Implant–abutment connections: influence of the design on the microgap and their fatigue and fracture behavior of dental implants

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Abstract  Microgap between implant and abutment can produce biological and mechanical problems such as peri-implantitis and/or fatigue failures. The aim of this study was to evaluate microgap size and fatigue behavior of external and internal connections. In both systems the torque to tighten the abutment screw of single crown abutments was 45 Ncm. Fifty implants for each connection type were studied. One subgroup (n = 5) was used by the observation and evaluation of the microgap, other (n = 5) was tested for fracture strength and the other (n = 40) was subjected to dynamic loading. The internal connection presents a lower microgap than the external ones. From fatigue results, the external hexagon interface showed superior result compared to the internal hexagon interfaces. The tolerances in the internal connections are better and favour the fatigue behavior but this factor alone is not sufficient to improve the fatigue response in relation to the external connections when the screw is subjected at the same torque. The external system presents a higher value of the area than the internal and it produces a better load distribution. Microgaps and mechanical properties are very important for the long-term behavior of the dental implants and these aspects should be known by the implantologists.

1 Introduction

Most dental implant systems consist of two components: the implant and the abutment. The first is the endosteal component, which is placed in the first surgical phase, and the second is the transmucosal connection, which is generally attached after implant osseointegration to support the prosthetic restoration. Colonization of oral microorganisms through gaps between these parts may produce soft tissue inflammation or the failure of peri-implantitis treatment [1].

During chewing and biting, the prosthetic restoration and the implant–abutment connection is affected by various physiological forces, on a single molar implant this might be about 120 N in the axial direction [2, 3]. In addition, there might be a short force maximum up to an average of 847 N for men and 595 N for women [4]. Cyclic loading forces during physiological function that do not exceed the maximum strength of an implant–abutment connection might loosen the implant–abutment connection gradually or make it fail suddenly due to fatigue. The reason for the fatigue failure is either a lack of force fitting or form-closure of the connection design. The critical reason for loosening of the implant–abutment connection is the loss of preload at the abutment screw and the resulting unscrewing or fatigue failure of the screw material [2].

An analysis has been recently published on implant related complications which calculated a cumulative incidence of connection related complications (screw loosening or fatigue) of 7.3 % after 5 years of clinical service [5].

Maeda et al. [6] and Khraisat [7, 8] studied the stress distribution patterns between implants with external-hexagon or internal-hexagon connection systems using in vitro models. The results showed that almost the same force distribution pattern was found under vertical load in both systems. Fixtures with external-hexagon showed an increase in
strain at the cervical area under horizontal load, while internal-hexagon fixtures the strain was at the fixture tip area. Within limitations of the model study, it was suggested that fixtures with internal-hexagonal showed widely spread force distribution down to the fixture tip compared with external-hexagon.

The problem of a microgap between implant and abutment is biological and also mechanical. The biological problem relates to the presence of bacteria that have been found in the apical portion of the abutment screw [9, 10]; in vivo, this could produce a bacterial reservoir that could interfere with the long-term health of the peri-implant tissues. The mechanical problem relates the micromovements and possible loosening or fracture due to the fatigue of screw-retained abutments. Huang et al. [11] studied the relationship between fractures surface morphology and applied stress level for dental abutment screw loaded in cyclic fatigue. They found a linear relationship between the number of cycles and the stress applied to the screws.

The purpose of this study was to evaluate and compare the implant–abutment microgaps for the two-piece abutments for external hexagon joints (external connection) and comparative for internal-cone joints with hexagon antirotational device (internal connection). Furthermore, the fatigue behavior was evaluated for each connection type. The dental implants were sourced from the same implant manufacturer, with identical surface and with the same retention force of the connection screws.

2 Materials and methods

Two implant systems with the implant–abutment were evaluated. The dental implants were fabricated by Klockner® (SK2, with external connection and Essential Cone, with internal connection). These specific systems are very similar to other dental implants existing in the market with comparable contact areas, and the results can be generalized. Figure 1 illustrates the designs studied. In both systems the torque to tighten the abutment screw of single crown abutments was 45 Ncm, leading to better force-fit. Fifty dental implants for each connection type were studied. One subgroup (n = 5) was used for observation and evaluation of the microgap, another subgroup (n = 5) was tested for fracture strength and the remainder (n = 40) was subjected to dynamic loading.

For evaluation of the microgaps, the implant–abutment systems were embedded in a glycol methacrylate resin. After polymerization, each specimen was sectioned along its longitudinal axis with a high-precision diamond disc. A total of three slides were obtained for each implant. The samples were observed by scanning electron microscopy (JEOL 6400, Japan) coupled with an analysis image system. The sensitivity of the measures was 0.2 μm. This method is very similar at the technique to evaluate the

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Fig. 1  a Implant–abutment with internal connection and b implant–abutment with external connection
implant–abutment gap of an external hexagon implant system as a function of radius proposed by Coelho [12].

Five flexural tests at 30° were conducted, at the selected inclination, to determine the yield strength of the material and the ultimate flexion strength. The resulting percentages of yield strength that were obtained from these tests, ranging from 60 to 90 %, were later used to perform fatigue tests to obtain the number of cycles until fracture.

The fatigue behavior and the fatigue limit of the prototype were set using the Wöhler’s curves (stress – number of cycles) that describe the relation between the amplitude of the cyclical tensions and the number of cycles to break. During the test, the implant–abutment system was subjected to both cyclical compressive and lateral forces, without any lateral constraint. Forty specimens were tested.

The tests were performed in simulated body fluid [13] at 37 °C with the servo-hydraulic testing machine MTS Bionix 858, which is specially designed to test biomaterials because it is equipped with triaxial stresses (tension, compression and torsion). The torsion of 3° was applied in the fatigue test, this value is the typical regarding the teeth movement. This machine was equipped with a load cell MTS of 10 KN, and controlled by means of a PC equipped with the software TESTAR II®.

The tests were performed following the guidelines previously published by the FDA at the Class II Special Controls Guidance Documents: Roots-form Endosseous Dental Implants and Endosseous Dental Implants–Abutments and the ISO 14801:2007. The tested implants supported an abutment that was in line with the axis of the implant. The testing setup clamped the implant so that the implant’s long axis made a 30° angle with the loading direction of the testing machine and, consequently a flexural load was applied (Fig. 2). The implants were fixed with a 30° inclination from the z-axis of the traction–compression machine. A 30° angle to the z-axis of the tensile–compression machine is recommended by the standards of the FDA as the most unfavorable position. Moreover, the implant was placed 3 mm below the anticipated crestal bone level, simulating 3 mm of bone resorption.

The aim was to find the level of stress at which the sample supported five million cycles, and which will be considered the fatigue limit. Seven of the tests that were carried out to determine the level of stress analyzed the fatigue limit whilst three tests focused on the rest of the tested stresses. The implants were loaded with a sinusoidal function of fatigue at a frequency of 15 Hz and the relationship between maximum and minimum applied stress was 10 %. The tests were performed at room temperature. The obtained data was represented as number of cycles to failure as a function of applied stress. The first stress applied was 1450 N, a load lightly lower than the maximum compressive strength, and the following loads decreased by around a 10 %.

The data were statistically analysed using Student’s t tests and one-way ANOVA tables with Tuckey’s multiple comparison in order to evaluate statistically significant differences between sample groups. The differences were considered to be significant when P value < 0.01. All statistical analyses were performed with Minitab software (Minitab release 13.0).

3 Experimental results

The gaps obtained are presented in Table 1. In some cases, excellent adaptation between implant and screw-retained abutment was observed as the separation distance was lower than the bacteria diameter and consequently would not permit infiltration of microorganisms. In some cases, the connection is like cold-welding where the distance is zero. The internal connection design presented a lower
microgap than the external design with statistically significant differences. In Fig. 3 we can observe an example for each microgap connection type.

The fatigue behavior of each type of abutment–implant connection can be observed in the S–N curves in Fig. 4. Statistically, the external hexagon interface presented bigger fatigue long life than the internal hexagon interfaces.

A loss of retention between abutment and implant was assessed as a failure. In all cases the failures were caused by abutment screw loosening and later fracture, but not due to destruction of the implant neck or shoulder. Analysis of fractured screws by SEM revealed that the mode and the region of fracture were the same for the two systems evaluated. Fatigue striations were seen on the SEM micrographs (Fig. 5). Such striations are an indication of fatigue failure. Overloads or fast fracture zone, that is, the portions of the components where final catastrophic failure occurred were also observed. The fracture surfaces were similar for all implants, as can be observed in Fig. 6. The fractures are in the connection zone and fracture the body of the implant. The international standards for fracture fatigue behavior indicates that the fractures in the dental implants must be localized in the connection abutment–implant [14, 15].

4 Discussion

Binon and Curtis [16] indicated tolerances of manufacturing as a reason for the described loose-fit of the prefabricated parts and requested the manufacturer to improve the fit of implants components. In loose-fit situations, the possibility of horizontal movement and micro rotation between implant and abutment screw and lower that the forces to tighten it, micromovements could have led to a progressive unscrewing of the abutment screw under conditions dynamic loading. In our study, the main cause of the high fatigue life of the external connection is due to the size of the resistant section, the external system presents a higher value of the area than the internal. This fact produces a better load distribution of the load and this is a main factor that explains the differences in the mechanical properties. The tolerances in the internal connections are better and favour the fatigue behavior of the internal connection system; however this factor is not sufficient to improve the fatigue response in relation to the external connections. Raoofi et al. [17] studied by finite element analysis that the stress concentration decreased when the internal surface area increase.

Many authors indicate that the external connections in different implant–abutment systems present better fatigue behavior due to the differences in force-fit in the connection design [2, 3, 5]. In all cases, the external connection systems studied present a higher force-fit than the internal. In this contribution, the force-fit was constant and consequently this factor is not considered [1–3, 5].

Freitas-Junior et al. [18] evaluate the reliability and failure modes of anterior single-unit restorations in internal conical interface (ICI) implants using step-stress accelerated life testing (SSALT). A number of implants were used: Forty two ICI implants were distributed in two groups (n = 21 each): AT-OsseoSpeed™ TX (Astra Tech, Waltham, MA, USA) and another group SV-Duocon System Line, Morse Taper (Signo Vinces Ltda., Campo Largo, PR, Brazil). The corresponding abutments were screwed to

| Table 1 Measurements of the microgap for internal and external connections |
|-----------------------------|-----------------------------|
| Type of connection         | Average of microgap (µm)   |
| Internal                    | 0.97 (0.09)                |
| External                    | 1.22 (0.08)                |

Each type of connection was measured in five different implants, the total measures for each connection was 350. The result is the average of all measurements and into brackets is the standard deviation. The results present statistically differences with $P < 0.01$. 

Fig. 3 Observation by optical microscope with image analysis the microgap of two types of connections: a Internal and b external.
the implants and standardized maxillary central incisor metal crowns were cemented and subjected to SSALT in water. Use-level probability Weibull curves and reliability for a mission of 50,000 cycles at 200 N were calculated. The tests showed no significant difference between the groups tested \( (P > 0.27) \) in all specimens of both designs of ICI connection. The chief failure mode was abutment fracture at the conical joint region and screw fracture at neck’s region. Failure modes were similar.

The short external hexagon does not stabilize the connection against lateral loads, and so the screws have to absorb most of the load. This is usual in the implants with height of the external hexagon around 0.6 mm. One reason for the still good outcomes of this group may be the improvements in screw design made by the manufacturer and the increase of the height of the external hexagon. In this study the height of the external hexagon was 1.8 mm. This height produces an increase of the stability and an increase of the flexural load transfer hexagon as shows the scheme of Fig. 7.

Each implant–abutment interface has its advantages and disadvantages. According to Maeda et al. [6] the external hexagon interface has advantages such as suitability for the two stage method, provision of an anti-rotation mechanism, retrievability and compatibility among different systems. However, increased screw loosening, component fracture, and difficulty in seating abutments in deep subgingival

Fig. 4  S–N curves for each connection type

Fig. 5  Fracture surface observed by scanning electron microscope

Fig. 6  Fracture of the dental implants
tissues are problems commonly experienced with external hexagon connectors.

The advantages of the internal hexagon following Maeda are: ease in abutment connection, suitability for one stage implant installation, higher stability and suitability for single-tooth restoration, higher resistance to lateral loads due to the lower centre of rotation and better force distribution [6].

5 Conclusion

The internal connection had a smaller microgap than the external ones with significant statistical differences. Very good adaptation between the implant and the screw-retained abutment were observed, in many cases the distances were smaller than the bacteria diameter and consequently is not possible an infiltration of microorganisms. The fatigue behavior of the external hexagon interface presented superior result compared to the internal hexagon interfaces. The high fatigue life of the external connection is due to the size of the resistant section. This fact produces a better load distribution of the load and this is a main factor which explains the differences in the mechanical properties.

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