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Comparation of Mechanical Responses of Dental Implants Manufactured by 3D Printing and Machining

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Abstract. This paper deals with the basic comparison of dental implant stems behavior during static loading tests. The implants used for the tests were manufactured by the mechanical machining method with use of the standard alloy Ti6Al4V and experimental alloy Ti35Nb6Ta. Another implant used for loading tests was produced by the method of 3D printing from the standard alloy Ti6Al4V. The shape solutions of used implants are based on patent files no. CZ 306456 and CZ 306457. The method of loading test is based on valid legislative, which is necessary for product launch on the market and it is managed by ČSN EN ISO 140801 (Dentistry – Implants – Dynamic loading test for endosseous dental implants).

Introduction

The stems of dental implants are conventionally manufactured by machining the titanium alloy Ti6Al4V. To ensure a good stability of the implant in the bone, a very good level of material biocompatibility is required [1]. The Ti6Al4V alloy has a long recorded history of success, but its use is usually coupled with applying a special coating (i.e.: plasmatic Ti coating, acid etching, blasting) and limiting the complexity of the intraosseous implant geometry. The overall stiffness of the implant then substantially exceeds the stiffness of the former tooth and the surrounding bone tissue [2]. This paper is dedicated to the comparison of mechanical load capacities of four different dental implant stems. For the purpose of mechanical tests, we used two different implant stem geometries, two different materials and two different manufacturing methods. The methods and materials were chosen with consideration of utilizing more complex geometries (3D printing), high biocompatibility (Ti35Nb6Ta) and lower material stiffness. The main goal of this research was to determine the ultimate bearing capacity of various implants according to the ČSN EN ISO 14801 (Dentistry – Implants – Dynamic loading test for endosseous dental implants) [3] and their comparison.

Methods

Two basic intraosseous implant geometries were used in the experiment - the „ribbed“ [patented CZ patent n. 306456] and the „four leaf clover“ [patented CZ patent n. 306457] variants (Fig. 1). A total of 24 specimens were created and divided into four groups (Table 1).

Fig. 2: Computer 3D models: left – “ribbed” implant, right – "four-leaf clover" implant.

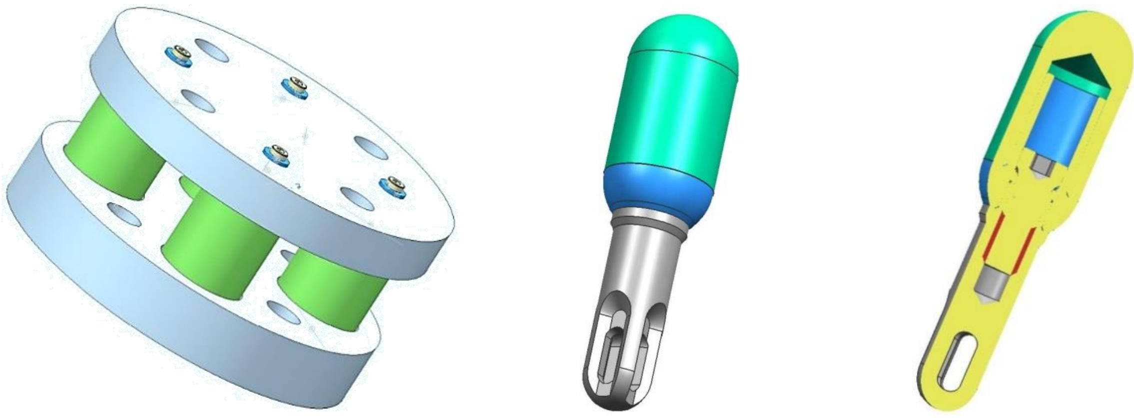
The use of alternative material with beta-structure Ti35Nb6Ta and the optimization of the intraosseous part of the implant is based on the need to lower the total stiffness of the implant stem. High stiffness of the stem causes stress-shielding and thus an unwanted distribution (lowering) of stress in the surrounding bone tissue.

Table 1.: Implant specimens specificatitons

Implant type	Geometry	Material	Manu. method	Diameter [mm]
Variant I	ribbed	Ti6Al4V	machined	Ø3.8-10
Variant II	ribbed	Ti35Nb6Ta	machined	Ø3.8-10
Variant III	four leaf clover	Ti35Nb6Ta	machined	Ø3.8-10
Variant IV	four leaf clover	Ti6Al4V	3D printed	Ø3.8-10

Accurate comparison of used materials behavior was based on comparative measurement of micromechanical properties (reduced elastic modulus and hardness) analyzed by the nanoindentation method [4]. Material samples were fixed in epoxy resin, cut, polished and measured by the CSM Instruments device. Reduced modulus E_r values are around ~ 126 GPa in case of the Ti6Al4V material, around ~ 122 GPa in case of the Ti6Al4V material manufactured by the 3D printing method and around ~ 82 GPa in case of the Ti35Nb6Ta material. Hardness H_{it} values are around ~ 4.58 GPa in case of the Ti6Al4V material, around ~ 5.21 GPa in case of the Ti6Al4V material manufactured by the 3D printing method and around ~ 2.98 GPa in case of the Ti35Nb6Ta material [5].

Other components have to be produced for mechanical loading text realization, for example grouting plate, loading adapters with cylindrical surface, contact caps and connecting screws (Fig. 2). The grouting plate meets the requirements of the norm and allows repeated precision grouting of the implant’s intraosseous part by the two-component methyl methacrylate resin (Dentacryl). Other used components replace the extension part of the implant (abutment with crown) and ensure the force transmission to the implant body.



A B

Fig. 2: Computer 3D models: A – grouting plate for samples preparation, B – ribbed implant with loading adapter.

For the purpose of testing, we used the MTS Mini Bionix 8_58.02 system and the methodology according to the ČSN EN ISO 14801 standard. The mechanical tests were carried out by anchoring the test specimens in a special mount, fitting on a special cover and loading. Static loading was done at a constant speed of 4.0 mm/min. The air temperature was 20±5°C.

Results

For the 4 tested groups of newly designed implants, we determined the values of ultimate bearing capacities for static load F_{ST} [Table 2]. During the next phase of measurement, we will determine the limit fatigue F_{FL} for 5 x 10^6 cycles.

Table 2. Ultimate bearing capacities for static load of tested implants

	Variant I	Variant II	Variant III	Variant IV
Ult. bearing capacity F_{ST} [N]	586.0	446.0	335.0	484.4
Std. dev. [N]	35.0	17.0	8.0	4.5
Expanded uncertainty [N]	69.0	33.0	17.0	9.3

Different type of damage was detected for individual implant variants after the loading tests (Fig. 3). Bearing capacity was achieved in case of variant I and II by screw collapse at the connection between the implant and the abutment. The intraosseal part of the implant was not damaged by fracture. In case of variant III and IV the fracture damage was detected at the interface of the implant and the grouting resin in accordance with the assumption of lower stiffness of the implant stem. The most frequent response of variant III during the loading test is the creation of a great plastic deformation with following non-increasing loading force. The most frequent collapse of stem variant IV was caused by fracture damage inside the body of the intraosseal part of the implant.

Variant I Variant II Variant III Variant IV

Fig. 3: Example of collapse in case of individual implant types after the loading tests.

Conclusions

The experimental tests have shown a great difference in the ultimate bearing capacities of different implant variants. As predicted, the highest attained load capacity was recorded in the conventionally machined Ti6Al4V specimen. By introducing the beta-structured titanium alloy, a great reduction in stiffness was observed. The „four leaf clover“ geometry scores a lower value of load capacity as well. The reduction of overall stiffness of the implant is beneficial in regard to the elimination of stress-shielding in the intraosseous implant stem.

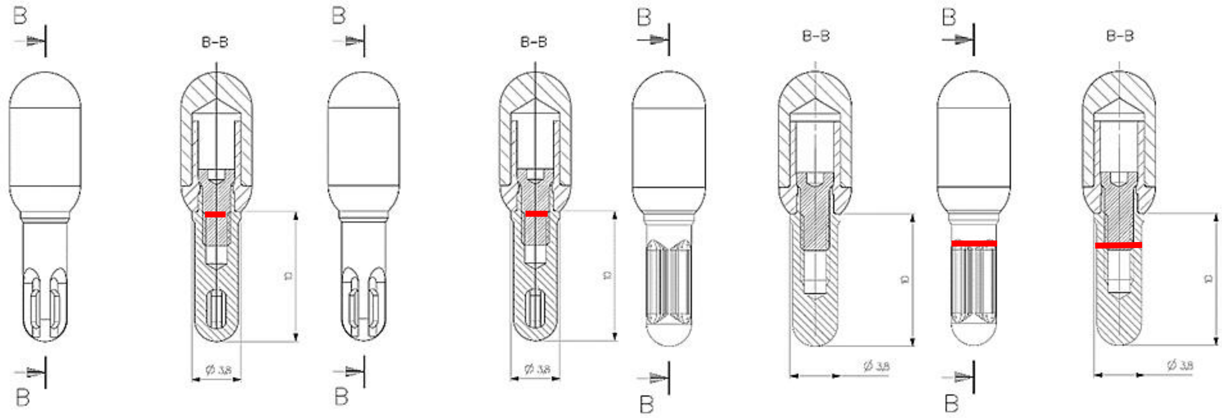


Fig. 4: Schematic illustration of common fracture localities (red line) in case of tested implants after the loading tests. From left side: variant I (screw damage), variant II (screw damage), variant III (plastic deformation without fracture), variant IV (implant damage at the anchoring interface)

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