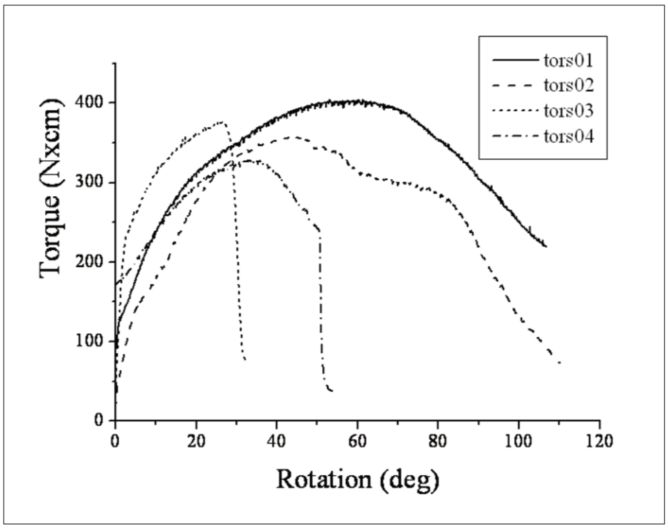

Fig. 4 - ***Torque tests: torque vs. rotation curves for four specimens of dental system S-T.***

cle was selected as 10% of the maximum nominal load. The loading frequency was 10 Hz. Eighty percent of the average maximum load calculated from the static tests, described above, was used as a starting maximum load for fatigue tests. Figure 3 reports the load vs. cycle diagram; in this case, 10 identical specimens were tested for system S-T. The fatigue limit at 5 million cycles was identified at 354 N, corresponding to a maximum bending moment of 154 N cm.

Further mechanical tests were performed on dental system S-T in order to evaluate the torque resistance of the connection system between the fixture and the abutment, as described in the experimental section. Figure 4 shows the torque vs. rotation plot results; the maximum average torque proved to be 366.5 ± 32 N cm. Failure of all four tested implants took place inside the hollow abutment, and the connection between the fixture and the abutment did not fail at all (Fig. 5).

Finally, compression tests were performed on specimens S-T. Fixtures were screwed into true 10 mm diameter stainless steels rods; tests were performed by applying a 0.05 mm/sec ramp, and repeated on four specimens. Figure 6 shows the results of the compression tests performed on the dental implants S-T. A maximum average compression load of 6625 ± 377 N was measured.

During the compression tests, some adjustment occurred on all specimens tested, up to a position of 3-4 mm; this was related to the gradual insertion of the fixture in the connection jig, and was not connected with the mechanical performance of the dental system.

From the static bending tests performed on the three dental systems with a triangular prismatic connection, ie the standard system S-T, a modified system

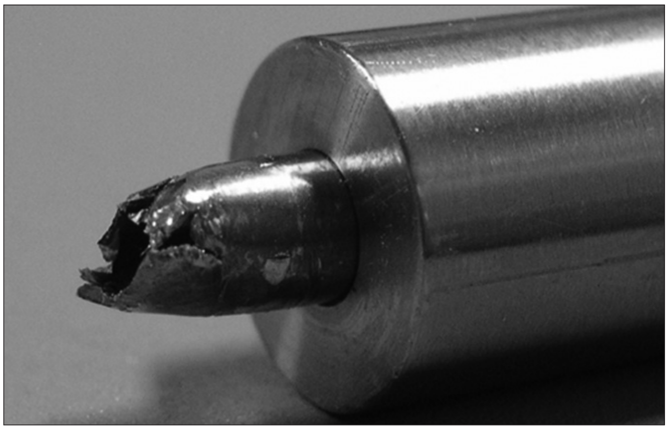

Fig. 5 - ***Failed abutment of implant system tors04 after the torque test.***

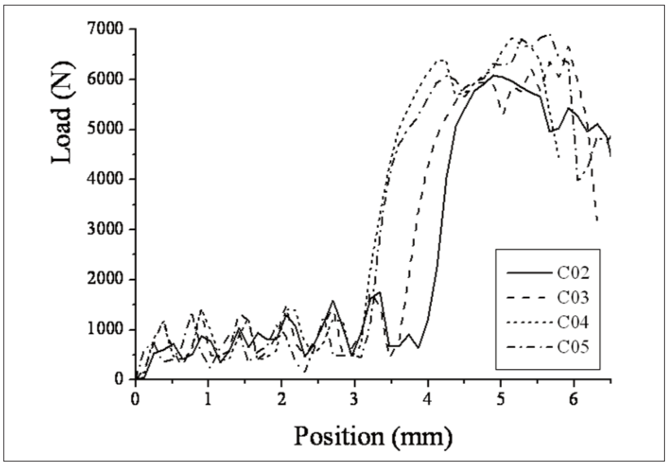

Fig. 6 - ***Compression tests: load vs. position curves for five specimens of dental system S-T.***

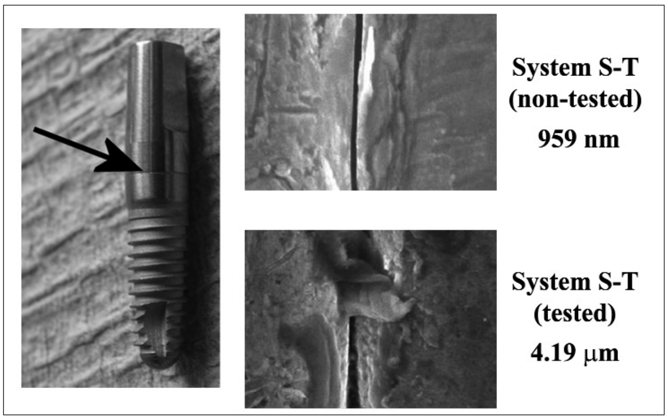

Fig. 7 - ***Example of measurement of fixture-abutment gaps on non-tested specimens and fatigue-tested specimens by SEM analyses.***

having shorter threads and a larger core (S-S), and a system showing a 25° angulated abutment (S-A), the major resistance of system S-S was proved by virtue of its lower aspect ratio. Nevertheless, values were well above the typical stress values encountered by dental implants, experienced during mastication.

In the standard case S-T, a fatigue limit of approximately 354 N was detected at 5 million loading cycles, being the maximum applied load 80% of the resistance measured in the previous test; the torque resistance was fixed at 366 N cm, while the compression resistance was 6625 N. In addition in this case, the observed resistance was higher than that required during the implant service life.

Surface characterization

After mechanical testing, the connection effectiveness was evaluated through SEM analysis of the gap between the fixture and the abutment on dental system S-T, both on non-tested specimens and on specimens that survived the fatigue test (5 million cycles at 354 N). The measured gaps on non-tested specimens and on fatigue-tested specimens were always minimal and well below 10 μm, which ensures an optimal sealing ability (Fig. 7).
SEM analyses were also performed to provide the qualitative aspect of surface morphology, as well as an evaluation of surface contamination. Two different surface finishing treatments were applied: BT-Tite and DMA (Figs. 8, 9).

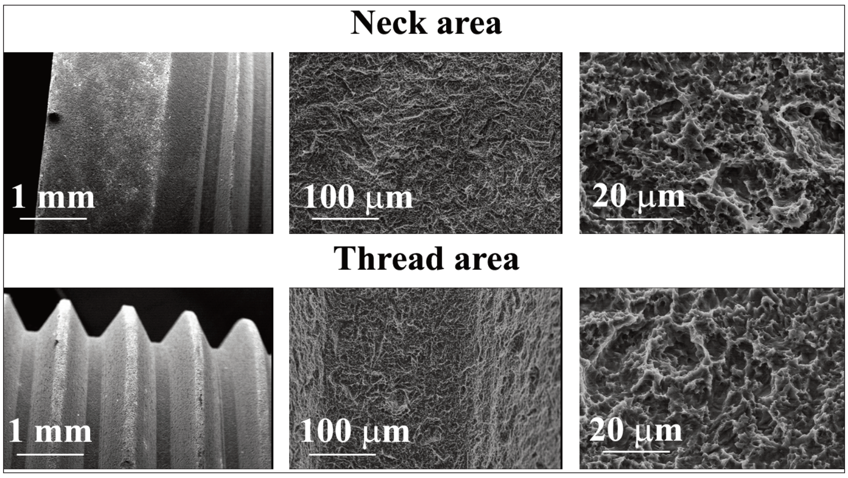

Fig. 8 - ***DMA surface: neck and thread areas at different magnifications.***

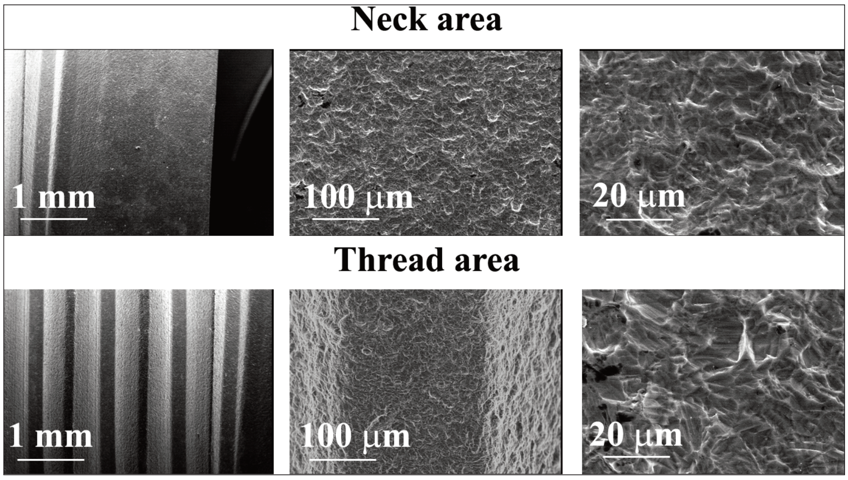

Fig. 9 - ***BT-Tite surface: neck and thread areas at different magnifications.***

Both DMA and BT-Tite surfaces showed a homogeneous surface finishing treatment on both neck and threads areas. All analyzed surfaces were found to be clean and decontaminated. Roughness analyses were performed by using a 3D laser profilometer (UBM, Germany), and provided R_a values around 0.7 µm for the DMA treatment and 0.65 µm for the BT-Tite treatment.

CONCLUSIONS

In this work, the mechanical resistance of a dental implant characterized by an innovative abutment-fixture connection system was tested: bending, torque and compression resistances were evaluated, as well as the behavior of the implant subjected to cyclic loading through fatigue tests.
The system investigated presented design variations necessary to promote implant sealing; therefore, increasing its resistance to infiltration and consequently to bacteria proliferation, and its rotational stability for an improved functionality. Nevertheless, after an in-depth analysis of its mechanical characteristics, an optimal resistance of the dental implant was observed. The measured resistance values were all located in the upper range of mechanical resistances exhibited by implants of analogous dimensions; therefore, proving a brilliant combination of mechanical reliability and implant functionality. The connection effectiveness was confirmed by observing the narrow gap established between the fixture and the abutment, which was maintained to restricted values even after fatigue tests.

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REFERENCES

1. Binon PP. Implants and components: entering the new millennium. Int J Oral Maxillofac Implants 2000; 15: 76-94.
2. Schweizer CM, Schlegel KA, Rudzki-Janson I. Endosseous dental implants in orthodontic therapy. Int Dent J 1996; 46: 61-8.
3. Zonfrillo G, Pratesi F. Mechanical strength of dental implants. Journal of Applied Biomaterials & Biomechanics 2008; 6: 110-8.
4. Visai L, Rimondini L, Giordano C, et al. Electrochemical surface modification of titanium for implant abutments can affect oral bacteria contamination. Journal of Applied Biomaterials & Biomechanics 2008; 6: 170-7.
5. Draghi L, Cigada A. Nanostructured surfaces for biomedical applications. Part I: nanotopography. Journal of Applied Biomaterials & Biomechanics 2007; 5: 61-9.
6. Forsgren J, Svahn F, Jarmar T, Engqvist H. Structural change of biomimetic hydroxyapatite coatings due to heat treatment. Journal of Applied Biomaterials & Biomechanics 2007; 5: 23-7.
7. Giordano C, Pedeferri MP, Olivero P, et al. In-vitro study of a new treatment for controlling bacterial adhesion to titanium and titanium-alloy dental implants. In: XXV Conferenza Nazionale di Citometria Abstracts. Cytometry A 2008; 73: 48-108.
8. Baggi L, Cappelloni I, Di Girolamo M, Maceri F, Vairo G. The influence of implant diameter and length on stress distribution of osseointegrated implants related to crestal bone geometry: a three-dimensional finite element analysis. J Prosthet Dent 2008; 100: 422-31.
9. Lazzara RJ, Porter SS. Platform switching: a new concept in implant dentistry for controlling postrestorative crestal bone levels. Int J Periodontics Restorative Dent 2006; 26: 9-17.
10. Luongo R, Traini T, Guidone PC, Bianco G, Cocchetto R, Celletti R. Hard and soft tissue responses to the platform-switching technique. Int J Periodontics Restorative Dent 2008; 28: 551-7.
11. Berglundh T, Persson L, Klinge B. A systematic review of the incidence of biological and technical complications in implant dentistry reported in prospective longitudinal studies of at least 5 years. J Clin Periodontol 2002; 29: 197-212.
12. Tortopidis D, Lyons MF, Baxendale RH, Gilmour WH. The variability of bite force measurements between sessions in different positions within the dental arch. J Oral Rehabil 1998; 25: 681-6.
13. Brunski, BJ. In vivo bone response to biomedical loading at the bone/dental-implant interface. Adv Dent Res 1999; 13: 99-119.
14. Dentistry - implants - dynamic fatigue test for endosseous dental implants. ISO 14801.
15. Implants for surgery - Metallic materials. ISO 5832.