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Analysis of resistance to fatigue between straight solid and anatomic abutments of Morse taper system

Análise da resistência à fadiga entre pilares retos e anatômicos do sistema cone Morse

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Resumo

Contexto: O estudo do fenômeno de fadiga é essencial porque as falhas de implantes geralmente são causadas por este processo. **Objetivo:** O objetivo deste estudo foi analisar a resistência à fadiga de conjuntos de pilares retos e anatômicos que foram submetidos a cargas cíclicas. **Material e método:** Foram utilizados 37 implantes cone Morse e 37 pilares, divididos em dois grupos (n = 16: pilares retos, n = 21: pilares anatômicos). Os conjuntos foram submetidos à carga cíclica (5.000.000) usando o equipamento servo-hidráulico. Três conjuntos de cada grupo foram submetidos a testes de flexão para determinar a resistência de carga máxima, o que serviu de parâmetro para comparação dos testes cíclicos. Foram avaliados número de ciclos, carga e momento de flexão. **Resultado:** Dos 31 pilares ciclicamente testados, 17 (54,8%) fraturaram em menos de 5 milhões de ciclos; 8 (25,8%) destes eram pilares retos, e 9 (29%) eram anatômicos. Um total de 14 amostras (45,2%) resistiu à carga cíclica. De acordo com o teste exato de Fisher, não houve diferença entre os grupos quanto à fratura. **Conclusão:** Apesar dos pilares retos terem maior carga média e momento de flexão que os anatômicos, os dois tipos de pilares apresentaram desempenho semelhante quanto a resistência à fratura *in vitro*.

Descritores: Implantes dentários; resistência de materiais; fenômenos mecânicos.

Abstract

Background: The study of the phenomenon of fatigue is essential because implant failures usually are caused by this process. **Purpose:** The objective of this study was to examine the fatigue resistance of straight and anatomical abutments joints that were submitted to cyclic loads. **Material and method:** We used 37 Morse taper implants and 37 abutments, divided into two groups (n= 16: straight abutment, n= 21 anatomical abutment). The sets were submitted to cyclic loading (5 million) using servo-hydraulic equipment. Three sets from each group were subjected to bending tests to determine the maximum load resistance, which served as the parameter for comparison of the cyclic tests. We evaluated number of cycles, load and bending moment. **Result:** Of the 31 abutments cyclically tested, 17 (54.8%) fractured in fewer than 5 million cycles; 8 (25.8%) of these were straight abutments, and 9 (29%) were anatomical. A total of 14 samples (45.2%) resisted the cyclic loading. According to Fisher's exact test, there was no difference between groups as the fracture. **Conclusion:** Despite of the straight abutments have higher average load and bending moment on the anatomical, both types of abutments showed similar performance as the fracture strength *in vitro*.

Descriptors: Dental implants; material resistance; mechanical phenomena.

INTRODUCTION

Mechanical problems, such as the loosening or fracture of prosthetic abutments, screw loosening and fixation instability are commonly reported in oral rehabilitation with implants[1]. Poor bone quality, a lack of initial stability, overload and fractures of implant and abutment screws has also been associated with failures in prosthetic rehabilitation. Additionally, occlusal imbalance can lead to material fatigue, and intrinsic failures may be related to the components of fracture[2].

Successful implant outcomes require pleasing aesthetics, a functional restoration and stable levels of health of the peri-implant tissues in addition to harmony with existing dentition. Crestal bone loss can lead to a collapse of the soft tissues and affect the aesthetics of prosthetic elements, so maintenance of the bone is an important prognostic factor for rehabilitation[3-5].

The type of connection used for the implant/abutment junction is another important aspect in the occurrence of implant loss.

An internal conical connection (Morse taper) is an alternative to internal and external hex connections. Overlaying the components leads to a better fit between the parts and leaves a smaller gap, which in turn influences bacterial infiltration, reduces bone loss, improves stability and reduces loosening of the abutment[6,7].

The various existing connection designs are the result of a search for the designs that are the most stable and resistant to masticatory loads. Endurance tests such as twisting, bending and cyclic fatigue are used to compare the properties of materials used in oral rehabilitation[8].

The localized, progressive and permanent structural damage that occurs when a material is subjected to cyclic deformation is called fatigue. Fatigue occurs in three stages: nucleation (initiation of fatigue cracks), crack propagation and lastly, fracture of the material[9]. The study of the phenomenon of fatigue is essential because implant failures usually are caused by this process.

A survey of complications occurring in 561 patients (600 prostheses) reported that 10% of the failures were related to problems with the infrastructure (mobility, loosening of the abutment screws and/or gold, through bolt fractures, defects infrastructure)[10].

To characterize the properties of fatigue resistance of implants with straight and anatomical abutment systems, the present study focused on investigating the mechanical-structural behavior of such components using bending tests and cyclic mechanical loading tests.

MATERIAL AND METHOD

We used 37 cylindrical implants made of titanium (3.75×11mm) (Código 109.609) with a Morse taper coupling to 37 abutments (titanium), and there were two groups: solid straight abutments (3.3×6×3.5mm; n=16) (Cód. 114.088) and anatomical abutments with through-bolts (3.5mm; n=21) (Cód. 114.330) (Neodent® Curitiba, Brazil – Catálogo 2016).

The test criteria were based on ISO 14801 (Dentistry-Implants-Dynamic fatigue test for endosseous dental implants)[11]. This standard specifies the method for testing a single endosseous dental implant (transmucosal type) and its prefabricated prosthetic components.

The implant/abutment sets were subjected to fatigue testing with 5 million cycles of loading, simulating a period of five years of *in vivo* masticatory function[12]. A servo-hydraulic apparatus with a 15 kN load cell and a Test Star II controller (Material Test System-MTS Bionix Landmark 3070.02, MTS Systems Corporation, Eden Prairie, USA) were used. This system had a measurement error of less than 1% (Figure 1).

For the mechanical loading, the implant/abutment sets were embedded in a device that was fixed to a bench fixed to the equipment. In accordance with ISO 14801[11], the load was applied 11mm±0.5mm from the point of fixation of the implant with an inclination of 30°±2° to the axis of symmetry, with the aid of a function generator in the form of a sine wave and a frequency of 15Hz. This test was used to evaluate the fatigue resistance of the sets when subjected to cyclic bending loads and flexion.

The implant/abutment was assembled on a prefabricated aluminum base (stub) according to the manufacturer's instructions.

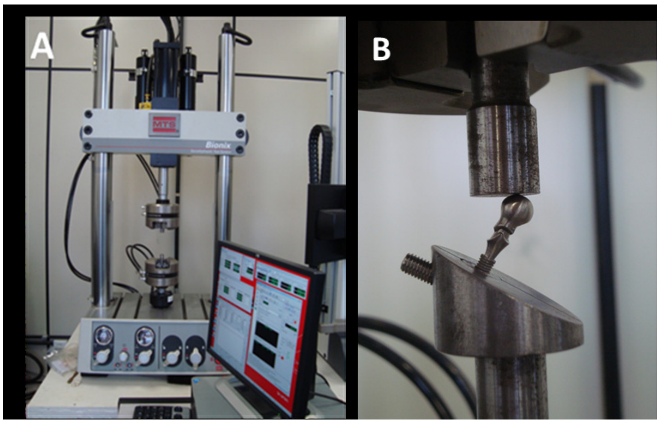

Figure 1. (A) Test System Material Equipment - MTS Bionix Landmark 3070.02 with Test Star II Controller (MTS Systems Corporation, Minnesota, USA); (B) Set implant/anatomical abutment positioned on the test platform.

For implant fixation, a torque of 60Ncm was applied with a surgical manual torque wrench. To assemble the upright and anatomical abutments, torques of 32Ncm and 15Ncm, respectively, were applied using a pre-calibrated prosthetic manual torque wrench. The stubs/aluminum bases were embedded on top of a slant device made of carbon steel. According to the norm, the implants should be 3mm±0.5mm above the level of the device, simulating bone loss. A hemispherical loading device was seated on the abutments in uniform contact with the surface of the abutment.

A bending test was performed on three sets from each group (straight and anatomical abutments) to determine the maximum load resistance of the specimen by applying an increasing axial compressive load speed of 0.5mm/min. The initial loading parameter of the cyclic test was 80% of the load corresponding to the maximum load determined from the bending test. The loading rate applied was R=0.1.

To define resistance characteristics, the bending moment for each set was calculated by multiplying the height of the assembly relative to the support base wherein the implant (length-|) in mm was set for the maximum load and a constant for each pillar (0.5). The resulting unit is in Newton x millimeters (Nmm).

To compare the results of the tests on the samples, we used Fisher's Exact Test and the Mann-Whitney Test. The criterion for rejecting the null hypothesis (H0) was set at a significance level of 5% (p<0.05). The null hypothesis tested was that there was no difference between the types of abutments in terms of the strength. To characterize the survival times of the test samples, the Log-Rank Test was used. The analysis was performed using SPSS version 20 (IBM Corporation, New York, USA).

RESULT

Flexion tests performed on three sets of implants/straight abutments showed that the average maximum fracture load observed in these components was 788.2N (±153.7), and the mean bending moment was 4335.2Nmm (±845.8). In the three sets with anatomical abutments, the average maximum fracture load was 335.7N (±13.8). The mean bending moment was 2434.4Nmm (±100.3).

A total of 31 implants/abutment sets (13 sets with straight abutments and 18 with anatomical abutments) were tested; initially, 13 sets in each group were tested for fatigue. During the tests, it was necessary to increase the number of samples in the anatomical group because they behaved in a scattered way that did not allow the fatigue limit to be defined. Of the 31 samples, 17 (54.8%) fractured in fewer than 5 million cycles; 8 (25.8%) were in the straight abutment group, and 9 (29%) were in the anatomical abutment group. A total of 14 (45.2%) samples withstood the tests: 5 straight (16.1%) and 9 anatomical (29.1%).

Fisher's Exact Test showed no significant difference between straight and anatomical abutment groups as the fracture (8/13 vs. 9/18; p=0.394). Figures 2 and 3, respectively, illustrate the performances of the straight and anatomical abutments with fatigue curves.

The straight abutments bore greater loads than the anatomical abutments (mean: 566N±59.8N). Five sets of implants with straight abutments resisted the loading cycles, supporting larger loads than those supported by the anatomical abutments, nine sets of which did not fail. The highest average bending moment was also found for the straight abutments.

The Mann-Whitney Test revealed that the difference between the behavior of the two groups of fractured samples was slightly significant (p=0.09; type II error). Regarding the variable load (N), a significant difference was observed (p=0.000).

When analyzing the non-fractured samples, the bending moment (Nmm) and load (N) for the straight group (n=5) and the anatomical group (n=9) were significantly different. There was no difference in the number of cycles. The mean moment and load were significant for all samples. Table 1 summarizes the values obtained by the two groups.

In the straight abutment group, most of the failed specimens fractured at the height of the 4th screw thread of the implant, a location that coincides with the internal thread of the post and the top of the empty space within the set. In the anatomical abutment group, fractures occurred between the 4th and 5th screw thread below the implant platform, a region that coincides with the point bending passer abutment screw and the point of fixation of the implant to the aluminum base, the height of the greatest bending moment in the system.

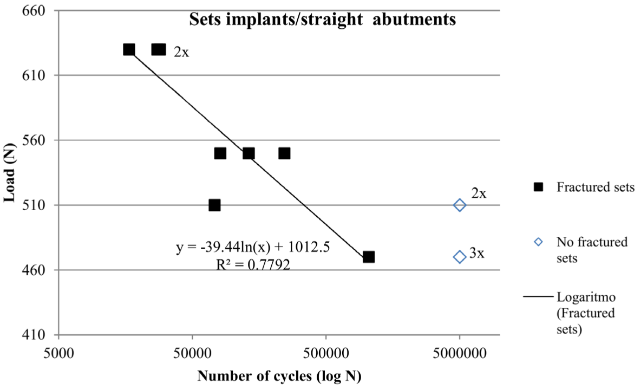

Figure 2. Straight implant/abutment sets subjected to fatigue testing according to load and number of cycles, where x=number of samples subjected to load and cycles.

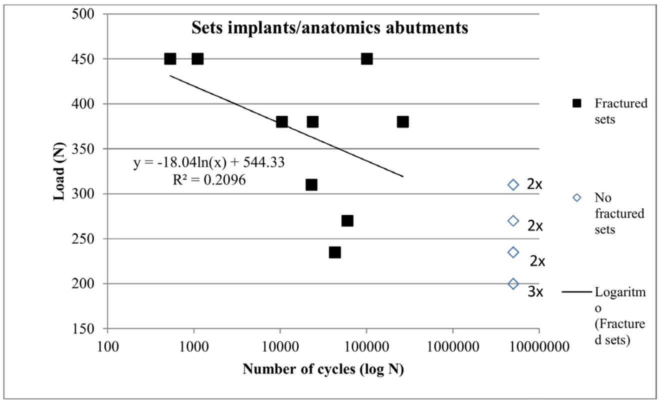

Figure 3. Anatomical implant/abutment sets subjected to fatigue testing according to load and number of cycles, where x=number of samples subjected to load and cycles.

Table 1. Values obtained for straight and anatomic abutments according to the occurrence of fracture in cyclic fatigue tests

Status	Variables	Abutment Type		p-value[a]
		Straight	Anatomical	
		Mean±SD	Mean±SD	
Fractured	Moment (Nmm)	3,190±301	2,671±582	0.09
	Cycles	178,428±351,901	58,507±83,306	0.236
	Load (N)	566±59	367±80	0.000
Not Fractured	Moment (Nmm)	2,763±71	1,802±324	0.001
	Cycles	-	-	-
	Load (N)	488±20	247±44	0.001
All	Moment (Nmm)	3,026±318	2,237±639	0.002
	Cycles	2,032,879±2,456,246	2,529,253±2,543,019	1.000
	Load (N)	536±61	307±87	0.000

SD=standard deviation. [a]Mann-Whitney Test.

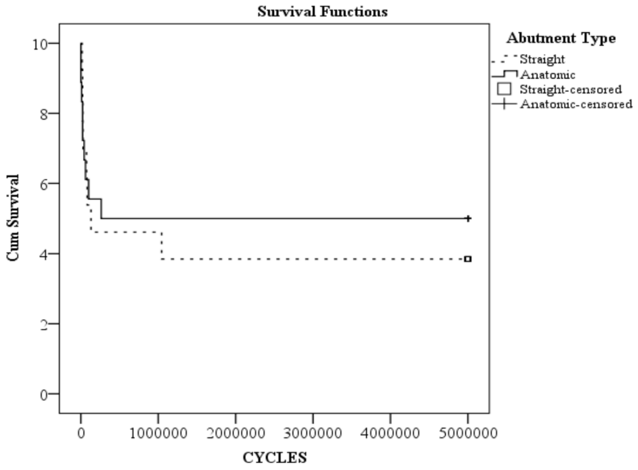

Figure 4. Kaplan-Meier curve showing the survival time (cycles) of straight and anatomical abutments subjected to fatigue testing.

The survival analysis (Log-Rank Test) related the cycle variable representing the time factor to the cumulative probability of survival or cases in which there was no fracture event. The straight abutments survived 2,032,879 cycles on average (±37.6h), while the anatomical abutments withstood 2,529,253 cycles on average (±46.8h) (p=0.74). A Kaplan-Meier curve shows that the anatomical abutments (top row) survived longer in the trials; in this respect, they showed a better performance than the straight pillars (Figure 4).

DISCUSSION

In this study we compared the fatigue strength characteristics between straight and anatomical abutments. Both abutments showed similar performance as the resistance, after cyclic fatigue test.

The fatigue strength of dental implants and abutments is a topic that is frequently discussed in the literature[12-15]. However, despite the presence of standards for testing, changes in testing are adopted according to the subject of investigation. This study was conducted with groups of abutments comparable to the diameter, connection type, materials and directions for use reported in other studies, as well as the cyclic loading (5 million)[12,13,16].

Due to the possibility of inhomogeneity in the material's microstructural features[17], as well as the variations in the roughness of the implants, sample alignment in the test equipment, mean stress and test frequency, the results of fatigue strength can vary significantly.

In the group of anatomical abutments, the cyclic testing of 13 samples initially showed a large degree of variability, which hindered the establishment of the fatigue limit. To define the tensile strength, increasing the number of samples (n=18) was proposed until at least three samples could withstand the same load for 5 million cycles without failure.

In a comparative study of the flexural strength of implants with internal conical connections and internal hexagon connections, it was found that solid abutments with a Morse taper design showed greater resistance to compressive loading. In addition, the solid straight abutments exhibited better characteristics of resistance in both bending and fatigue tests compared to the abutments with through bolts[18]. Those results corroborate of this study, in which the straight solid abutments exhibited better strength characteristics during cyclic bending tests, with significant differences between the groups in relation to both loading and bending moment. This can be explained by the structure of the straight solid abutments, which show a better dissipation of forces.

Schmitt et al.[19], in a systematic review of the performance of tapered abutments, claimed that the connection is the weakest point of the delivery system, as it must withstand both the maximum and permanent masticatory forces as well as the penetration of bacteria. The authors found relevant evidence to support this claim from *in vitro* and *in vivo* studies of such connections. In *in vivo* studies, the tapered systems appear to reduce marginal bone loss. Likewise, the results of the *in vitro* tests in the present study indicate the reliability of the Morse taper connections in oral rehabilitation assemblies, as shown by the high fatigue strength conditions.

The presence of the through bolt at the abutment/implant connection is described by some authors as the weakest link of the whole assembly and is designed to break apart first in case of occlusal overload, thus protecting the implant and bone tissue from the consequential damage from overstressing[20,21]. In contrast, in this study, the majority of fractures in implant/straight abutment assemblies occurred at the height of the 4th screw thread of the implant location; this region coincides with the internal thread of the abutment and the start of the empty space within the set, which can cause stiffness and reduce the tendency of the component to fracture.

In the group of anatomical abutments, the region between the 4th and 5th screw thread below the implant platform was the most frequent area of fracture, coinciding with the point of flexion of the through bolt on the pillar and the point of attachment of the implant to the aluminum base.

Such a situation can be extrapolated to *in vivo* conditions in clinical situations where an implant loses bone support; specifically, in cases of buccal bone plate fracture. For example, straight abutments in the region of lower rigidity of the assembly will be exposed to loading and may increase the chance of implant rupture. Studies to optimize the assemblies to reduce the occurrence of fracture may be warranted.

Khraisat et al.[22] reported that between 1,800,000 and 5,000,000 cycles, severe failures occurred in samples subjected to cyclic tests. Other authors[13,21,22] emphasize that fatigue failures are system-dependent and occur in regions of fragility, particularly the screws, and especially in parts of the screw or between parts with and without threads of the abutments.

In addition to the interface geometry, the pattern of resistance to fracture can be influenced by other conditions, such as the number of components (abutments with one or two pieces), the length and diameter of the screw/implant thread design, the manufacturing process, the material and the contact area between the pieces[18,23] Furthermore, the presence of machining defects, the type of prosthesis (multi/unit), the type of fastening (screw/cementless) and the material hardness, among other factors, can also affect the fracture resistance.

In a systematic review that brought together evidence from 29 studies on the performance of implants and abutments, 23 studies totaling 4973 abutments provided data on the survival of the abutments. Of these, 4807 were metallic. Together, 82 pillars were lost, 81 metal and 1 ceramic. Among the metal pillars, nine were lost due to fracture of the abutment, and fifty were lost due to bone loss. Fracture and loosening of the abutment screw were the most commonly reported complications[24].

This finding disagrees with the present study because in both types of abutments, failure occurred more frequently due to fracture in the implant body. This may be evidence of failure of the implant/abutment joint assembly because fracture of the implant causes major clinical complications.

Despite performing the tests under standardized conditions, the significance of this study may be limited due to the small sample size. However, other authors have also conducted tests with small sample sizes[13,14,25] which can be justified by the fact that the samples were standardized. Such tests contribute to the understanding of mechanical fatigue in the prosthesis due to force. However, the results are not representative of clinical results because the test conditions do not simulate the aggressive body environment (temperature variations, presence of oral fluid, occlusal interference and conditions such as bruxism) or the action of the muscles of mastication. In addition, the stiffness of the stub is different from the stiffness of bone, allowing the distribution of different voltages, and lastly, the study conditions do not simulate the interplay between implant and bone tissue, including the formation of peri-implant tissues and bone resorption.

CONCLUSION

Despite of the straight abutments have higher average load and bending moment on the anatomical, both types of abutments showed similar performance as the fracture strength *in vitro*.

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CONFLICTS OF INTERESTS

The authors declare no conflicts of interest.

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