Importance of Crown Height Ratios in Dental Implants on the Fracture Strength of Different Connection Designs: An In Vitro Study

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ABSTRACT

Purpose: The aim of the present in vitro study was to assess the resistance to static fatigue of implants with different connections at various crown heights.

Materials and Methods: Sixty conical implants and 60 abutments were used with the smallest diameters available for each model. Three groups ($n = 20$) were established based on the implant connections: Morse taper Ø3.50 mm (group 1), external hexagon Ø3.50 mm (group 2), and internal hexagon Ø3.50 mm (group 3). Four crown heights were tested: $h_1 = 8$ mm, $h_2 = 10$ mm, $h_3 = 12$ mm, and $h_4 = 14$ mm. All groups were subjected to quasi-static loading at a 30° angle to the implant axis in a universal testing machine.

Results: The mean fracture strengths for group 1 were 1524 N (h_1), 1469 N (h_2), 750 N (h_3), and 729 N (h_4). Those for group 2 were 1504 N (h_1), 814 N (h_2), 491 N (h_3), and 325 N (h_4). Those for group 3 were 1543 N (h_1), 672 N (h_2), 403 N (h_3), and 390 N (h_4).

Conclusions: Resistance to loading decreases significantly with increasing crown height, and the connection design can affect the performance.

KEY WORDS: abutment, crown height, dental implant, fracture mode, fracture strength, implant connection

INTRODUCTION

Implants are common tools for the replacement of missing teeth and have become routine elements of dental practice, with a success rate higher than 90%.[1] However, these systems may fail because of mechanical or biological causes.[2]

The failure of dental implants can be attributed to poor planning or the use of an improper design and/or dimensions[3] for a given region of the maxilla or mandible,[4,5] as well as inadequate integration with the supporting structures,[6–9] potentially leading to overloading of the implant.[6] Occlusal conditions such as parafunctional habits or excessive occlusal forces have been identified as other potential causes of implant fracture.[7] Finally, the passive fit and seal between the implant and its abutment components are factors that further determine the success and longevity of the system.

Another situation that often occurs in areas of tooth loss is an increase in the interocclusal space because of bone resorption, requiring lengthy crowns and thus a disproportionate crown implant ratio (CIR), that is, with implants shorter than crowns (Figure 1). The crown height space (CHS) is measured from the crest of the bone to the proposed incisal edge position. The ideal CHS for a fixed implant prosthesis should measure between 8 and 12 mm.[8,9] When CHS is increased by bone loss, to reduce this space, an extensive grafting would be necessary or compensation by the crown height ratio (CHR).

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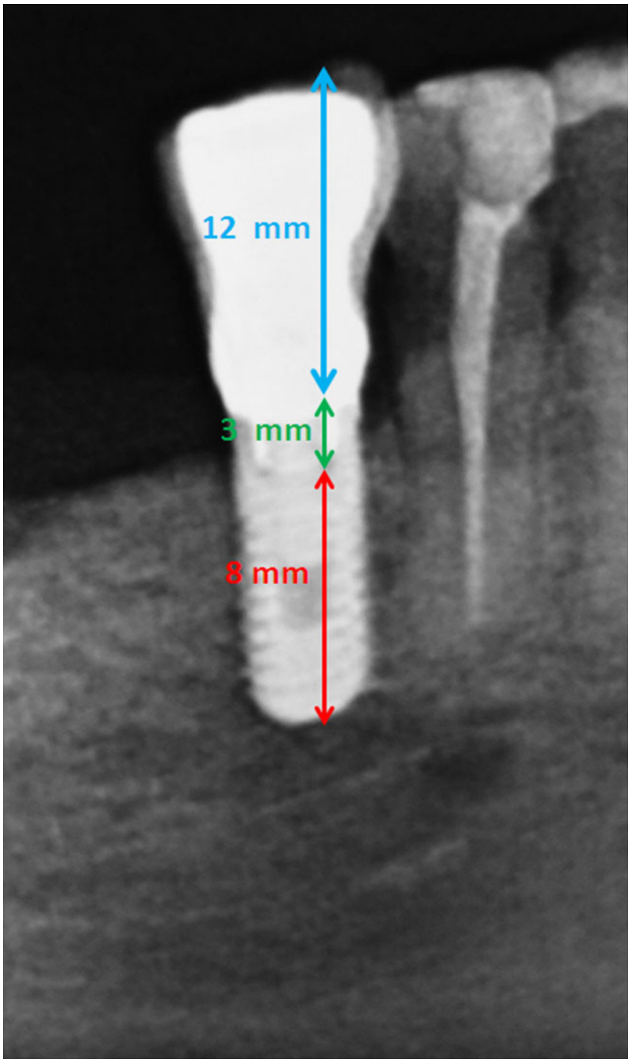

Figure 1 Image presenting an example of crown implant ratios, where the implant insertion (8 mm) needs to support a lever arm of 15 mm (12 + 3 mm).

On the other hand, as the height of the prosthesis increases, the risks of component and material fracture increase because of elevated forces on the restoration [8]. An elevated CIR has been described as a type of nonaxial loading that can detrimentally affect a prosthesis.[10,11] Therefore, increased crown height should be considered as a factor that can affect clinical outcomes both technically and biologically.

From a different perspective, unanswered questions remain regarding these implants. For example, it is a matter of debate whether the fulcrum point for prostheses with a large CIR is the crown implant connection or the most coronal bone-implant contact area.[12] Most studies used the former for measurements, and only one investigation[13] used the bone-implant contact area as the fulcrum point to calculate CIRs. Obviously, for the latter fulcrum, components connected to the implant were stronger than the cortical bone.

In an effort to reduce the frequency of this outcome, the mechanical causes of fracture are under study, with multiple studies examining mechanisms to retrieve fractured dental implants[14–18] and to determine the causes of these fractures.

The hypothesis of this work was that the type of implant and its connections would impact the strength-to-fracture of the implant. The use of an implant more resistant to fracture would be particularly crucial in areas where the CHS is <12 mm. Thus, the objective of the present in vitro study, at static fatigue, was to evaluate the relationship between CHRs and the resistance to fracture of implants with different connections at various crown heights.

MATERIALS AND METHODS

Sixty dental implants and 60 abutments were manufactured by the same company (Implacil De Bortoli, São Paulo, Brazil), with characteristics as described in Table 1. Three implant types were used for the final analysis: Morse taper Ø3.50 mm (group 1), external hexagon Ø3.50 mm (group 2), and internal hexagon Ø3.50 mm (group 3). Figure 2A illustrates the dimensions and appearances of the conical implants (13 mm in height).

Cementable titanium abutments were used for all groups (Figure 2B), with some prepared (sectioned) according to the height required for each proposed situation. All abutment screws received a torque of 25 N, as recommended by the product manufacturer. A metal hemisphere was created to simulate four different crown heights: $h_1 = 8$ mm, $h_2 = 10$ mm, $h_3 = 12$ mm, and $h_4 = 14$ mm (Figure 3). The crowns were cemented on the abutment using conventional zinc phosphate. For each height, five implant specimens were used for each group (a total of 20 implants per group).

TABLE 1 Experiment Groups with Characteristics of Each Implant Model

Group	Connection	Diameter	*n*
1	Morse taper	3.50 mm	20
2	External hexagon	3.50 mm	20
3	Internal hexagon	3.50 mm	20

Figure 2 Image of the conical implants (A) and abutments (B) used in the study: Morse taper (3.50 mm), external hexagon (3.50 mm), and internal hexagon (3.50 mm), respectively.

Test implants were loaded with static compressive forces. The static fatigue strength of the dental implants was tested according to previous guidelines (Figure 4), which recommend the selection of the smallest diameter implant available for each model because this critically impacts the efficacy of the implant. Testing was performed at an implant angle of 30 ± 2° with respect to the applied load, with 3 mm of the exposed implant, reproducing bone loss.[19] The implants were embedded in epoxy resin with a Young's modulus of elasticity similar to that of cortical bone.

According to the study design, all groups were subjected to quasi-static loading until fracture using a properly calibrated universal testing machine (model AME-5kN, Técnica Industrial Oswaldo Filizola Ltd, Guarulhos, Brazil) with a test capacity of 5.0 kN. Tests were conducted at the Testing Laboratory of Biomechanics (Biotecnos, Santa Maria, Brazil) at a test speed of 1 mm/minute.

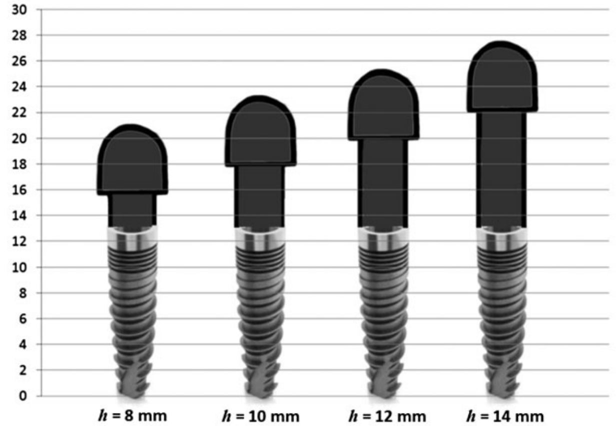

Figure 3 Image showing the crown heights examined in this study.

After the quasi-static loading test, all fractured samples were ultrasonically cleaned in 96% isopropanol and observed under low-power magnification. Digital photographs were taken using a Sony H9 digital camera (Sony, Tokyo, Japan), and the data were reported descriptively.

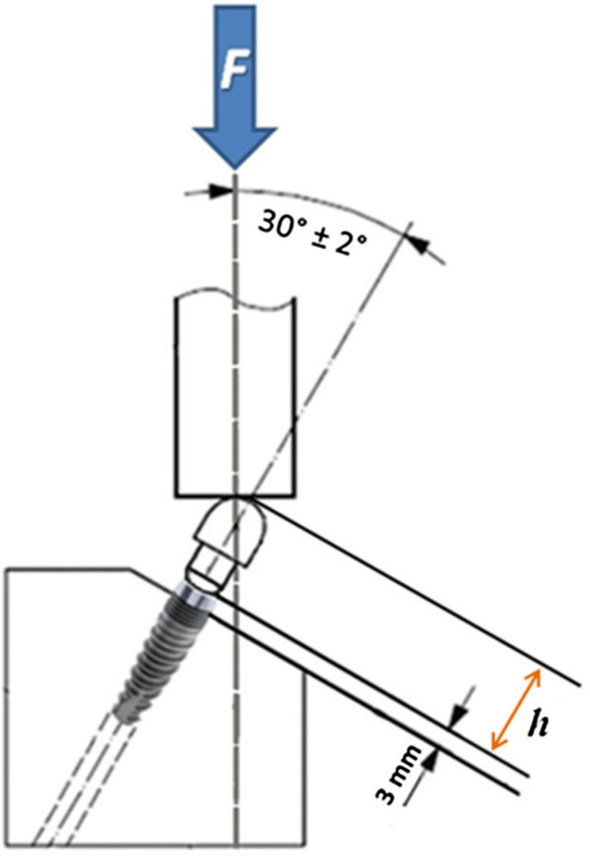

Figure 4 Scheme used in the compression test based on ISO 14801/2007 standards.[19] The distance between the two lines ("*h*") was varied during the compression test.

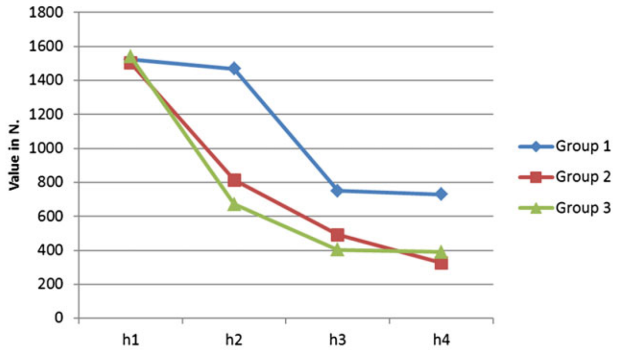

Figure 5 Forces required to rupture for each group at each proposed crown height.

Statistical analyses were performed using a one-way analysis of variance (ANOVA) to determine the differences between the three groups.

RESULTS

The fracture strength values of all groups recorded during quasi-static loading are reported in Figures 5 and 6. All three implant types (groups 1–3) showed the greatest resistance at height 1 ($h_1 = 8$ mm), with similar values: 1524 N for group 1, 1504 N for group 2, and 1543 N for group 3.

For the Morse taper implants (group 1), in all samples, the abutments bowed but did not fracture completely, with the cervical portion of the implant also deformed (Figure 7). Analyzing each crown height for this group showed that similar resistance was observed for h_1 and h_2, 1524 and 1469 N, respectively. The h_3 and h_4 samples were half of the previous values, with average strengths of 750 and 729 N, respectively.

For the external hexagon implants (group 2), at all crown heights, the sets (abutment/implant) were separated by a fracture screw and a small deformation at the edge of the implant platform on the side opposite the application of force, but no deformation of the abutments was observed (Figure 8). At h_2, the strength of the sets was reduced by approximately 50%, with a mean of 814 N. At h_3, the average value was quite low, 491 N, reaching 325 N at h_4.

Figure 7 In group 1, the abutments bowed but did not fracture completely, also deforming the cervical portion of the implant (*arrow*).

For the internal hexagon implants (group 3), at all studied crown heights, the sets (abutment/implant) were separated by a rupture at the wall of the hexagon and fracture screw, with no deformation of the abutment observed (Figure 9). The samples in this group exhibited a high degree of resistance at h_1 ($F = 1543$ N). At h_2, the mean strength was 672 N for the most abrupt reduction in resistance among all three groups. At h_3 and h_4, the mean values decreased to 403 and 390 N, respectively.

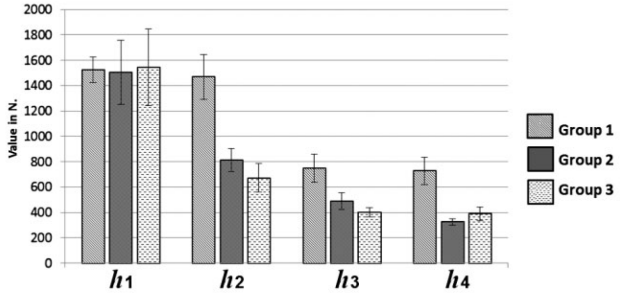

Figure 6 Average force required to overcome the resistance to static fatigue in the various implants with different connections at various crown heights and standard deviation.

Figure 8 Image of the sets of group 2 that was separated by a fracture screw and deformed at the edge of the implant platform, but no deformation of the abutments was observed.

For a one-way ANOVA test, the fact that F crit (1.994580) is smaller than F calc (56.881645) indicates that the test is highly significant, enabling the conclusion that there is an important effect among the groups at a significance of $p < .05$. Among all groups, the variations in the CHR significantly affected the resistance of the implants, especially in groups 2 and 3 where the decrease was more pronounced. In group 1, a significant reduction in the resistance values was observed, but this reduction was less than that of the other two groups, and only the abutments were deformed in this group.

DISCUSSION

Currently, dental implants are considered a consistent and predictable form of treatment with infrequent failures[20] and are widely used for prosthetic treatment in fully or partially edentulous patients. In situations

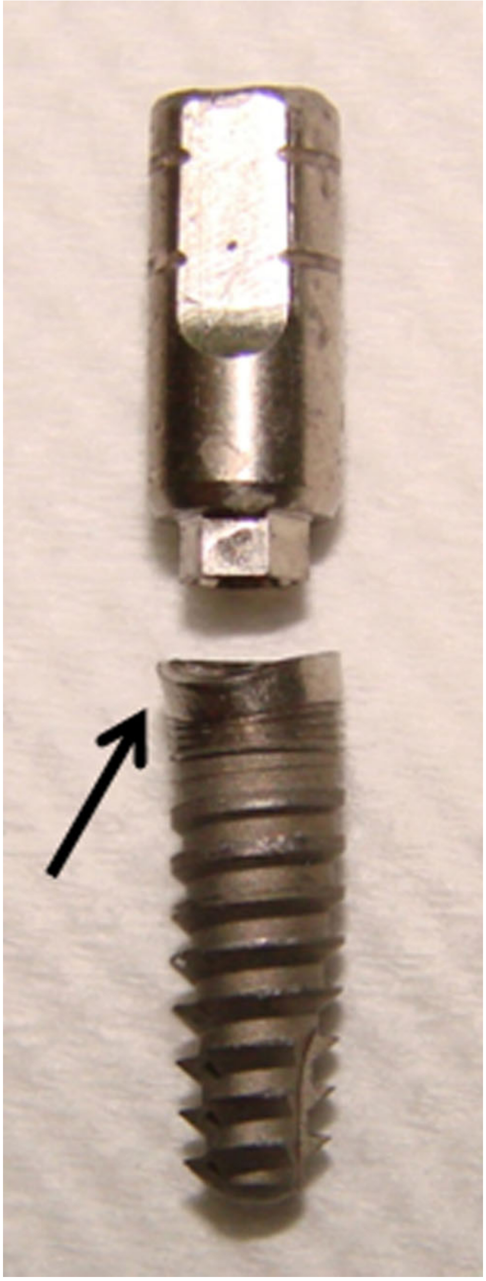

Figure 9 Image of the sets of group 3 that was separated by the rupture in the wall of the hexagon and fracture screw, but no deformation of the abutments was observed.

where implant fracture occurs, it is difficult to repair the implant because of technical and physiological complications. The causes of fracture can be classified into three broad groups: (1) failure of the implant design or the employed material; (2) an absence of passive adaptation of the prosthetic crown to the implant substructure; and (3) overload because of parafunctional habits. The type of treatment may also be influenced by the load and stress that are transmitted to the implant following reconstruction. The results of this study demonstrated that the CHR and the connection model can significantly affect the level of resistance to the nonaxial forces provided by the system (abutment/implant).

The stress that is transmitted to the implant is affected by the nature of the antagonist teeth, the bite force, the number of implants available to support the load, and the structure of the prosthesis with respect to the position of the implant.[1] This study proposed to examine the resistance to the static fatigue of implants with different CHRs and found significant differences between the connection types. In accordance with ISO 14801:2007,[19] the smallest diameter implant of each model was used, set at an inclination of 30° with 3 mm of the cervical implant portion not inserted, reproducing bone loss in that area. The implant diameter relative to the dimension of the supporting bone is critical for successful treatment.[21] The average maximum bite force for adults in the premolar and molar regions is 789 N for men and 596 N for women.[22] In our study, fracture strength after static loading of the specimens was significantly higher for all groups when the CHR was 8 mm. When the CHR was 10 mm, the groups 2 and 3 presented the values of resistance approximated to the previously reported for the masticatory forces,[22,23] differently from group 1, that exhibited a higher load resistance. At CHRs of 12 and 14 mm, groups 2 and 3 showed very low resistance values under these conditions, whereas group 1, even at this crown length, demonstrated values close to those of previously reported masticatory forces.[22,23]

Prostheses with an increased CIR are subject to increased occlusal forces. This can result in amplified stress on the prosthesis and the surrounding bone.[24,25] Accordingly, it is preferable to reduce forces on restorations by increasing CIR. Some suggestions were described as diminishing stresses on prostheses with increased CIR, thereby potentially reducing biological and technical complications and increasing the survivability of these rehabilitations. Among these, we highlight the fact that in posterior areas, lateral contact in mandibular excursions is minimized;[26] another suggestion is to reduce the occlusal width of posterior teeth and have contacts centered over the implants and flatten cuspal inclines.[27]

Studies have indicated that with increased CIRs, additional bone loss occurred compared with locations that did not have increased CIRs.[28–33] However, little information is available on how often technical complications occur around restorations with increased CIRs pertaining to various prosthetic designs. Some authors noted the incidence of screw loosening (7.8%) and porcelain fractures (5.2%) among teeth with increased CIRs. These data are within the 23% technical complication rate for implant-supported fixed prosthesis as was noted in the systematic review.[34]

The fatigue test established by ISO 14801:2007 is an extremely important method of evaluating dental implants.[19] These guidelines enable mechanical analysis of the samples with the intention of mimicking clinical behavior. This study used static implant fatigue testing for different products at various CHRs and demonstrated that implant strength is maximized by short crowns (≤8 mm). Morse taper implants showed the lowest loss in strength of all groups in all proposed situations because of the relationship between the implant and abutment in this system. These results demonstrate that the type of implant and abutment can change the performance and resistance of the system when the interocclusal space requires the development of long crowns. The selection of a connection type is an important consideration to the longevity of the implant system for dental repair. Although other meaningful results have been reported such as chewing simulation or fatigue loading studies of implant abutment systems,[35–36] clinical trials are necessary to validate the results of these investigations as well as those of the present in vitro study.

CONCLUSIONS

Within the limitations of this in vitro study, these results enable the conclusions that the crown height level of implants affects the resistance to external forces during the application of nonaxial strength and that the connection design between implants and abutments can change the performance and resistance of the system.

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