The purpose of this study was to analyze the influence of the setting and the presence of solid lubricant on the abutment screw surface on the flexural strength of the joint implant/abutment/screw. Forty abutments were connected to external hex implants, divided into 4 groups (n = 10): FE (titanium alloy screw threaded in the extremity), LE (titanium alloy screw with solid lubricant and thread in the extremity), FT (titanium alloy screw with threaded in all its length), and LT (titanium alloy screw with solid lubricant and thread in all its length). Through the mechanical flexural test, the implant/abutment resistance was evaluated with load applied perpendicular to the long axis in a mechanical testing machine (EMIC) under a speed of 0.5 mm/min. Data were submitted to a statistics test, and results showed statistically significant differences between the FE group and the other groups, and the FE group showed the lowest values. The LE group showed greater values than the LT group, and the values were statistically significant. According to the methodology used, it can be concluded that within noncoated titanium screws, a screw threaded along its entire length provided greater rigidity to the implant set, while with the screw containing solid lubricant, the screw threaded in all its length provided less rigidity of the implant set than screws with the thread only on the end. Among screws with the same geometry, those with the solid lubricant are statistically higher than those which do not have threads just at the end, but those with threads along their entire length do not show statistically significant differences.

Key Words: dental implants, implant prosthesis, surface properties, solid lubrication, implant screw

INTRODUCTION

Since Branemark introduced the osseointegration concept, dental implants have been successfully used as a viable treatment option for edentulous patients. The predictability and success of implant treatment are strongly related to the several loads and conditions to which the implant is submitted during its functional life. Unfavorable biomechanical conditions can induce bone resorption and failures such as screw loosening, porcelain fracture, peri-implantitis, and patient dissatisfaction. Screw loosening is the second most common failure in unitary cases, surpassed only by loss of osseointegration.1,2

In this context, the stability of the connection between different implant parts is crucial for the overall success of the rehabilitation. As internal junctions, an external-hex butt joint, axial preload of the abutment screw stabilizes the connection between the abutment and the implant fixture.3 When the implant set is submitted to functional loads, occlusal forces to the connection are
concentrated at the abutment screw. Consequently, the optimum preload is critical for joint stability and to avoid screw loosening. Higher preload of a screw provides a more stable joint, so less screw loosening is theoretically possible; however, actual preload is dependent on the finish of the interfaces, friction between the components, geometry, and material properties. Since only 10% of the initial rotational torque force is transferred to preload and 90% is used to overcome the friction of the mating surface of the components, some reports claim that higher preload is achieved with new screws coated with solid lubrication.

Interposing a lubricating film between joint surfaces is an applied method with the aim of reducing friction. Lower coefficients of friction between metallic surfaces may increase the screw rotation and, consequently, could result in higher preload. A material with low shear strength, such as pure gold or synthetic diamond-like carbon (DLC), may act as a solid (or dry) lubricant. Studies about coated screws had shown higher preloads and higher initial removal forces. However, there are reports showing contrasting findings, linking lower frictional coefficients to the process of screw loosening, considering that the solid lubricant could ease counterclockwise removal.

Given the role of the abutment’s screw features in the mechanical behavior of the implant/abutment joint, this study aims to evaluate the influence of the design of the abutment screw and the presence of solid lubricant on the bending flexural strength of the external-hex butt joint (implant/abutment/abutment screw interface). The hypothesis is that both the design of the abutment screw and the presence of solid lubricant have significant influence on the bending flexural strength.

**Materials and Methods**

**Specimen confection procedures**

Forty abutments (4.5 × 2 × 6 mm; Neodent, Curitiba, Brazil) were connected to 40 external hex implants (13 × 4 mm; Neodent) using 4 types of titanium screws and were divided into 4 groups (n = 10): FE (milled titanium screw threaded in the extremity), LE (titanium screw with solid lubricant and thread in the extremity), FT (milled titanium screw threaded in all its length), and LT (titanium screw with solid lubricant and thread in all its length). All of the screws were cylindrical and also provided by Neodent, with a standardized amount of DLC coating and in controlled industrial ambiance process of the screw’s coating.

The implants were inserted in a custom device fixed to the mechanical testing machine (EMIC, DL 2000, São José dos Pinhais, Paraná, Brazil). The customized device comprises a steel cube (5 × 5 × 5 cm) and a base adapter that fits in a table clamp that was attached to the mechanical testing machine. The steel cube has holes with 6-mm diameters for implant placement. An Allen’s screw lock avoided any implant dislodgment during the test (Figure 1). The remaining 4.0 mm (from the custom device surface to the implant base platform) were left, aiming to simulate a higher severity of bone resorption.

The abutment was attached to the implant with different screws according to the experimental group. All samples were tightened to 20 N.cm with corresponding abutments using a digital torque meter (Neodent).

**Bending flexural strength test**

A load application steel conical tip (1.0-mm diameter) was positioned on the abutment 4.0
mm away from the implant external interface. A static compression test was performed on each sample using a mechanical testing machine (EMIC, DL 2000). The loading angle was 90° to the implant main axis (Figure 2). All tests were performed at a cross-head speed of 0.5 mm/1 min. During the tests, the load was recorded until the specimen’s screw fracture or, according to a preliminary pilot test, displacements were higher than 3.0 mm.

The mechanical test machine has digital interface software (EMIC, Tesc) that can generate a load versus lengthening graph for each tested specimen. From the load versus lengthening graphs, the mechanical property of load in the yield period or yield strength (YS) was obtained and analyzed.

Load in the yield period or YS is the maximal load value registered in the elastic phase (OC in Figure 1), represented in Newtons (N). To determine the YS, it was necessary to delimitate the limit of proportionality or elastic limit, which corresponds to the end of the phase in which the force (N) is proportional to the displacement (mm). In the load (N) vs displacement (mm) graphics generated, it was necessary to convert the displacement (mm) in permanent deformation (0.2%). For this, an analytical model was built to obtain the displacement (dy) related to deformation of 0.2% of titanium. To find the relative displacement (dy), the Pythagorean theorem was used, and after determining this point, it was possible to use data obtained during the mechanical test, obtaining the force corresponding to the YS for each sample (Figures 3 and 4).

**Statistical analysis**

A Kruskal-Wallis test and Mann-Whitney U test were used to assess the statistical significance of the difference in the measured loads among the 4 groups. All statistical analyses were performed using SPSS 12.0 (SPSS Inc, Chicago, Ill), and the significance level was set at $\alpha = .05$. 

**FIGURE 2**. A load application steel conical tip (1.0-mm diameter) positioned on the abutment 4.0 mm away from the implant external interface. The remaining 4.0 mm (from the custom device surface to implant base platform) was left aiming to simulate a higher severity of bone resorption.

**FIGURE 3**. The relative displacement (dy) was calculated using the Pythagorean theorem. The initial length ($l_0$) was 8 mm. The final length ($l_f$) corresponding to 8.016 mm was calculated by means of approximation equations, and then $d_y \approx 0.51$ mm (relative displacement of 0.51 mm, corresponding to the deformation of 0.02%).
RESULTS

The means (and standard deviation) of YS data are FE, 372 N (30.46); FT, 464 N (52.8); LE, 503.2 N (29.07); and LT, 468 N (36.61).

The FE group presented a significant difference from all others (P = .001). A significant difference was also found in the comparison between the LT and LE groups (P = .029). The means and standard deviations of YS of the 4 groups are presented in the Table.

DISCUSSION

The hypothesis was accepted. Both the evaluated variables, the design of the abutment screw, and the presence of solid lubricant had significant influence on the YS of the implant set.

Most mechanical failures are associated with the instability of the junction between the implant and prosthetic component. When tightening an abutment screw, preload is generated within the screw, consequently increasing the stability of the implant set. Preload works to resist external stress, and on this premise, it is desirable that the preload remains virtually unchanged for as long as possible. Both of the analyzed variables in the current study could be directly related to preload.

The DLC-covered screws (solid lubricant) showed higher YS values in the LE group. There are reports in the current literature showing that solid lubricants reduce friction and increase preload. Coated screws have a low coefficient of friction and high preload, probably related to the higher YS detected for the LE group. In the current study, the presence of solid lubricant on screws with the same design (LE and FE) increased the YS values. These finds suggest that the evaluated DLC covering was effective for this screw situation.

However, the solid lubricant did not show any statistically significant increase when used in a screw with threads in all its length. The DLC covering seems to be less effective when more threads are present with regard to the mechanical property evaluated. This result can be explained by the fact that the mechanical integrity of the abutment implant system depends on 2 factors: the contact area between the components and the screw’s effectiveness. When 2 metal surfaces are in contact, adhesion and friction forces do limit the movement between them. When there is full contact between the surfaces, elongation properties of the screw will increase loosening resistance due to higher contact forces over the screw, but they do not seem to interfere in the YS of the implant set evaluated.

When analyzed without the presence of solid lubricants, a screw with threads in all its body increases the resistance to lateral forces and could be responsible for the higher YS values of the FT and LT groups compared with the FE group. According to Barbosa et al. and Binon, only the first 3 or 4 threads of the screw provide most of the load. In the current study, a screw with more threads had better results than the screw with threads just on the end on titanium implants without lubricants. The explanation may be that the completely threaded screw fills the implant and results in an almost solid block, increasing the contact area with less empty space between the screw and implant. Empty spaces could act as stress concentrators.
concentration sites, which could result in crack initiation and crack propagation, leading to catastrophic failure.\textsuperscript{10,11,20,21}

There were statistically significant differences between the screws containing DLC. The Group LE exhibited superior results (LE > LT). One may suggest that the increase of the threads in the body of the DLC-coated screws increased the surface in contact with the solid lubricant, making the maintenance of preload difficult. That is, a smaller amount of frictional drag between the screw and the implant, which theoretically would increase the preload values, could complicate the maintenance and stability of preload by facilitating the process of loosening.\textsuperscript{10,21} In other words, the higher preload obtained with fewer threads and the presence of the solid lubricate could overcome the lower contact surface area problems, resulting in higher YS values.

The screw’s fractured samples were observed in the FE and LE groups after exceeding its maximum yield point limit, but they were not detected in the FT and LT groups. This suggests a relationship with the increased number of threads. Balfuor and O’Brien\textsuperscript{22} observed catastrophic failures in the first internal thread in screws of internal hex and octagonal joints under compressive loading. The authors also reported implant damage after the screw fractured. In both geometries, the abutment screw could be removed and the implant restored. However, in samples of external hex joints, the abutment’s screw failure was inside the implant chamber. Clinically, it is interesting to note that the more superficial the damage, the easier the repair; that is, screws threaded only in the extremity could result in irreversible situations.

With regard to the presence solid lubricant (DLC), a positive influence on the mechanical behavior of the system was verified. In contrast, the loosening and fracture of abutment screws can be severe complications because it is necessary to remove the overlying restoration to gain access to the screw.

Despite the significant evolution of a number of implant systems, some implants’ screw features related to the mechanical behavior of implant-supported prostheses should be better investigated. Although the results of this study showed that surface-treated screws have a clear superiority of the resulting preload and then higher YS values, application of cyclic loads would be required for a closer simulation of the masticatory function on implanted-supported restorations with these screws’ variables. Considering the results of this study, further investigations should verify fracture resistance of the system and also conduct a finite element analysis aimed at understanding the incidence of failure stresses.

In conclusion, titanium abutment screws with threads along their entire length provide a significant increase in flexural strength of the implant/abutment/screw joint when compared with screws with threads only at the end, both without DLC. Titanium screws with threads at the end that are coated with solid lubricants (DLC) provide increased resistance to the joint implant/abutment/screw abutment than noncoated screws. However, in fully threaded screws, the presence of DLC does not imply an increase in flexural strength.

\textbf{ABBREVIATIONS}

DLC: diamond-like carbon
FE: milled titanium screw threaded in the extremity
FT: milled titanium screw threaded in all its length
LE: titanium screw with solid lubricant and thread in the extremity
LT: titanium screw with solid lubricant and thread in all its length
YS: yield strength

\textbf{REFERENCES}


