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Influence of Crown-to-Implant Ratio on Stress Around Single Short-Wide Implants: A Photoelastic Stress Analysis

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Abstract

Purpose: The aim of this study was to evaluate the photoelastic fringe patterns around two short-wide implants supporting single crowns with different crown-to-implant (C/I) ratios.

Materials and Methods: External hexagon (EH) cylindrical implants (5 × 7 mm) or Morse Taper (MT) conical implants (5 × 6 mm) were embedded individually into photoelastic resin blocks. Each implant received a single metal-ceramic crown, with a C/I ratio of 1:1 or 2:1 ($n = 10$). Each set was positioned in a polariscope and submitted to a 0.5 kgf compressive load, applied axially or obliquely (30°). The polariscope images were digitally recorded, and based on isoclinal and isochromatic fringes, the shear stress was calculated at 5 predetermined points around each implant. Data were analyzed by two-way ANOVA ($\alpha = 0.05$).

Results: Under axial loading, the stress was concentrated at the crestal region, and there were no differences between C/I ratio or implant types. In contrast, under oblique loading, EH implants showed lower stress values than the MT group and the 2:1 C/I ratio showed higher stress concentration for both implant types ($p < 0.05$). Moreover, MT implants showed stress distribution through a higher area than the EH implant did, with a tendency to direct the stress toward the implant's apex under oblique loading.

Conclusion: MT conical short-wide implants showed higher stress values that were distributed through a higher area directed to the implant apex. The C/I ratio influences the stress distribution only under oblique loading.

Limited bone height represents a challenge for rehabilitation of the posterior regions of the jaws. Although bone height augmentation has been proposed to allow the placement of dental implants, these procedures are associated with higher costs, greater morbidity, longer treatment times and, with the exception of sinus floor elevation, there are insufficient data about their predictability.[1] Thus, short implants can be an alternative to rehabilitate extremely resorbed ridges in a simpler manner.[2]

Short implants are usually defined as those implants with length less than 8 mm;[3] however, in some cases shorter implants, ranging from 5 to 7 mm, are required.[4,5] To compensate for their lower length and to maintain enough contacting surface area for osseointegration, these implants usually have a larger diameter.[6] Despite promising results in clinical trials,[5,7-9] the success rate of short-wide implants are lower when compared to standard longer implants,[3] and the biomechanical behavior of these implants is suggested as a reason for failure, since the lower size could lead to higher stress concentration in bone tissue.[3]

Short implants are usually used to rehabilitate challenging situations at the posterior region, which is often associated with unfavorable C/I ratio, higher occlusal forces, and lower bone density.[10] The greater crown height acts as a lever, creating a moment in the presence of lateral forces that empowers the stresses at the implant-to-bone interface.[11] Thus, the success of short-wide implants depends on a proper transmission of the stresses to the bone tissue.[12,13]

Implant geometry and the implant/abutment connection affect the stress dissipation at the bone/implant interface;[14] however, the influence of these factors on short-wide implants has not been evaluated yet. Therefore, a study was conducted to evaluate the photoelastic fringe patterns around two short-wide implants supporting a single crown with different C/I ratios.

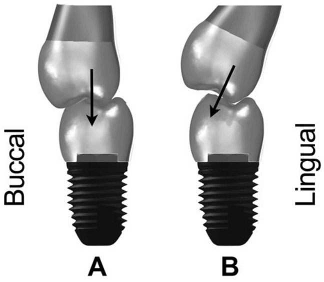

Figure 1 The antagonist crown was positioned in Angle's Class I relationship, and the load was applied axially (A) or obliquely (30°) to the implant long axis (B).

Materials and methods

Model construction

Two poly (methyl methacrylate) resin blocks ($50 \times 30 \times 10$ mm^3), one containing an implant analog of an external hexagon (EH) cylindrical implant (5×7 mm) and another with an implant analog of a Morse Taper (MT) conical implant (5×6 mm) (Neodent, Curitiba, Brazil), both positioned in the center and at the crest level of each block, were used as master models for manufacturing the metal-ceramic crowns. Forty metal-ceramic screwed crowns of a right first lower molar were manufactured. These crowns have different heights, 7 and 14 mm for the EH model and 6 and 12 mm for the MT model (n = 10), to simulate 1:1 and 2:1 C/I (C/I) ratios. A silicone mold was used to standardize the crowns' shape, while the occlusal surface was standardized using a metal mold to compress the ceramic before firing and finishing procedures.

To create the photoelastic specimens, a transfer component was attached to the implant analog in the master model, and a mold was obtained using silicone rubber (ASB-10 blue; Polipox Indústria e Comércio Ltda., São Paulo, Brazil). Short-wide implants were positioned inside the mold and were embedded with photoelastic resin (GIII Flexible Resin; Polipox). After 24 hours at room temperature, the photoelastic models were removed and checked for satisfactory optical properties, and a horizontal circular polariscope (LPM, Uberlândia, Brazil) was used to check for lack of residual stresses.[15] The models were used immediately.

Photoelastic analysis

The abutments and the crowns were attached to the implants following the manufacturer's recommendations. Each set was fixed into the polariscope, and an antagonist metal-ceramic crown attached to a loading cell (Kratos Ind., São Paulo, Brazil), was used to produce a 0.5 Kgf compressive load (Fig 1). This load was used to produce a satisfactory optical response within the models.

The polariscope image of each set was digitally recorded and processed with stress analysis software (Fringes; LPM, Uberlândia) developed in a MATLAB environment (The MathWorks Inc., Natick, MA). A numeric chart was generated in the software to define five points around the implants (Fig 2). These points were located 1 mm away from the implant/resin interface at the distal crest, distal body, apical, mesial body, and mesial

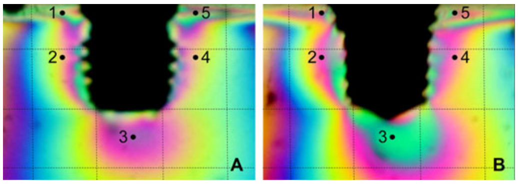

Figure 2 The five points were defined in the software to compute the shear stress around the EH (A) and MT (B) short-wide implants.

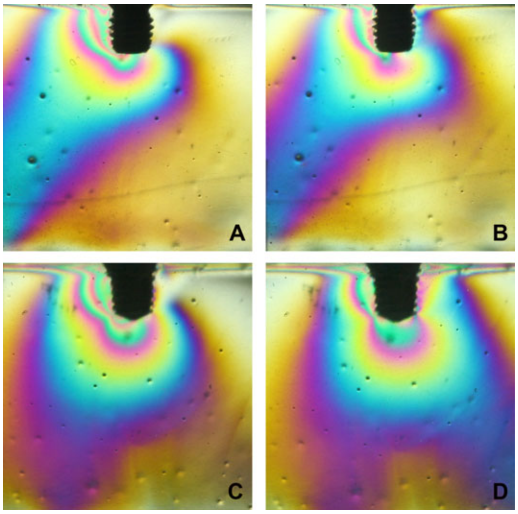

Figure 3 The fringe pattern visualized with the polariscope of the external hexagon short-wide implant with 1:1 (A) and 2:1 C/I ratio (B) and Morse Taper short-wide implant with 1:1 (C) and 2:1 C/I ratio (D) under axial loading.

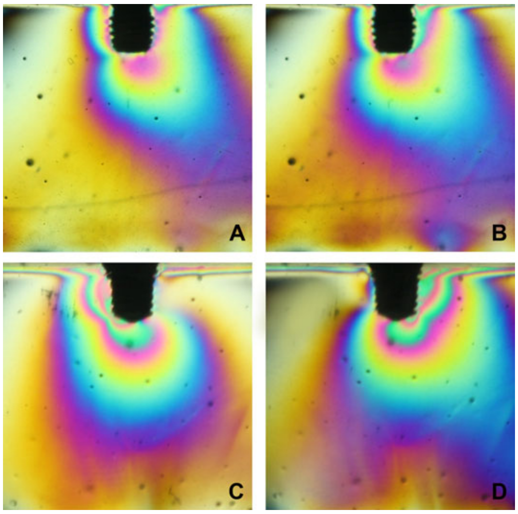

Figure 4 The fringe pattern visualized with the polariscope of external hexagon short-wide implants with 1:1 (A) and 2:1 C/I ratio (B) and Morse Taper short-wide implants with 1:1 (C) and 2:1 C/I ratio (D) under oblique loading.

Table 1 Shear stress (MPa) around Morse Taper (MT) and external hexagon (EH) short-wide implants with 1:1 and 2:1 crown-to-implant ratio submitted to axial and oblique loading (means ± SD; n = 10)

	Axial loading		Oblique loading	
Implant type	C/I 1:1	C/I 2:1	C/I 1:1	C/I 2:1
EH	40.3 ± 13.7 Aa	41.8 ± 15.0 Aa	34.6 ± 5.3 Aa	38.6 ± 7.1 Ba
MT	41.9 ± 10.0 Aa	45.1 ± 14.7 Aa	39.6 ± 9.0 Ab	44.3 ± 9.9 Bb

Different capital letters indicate statistical difference between C/I ratio ($p < 0.05$) and different lowercase letters indicate statistical difference between short-wide implants ($p < 0.05$).

crest. For each point, the isoclinal and isochromatic fringe were determined using the Tardy's compensation method, in which a precision of approximately 0.02 fringes can be reached.[16]

The software uses the stress optical law to determine the shear stress inside the photoelastic resin at each predetermined point. It is represented by the equation $\tau = (K_\sigma N)/2h$, in which the shear stress (τ) is related to the photoelastic constant of the material ($K_\sigma = 0.25$ N/mm, determined by a calibration test), the fringe value (N), and the resin thickness (h = 10 mm).[15] Data were analyzed by two-way ANOVA (SPSS 17.0; SPSS Inc., Chicago, IL) at a significance level of 0.05.

Results

The average stress values around the implants are shown in Table 1. The increase of C/I ratio showed a higher stress concentration on both implant groups; however, the MT group exhibited higher stress values than the EH group.

Loading direction revealed an important influence on the photoelastic fringe patterns around the short-wide implants (Figs 3 and 4). Under axial loading, there were no statistical differences between the C/I ratio or implant groups; however, under oblique loading, the EH group showed significantly lower stress values than the MT group, and the 2:1 C/I ratio showed higher stress concentrations in both implant groups. The fringe distribution pattern was different in the implant groups. The MT group distributed the fringes through a higher area than the EH group and more directed toward the implant's apex, especially at oblique loading.

The stress values around the implants are shown in Figure 5. Under axial loading, higher stress values were observed at the distal crestal region of both implant groups, which was not influenced by the C/I ratio. When the oblique load was applied, the stress values were more evenly distributed around the EH implant, while the MT implant showed higher values in the apex region. Moreover, the increase of the C/I ratio caused higher stress values around EH and MT implants; however, it did not concentrate at the crest level around the MT implant.

Discussion

The challenge of short-wide dental implants is to create a favorable biomechanical scenario able to prevent bone resorption under normal occlusal loading.[14] Therefore, any crestal bone loss has a higher impact on implants with reduced length. It is necessary to understand the stress distribution patterns around short-wide implants and how they are affected by different types of implant geometry, fixture connection, or C/I ratio.

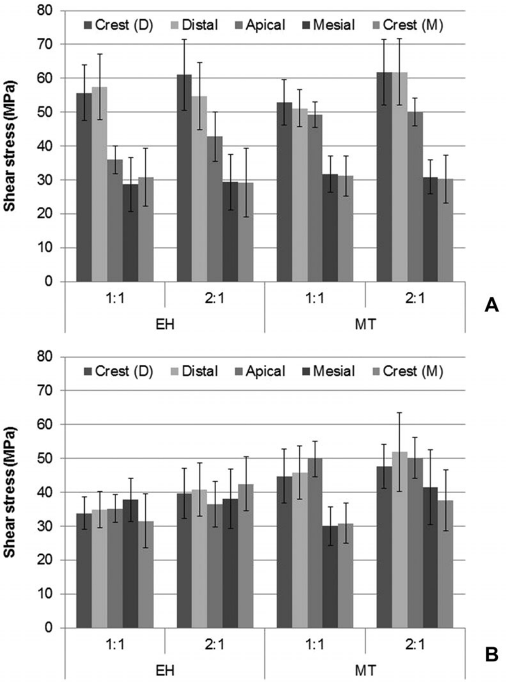

Figure 5 Stress distribution around the external hexagon (EH) or Morse Taper (MT) short-wide implants associated with different crown-to-implant ratios (1:1 or 2:1) under axial (A) and oblique loading (B).

Previous finite element analyses suggested that implant diameter should be more important than implant length or geometry to control overload in the bone tissue,[17] in which a more even stress distribution was found around a 5 × 6 mm cylindrical short-wide implant than narrower and longer implants.[18] However, the comparisons were always against implants with very different geometries (diameter and length). In this study, different short-wide implants with close proportions were evaluated, and the influence of length on stress level seems still to be applicable. Here, higher stress values were found around the MT implants, which were 1 mm shorter (15%) than the EH implants and have different macro geometry; however, in this study, loading direction was the factor that most influenced stress distribution. There were differences between the implant groups or C/I ratio under axial loading; however, higher stress at the distal crest region was observed. This can be explained by the relationship established between the crowns and the antagonist tooth, which allows contacting points at the center of the distal region of the occlusal surface.

Under oblique loading, the EH group showed a more even distribution of stresses than the MT group; however, the MT group showed a tendency to dissipate the stresses toward the apical direction, which is the most favorable condition for avoiding overload at the crest region. Therefore, further studies are necessary to evaluate this potential benefit, especially concerning other variables such as primary stability and bone density.

Although C/I ratio has been reported as a potential risk for prosthetic and biological complications,[3,11,19-22] this study showed that it is only significant when oblique loading is applied. The present results are in agreement with two previous studies, which found no clinical differences for 1:1 and 2:1 ratios when axial load was applied.[25,26] However, previous biomechanical studies indicated that an increased C/I ratio leads to higher stress under oblique loading.[11,20] Moreover, a 3:1 C/I ratio was reported as a potential risk for prosthetic or biological complications,[23] but this ratio was not evaluated in this study.

To minimize these complications, the use of internal connection, such as the MT, in a single prosthesis has been recommended, especially in the face of an adverse C/I ratio.[24] However, the benefits of this connection for stress distribution were not clear in this study, in which higher stress values were found in the MT group. This is in contrast to a previous study that reported less stress concentration in the cervical area and lower crestal bone loss around implants with an internal connection.[25,26] However, other variables such as the implant geometry could overcome the influence of implant/abutment connection on stress distribution.

Although implants shorter than 7 mm have a 92% success rate,[3,27] specific data regarding the longevity of single crowns supported by short-wide implants are still lacking.[22] The biomechanical performance of these implants can be one important factor to predict success; however, in this study the influence of the cortical bone layer and the presence of proximal contact with adjacent teeth was not considered. Moreover, in clinical situations the masticatory forces are not purely axial or oblique directions. Thus, further studies are necessary to determine the long-term effectiveness of short-wide implants.

Conclusion

It can be concluded that although the MT conical short-wide implants showed higher stress values than the EH cylindrical short-wide implants, they better distributed the stress toward the implant apex. The C/I ratio influences the stress distribution pattern only at oblique loading.

Acknowledgments

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