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Original Article

Stress on external hexagon and Morse taper implants submitted to immediate loading

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ABSTRACT

Background/Aims: This study aimed to evaluate the stress distribution around external hexagon (EH) and Morse taper (MT) implants with different prosthetic systems of immediate loading (distal bar (DB), casting technique (CT), and laser welding (LW)) by using photoelastic method.

Methods: Three infrastructures were manufactured on a model simulating an edentulous lower jaw. All models were composed by five implants (4.1 mm × 13.0 mm) simulating a conventional lower protocol. The samples were divided into six groups. G1: EH implants with DB and acrylic resin; G2: EH implants with titanium infrastructure CT; G3: EH implants with titanium infrastructure attached using LW; G4: MT implants with DB and acrylic resin; G5: MT implants with titanium infrastructure CT; G6: MT implants with titanium infrastructure attached using LW. After the infrastructures construction, the photoelastic models were manufactured and a loading of 4.9 N was applied in the cantilever. Five pre-determined points were analyzed by Fringes software.

Results: Data showed significant differences between the connection types ($p < 0.0001$), and there was no significant difference among the techniques used for infrastructure.

Conclusion: The reduction of the stress levels was more influenced by MT connection (except for CT). Different bar types submitted to immediate loading not influenced stress concentration.

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1. Introduction

The immediate loading technique has been widely used in oral implant rehabilitations in order to reduce treatment time.¹ This technique eliminates the necessity to wait during a healing time, permits the use of a provisional prosthesis after the implant insertion, and keeps the implants in function during healing.

In edentulous arches, this technique requires more caution. The stress levels around implants used in immediate loading are dramatically higher than for delayed loading.¹ Considering that all implants are available to support a denture, the presence of overload conditions can compromise the overall osseointegration process. Therefore, the best adaptation between the implant and the prosthesis is always clinically desirable.^{2,3} A deficient fit may induce tensile, compressive, and bending forces during the prosthesis attachment, which may result in further mechanical complications.⁴ The relationship between passivity and suitable distribution of occlusal loads among implants, prosthetic components, and bone tissue is essential for the success of the implant-supported prostheses rehabilitation.⁵⁻⁷

Rehabilitations in the complete dental arch offer the greatest risk since a larger number of implants and the curved shape of the infrastructure can induce higher values of misfit between implants and prosthetic components. In addition, this type of prosthesis has been commonly used in definite rehabilitations for many years, with a good predictability for clinical success.⁸ However, the decreased probability of stress induction on implants in the provisional technique is important to achieve successful osseointegration.

The manufacturing techniques used in infrastructure and impression methods are essential to ensure the precise representation of the implant position, to obtain a passive adjustment of the components and reduce the stress levels around the implants. There are some options to perform the prosthesis infrastructure for immediate loading technique. The laser welding method was proposed to minimize the metallic infrastructure distortion that occurs in monoblock castings.^{2,3,9} Many studies have been developed to investigate techniques employing welding to reinforce bars and the resulting passivity, and to determine where less stress may be induced on the bone tissue.^{2,4}

Another prosthetic alternative to immediate loading is the IOL DIEM system (3i Implant Innovation-USA). This system is a provisional rehabilitation treatment with an innovative absence of metallic infrastructure,¹⁰ aiming to reduce the stress during the implant-healing phase. This system is composed of cylinders with distal extension to support the cantilever, while the whole structure was manufactured with acrylic resin. The advantages of this technique are lower cost; a reduced clinical time that minimizes functional and psychological problems; increased patient's satisfaction; and substantial clinical interest.¹¹ A high success rate of 98.9% has been claimed for the immediate-loading technique even in the absence of metallic infrastructure.¹²

Another relevant aspect reported in the literature is the effect of the prosthetic connection type on the stress distribution, suggesting that the internal Morse-taper (MT)

connection provides a better fit between implant and pillar, increasing the contact area, when compared to the external hexagon (EH). This adjustment improves the biomechanical function, reducing the stress level on the peri-implant tissue.¹³⁻¹⁵ Thus, the implant connection can influence the stress transmitted by the bar in a relevant manner. To date, studies in the literature have not evaluated the influence of different frameworks used for immediate loading on the stress distribution around EH and cone MT implants.

The purpose of this study was to evaluate by means of the photoelastic method the influence of different frameworks used in immediate loading (distal bar (DB), casting technique (CT), and laser welding (LW)), associated with EH and MT implants on the stress distribution in the peri-implant bone. The working hypothesis is that different framework types could influence the stress distribution differently on the peri-implant bone tissue, in both implant connection types.

2. Materials and methods

Two polished metallic shaped matrix arches measuring 35.0 mm × 60.0 mm × 20.0 mm were used (Fig. 1). Five micro-unit abutment analogs (4.1 mm; Conexao Prosthetic System, Aruja, SP, Brazil) were installed in the following sequence: two in the first premolar region (A and E), two in the canine region (B and D), and one in the central region of the matrix (C). This procedure was in accordance with the classical Branemark protocol simulating a real clinical situation for the manufacturing of a mandibular prosthesis.

A prosthetic laboratory performed the DB, CT, and LW framework types. Each bar type was associated with each EH or MT implant, and submitted to a unilateral loading on the cantilever extension. The study was composed of six groups with three framework types and two connection types ($n = 2$). The metallic infrastructures were fixed on the metallic matrices and the complete set was embedded in silicone (ASB-10; Polipox, Sao Paulo, SP, Brazil). Photoelastic models were performed in these silicone impressions.

External Hexagon Master Porous (Conexao) and Morse taper Ar-Morse Porous implants (Conexao) with regular platforms of 4.1 mm and 13 mm in length were screwed to the respective

Fig. 1 – Implant positions on the metallic matrix.

abutments. The sets screwed to the metallic frameworks were included in the silicone impressions to ensure complete passivity between the framework and the final model. This passivity occurs when the placed implants are according to the previously built framework.

GIV flexible photoelastic resin (Polipox, Cesario Lange, SP, Brazil) was poured into the silicone impression and stored at room temperature for 24 h (material cure time). After this period, the photoelastic mold was removed from the silicone impression and analyzed for smoothness and transparency. Thus, an analysis with a polariscope (PTH-A-01 model; Federal University of Uberlandia, MG, Brazil) under polarized light ensured stress-free molds appropriated for the photoelastic analysis.

In order to perform the analysis of the stress induction on the photoelastic model, the infrastructures were readapted to the photoelastic model with a 10 N cm torque. Subsequently, the screws were sequentially fastened in the C, B, D, A, and E positions. All the models analyzed by the polariscope showed absence of stress induction by the metallic structure adaptation, as shown in Fig. 2. Aiming to ensure standardization of the load applied on all the infrastructures, referential grooves demarcated the ends of the cantilever region. After, these sites were submitted to a load of 4.9 N. This load value was predetermined through a pilot test comparing the three infrastructures. In this test, the resulting stress occurred in the fourth fringe order according to the sensibility level of the software (MATLAB platform of LPM/FEMEC/UFU).

Each model was submitted to two loading cycles at the cantilever: (1) left (next to A implant) and (2) right (next to E implant). The quasi-tridimensional photoelastic analysis was performed in the implant closest to the load using a circular polariscope enabling the visualization of the fringes, and the capture of the images was performed with a digital camera

Fig. 2 – Stress-free photoelastic model.

(Cannon EOS KISS X5; Cannon, New York, NY, USA). For each image, the isochromatic pattern of the order of the fringes (N) and the direction of the stress propagation were determined using the color scale for photoelastic resin (Fig. 3A). For a quantitative analysis, five points around the implants were predetermined (Fig. 3B), and the shear stress values were obtained with the Fringes software. Data were submitted to two-way ANOVA followed by Tukey's test to compare the averages ($\alpha = 0.05$).

3. Results

The stress was concentrated on the distal (close to load side) and adjacent implants, predominantly in more elevated fringe orders (N) that ranged from 0 to 4. The fringe orders of the implant images ($N = 0$) were found to be lower as the distance

Fig. 3 – (A) Complete color scale of the fringe orders (N) and its transitions: black, violet/blue, and red/green (B) Representation of the fringe points.

Source: Bernardes 2004; Federal University of Uberlandia, MG, Brazil.

from the load increased. For this reason, quantitative analysis was performed only in the distal implant (A or E), and adjacent implant (B or D), since both sides of the molds were alternatively analyzed. The quantitative analysis considered the averages and the standard deviations of the shear stress values for each technique on the infrastructures (DB, CT, and LW) and between the connection systems (EH and MT).

There was no significant difference between stress values when comparing infrastructure types for the distal implant (closest to the load side – A/E) (Table 1). However, the DB and LW infrastructures showed decreased tension when associated with the MT implant. The MT implant presented smaller stress values in the peri-implant region with a statistically significant difference between the connections. The CT infrastructure showed similar stress values for HE and MT, regardless of the connection. Fig. 4 shows the fringe

Table 1 – Mean (standard deviation) stress (kgf) for the A implant with regard to the infrastructure and connection type.

Framework	Distal implant (A/E)	
	External hexagon	Morse taper
Distal bar (DB)	47.94 (± 1.74) A,a	41.93 (± 1.57) B,a
Casting technique (CT)	44.90 (± 4.54) A,a	43.07 (± 0.92) A,a
Laser welding (LW)	49.28 (± 3.96) A,a	39.37 (± 1.58) B,a

Different capital letters in each row represent differences between implants. Similar small letters in each column represent no statistical difference among framework types by Tukey's test ($\alpha = 0.05$).

Fig. 4 – Illustration of stress distribution around the A implant.

patterns around the A implant for each group. The B implant presented similar results.

There were no significant differences between the frameworks associated with EH, while the DB or LW association with the MT implant reduced the stress values around the implant, with statistically significant difference between the connections. The connection type did not influence the result for the CT framework (Table 2). Fig. 5 illustrates the stress pattern around the B implant.

4. Discussion

Studies using the photoelastic method for analyzing stress in dentistry generally aim to obtain the fringe order values.¹⁶ This

Table 2 – Mean (standard deviation) stress (kgf) for the B implant with regard to the infrastructure and connection type.

Framework	Adjacent implant (B/D)	
	External hexagon	Morse taper
Distal bar (DB)	13.12 (± 2.00) A,a	8.54 (± 1.48) B,a
Casting technique (CT)	12.39 (± 0.31) A,a	12.51 (± 1.27) A,b
Laser welding (LW)	12.40 (± 0.96) A,a	8.72 (± 0.87) B,a

Different capital letters in each row represent differences between implants. Different small letters in each column represent no statistical difference among framework by Tukey's test ($\alpha = 0.05$).

Fig. 5 – Illustration of stress distribution around the B implant.

method uses qualitative analyses without the values of maximum shear stress. When establishing these values, numerical values can be considered in terms of statistical analyses, which allows the estimation of the stress values around the implant using the photoelastic method,¹⁷ enabling a quantitative comparison. In the current study, through the analysis of the images, it was possible to observe that the qualitative values of the fringes were similar among groups. This fact emphasizes the importance of quantitative analysis for photoelastic methodology and the literature suggests that the photoelastic method, associated with a quantitative analysis, is better for comparing stress at the bone-implant interface.¹⁸⁻²⁰

Shear stress values for the distal implant (A/E) showed no statistically significant differences between the infrastructure types, signifying that the bar type is irrelevant for reducing the stress levels around implants. This lack of influence of the bar type is probably due to the total passivity obtained with this technique, since the position of these implants is in accordance with the framework. Conversely, the complete fit of superstructures on implants is not possible using conventional laboratory procedures.⁴ Clinically, this passivity may also favor different techniques for infrastructure manufacture. However, the strategy used in the current study was essential to isolate factors and to determine the effect of the framework types and of the MT connection implant on the stress values, regardless of the infrastructure manufacturing process. In addition, this result demonstrates that the clinical differences of adaptation between the frameworks occur exactly due to the manufacturing process. Based on these results, the working hypothesis that the framework type would influence the stress distribution level on the peri-implant bone tissue for both implant connections is unfounded. The EH seems to be less significant for the bar infrastructure, while MT reduces stress, when associated with DB and LW.

Despite the absence of any significant difference between the techniques for manufacturing the infrastructures, the connection type values were statistically different since the framework and MT connection association reduced the stress values. However, the association of the DB and LW infrastructures demonstrated a significant difference. The DB and LW infrastructures presented different values when comparing the connections types, with a significant reduction in stress when associated with the Morse connection. In addition, the CT infrastructure presented statistically similar results for both connections, suggesting little influence of the connection type.

Previous studies have shown that MT implants present satisfactory stability.^{13,16,21} Furthermore, analytical calculations on different parameters of implants with inner joints showed that this type of interface could result in better retention and stability.^{13,22} In general, inner joints demonstrate improved mechanical stability, when compared to outer joints.¹³⁻¹⁵ This better mechanical stability may occur due to the design of the implant, composed of two elements that make close contact due to the friction that occurs during the contact of the "male" and "female" cones. This procedure may be considered as a bi-conical fitting mechanism, where the effectiveness is significantly increased by the preload generated between the inner cone and the intermediary screw surfaces, resulting in the

stability and maintenance of the torque.^{23,24} These previous reports showed that the MT inner joint had a better performance, due to a more satisfactory biomechanical behavior, reducing the levels of stress at the peri-implant region and possibly explaining the observations of the current study.

For the B implant, the CT infrastructure shows a similar behavior among the different connection types. In other words, the connections did not influence the results promoted by the CT infrastructure. However, the DB and LW infrastructures presented a significant reduction in stress values when associated with the MT connection. The results observed for the B implant reflect the levels of tension found on the A implant, considering that the CT and MT association presented higher stress values. DB and LW infrastructures associated with HE showed high stress values, when compared to the CT infrastructure. Conversely, when these same infrastructures were associated with MT, lower values than CT were obtained (same bar for both connections). These findings infer that the connection type was an important factor in the stress reduction in the peri-implant region; however, the CT infrastructures are not subject to this influence. A previous clinical study investigated the influence of different retained methods on survival and success restorations in immediately loaded implants, in an 8-year follow-up, and showed no statistically significant difference in alveolar bone resorption.²⁵

In qualitative terms, the other implants were not analyzed, as they did not present fringe formations. This fact may be due to the maximum passivity verified in the structures obtained by the technique, as well as the influence of the stress concentration on the loading side.²⁶ According to previous studies, this result occurs in the presence of the load on the cantilever, which promotes an increase in stress on closer implants.^{6,7} Therefore, the Class I lever system changes the direction and magnitude of the force applied to the pillars. In addition, the loading on the suspended end promotes a hinge effect that induces considerable compressive stress on the implant, adjacent to the load application site.²⁷

In the current study, there were generally higher stress concentrations on the medial and apical third regions of the implants, which were similar to those shown by earlier studies.^{16,28,29} This outcome occurred, most probably, due to the site of loading application. However, it should be noted that some important factors were not assessed in the study, such as chewing frequency, vertical and horizontal misfit, quantity and arrangement of implants, and alveolar bone quality.³⁰ Therefore, any extrapolation of the current study to a clinical approach would be premature, due to these disregarded aspects.

5. Conclusion

On basis of the statistical analysis and discussion, it can be concluded that the bar type used for immediate loading did not influence the reduction of stress around implants. Decrease in the stress levels occurred only for the CT connection.

Conflicts of interest

The authors have none to declare.

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