Stress distribution around short implants with different frictional joint designs: a photoelastic colorimetric analysis

Distribuição de tensão em torno de implantes curtos com diferentes designs de fricção: uma análise colorimétrica

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ABSTRACT

Aim: To compare, biomechanically, two types of short implants with different frictional implant/abutment joint designs. Methods: Two groups (n = 10) were divided in straight platform (DSP, 5 x 5.5 mm) and angled platform (30°) (Kopp, 5 x 6.0 mm). The loads applied axially were 100 N, 200 N and 400 N. A photoelastic colorimetric analysis around the implants was performed, based on the magenta fringes, measured in pixels. The data were analyzed by the One-Way ANOVA with repeated measures, Tukey and Mann-Whitney U tests ($p < 0.05$). Results: The short implants demonstrated similar biomechanical behavior, but statistical difference occurred in the group Kopp, under the axial load of 400 N ($p < 0.05$). Conclusion: The implant design showed influence on the stress distribution around the locking taper short dental implants. In both groups, the area of greatest stress distribution was at the apical region.

Keywords: Implants, Osseointegration, Biomechanical behavior.

RESUMO

Objetivo: Comparar, biomecanicamente, dois tipos de implantes curtos com diferentes designs de articulação de implante / pilar de fricção. Métodos: Dois grupos (n = 10) foram divididos em plataforma reta (DSP, 5 x 5,5 mm) e plataforma angular (30°) (Kopp, 5 x 6,0 mm). As cargas aplicadas axialmente foram de 100 N, 200 N e 400 N. Foi realizada uma análise colorimétrica fotoelástica ao redor dos implantes, com base nas franjas magenta, medidas em pixels. Os dadoss foram analisados pelo One-Way ANOVA com medidas repetidas, testes de Tukey e U de Mann-Whitney ($p <0,05$). Resultados: Os implantes curtos demonstraram comportamento biomecânico semelhante, mas diferença estatística ocorreu no grupo Kopp, sob a carga axial de 400 N ($p <0,05$). Conclusão: O desenho do implante mostrou influência na distribuição de tensões ao redor dos implantes dentários curtos *locking taper*. Em ambos os grupos, a área de maior distribuição de tensões foi na região apical.

Palavras-chave: Implantes, Osseointegração, Comportamento biomecânico.

1 INTRODUCTION

As osseointegration and primary stability have been proven to play an indispensable part in the clinical survival of a dental implant, it can be assumed that the biomechanical behavior of the implant plays an important role (Trisi *et al.*, 2015).

Considering that the stress distribution around the implants is much larger than around the teeth, and that bone loss is directly linked to this stress, we can confirm that choosing the correct implant is indispensable for successful treatment (Misch *et al.*, 2001).

The implant design is a crucial factor in biomechanics (Martini *et al.*, 2013; Trisi *et al.*, 2015; Zielak *et al.*, 2015). Therefore, the selection of an implant system should be followed in a way that it covers the needs of the patient without increasing the stress in the peri-implant bone (Misch *et al.*, 2001) Short implants (< 10 mm) have been shown to be effective in the prevention of bone loss and indicated as an alternative in cases where the bone height is restricted, help to avoid invasive surgical procedures such as bone grafts in the posterior maxillary and mandibular regions (Esposito *et al.*, 2009; Sheen and Nikoyan, 2021), as well as demonstrate a high survival rate (Maló *et al.*, 2007).

Photoelasticity is a method used for of the biomechanical evaluation of stress distribution of a body, commonly used to achieve stress distribution in dental implants (Akça *et al.*, 2008; Galvão *et al.*, 2016; Burgoa-la-Forcada *et al.*, 2018; Geramizadeh *et al.*, 2018; Pirmoradian *et al.*, 2020; Borges *et al.*, 2021). It is a technique where a photoelastic resin plays the role of bones and teeth, allowing study of the effect of dental implants when installed in the patient (French *et al.*, 1989; Pesqueira *et al.*, 2014**)**. It should be considered that in the photoelasticity, the magenta color is the color that represents the transition between the stress fringes, i.e., the stress transitions areas (STA) (Zielak *et al.*, 2015).

The aim of this study was to perform the biomechanical comparison of two types of short implants with different frictional implant/abutment joint designs, one with straight platform and the other with an angled platform (30°), using photoelastic colorimetric analysis under different axial loads. The null hypothesis is that there is no difference between the groups tested.

2 MATERIALS AND METHODS

Twenty locking taper short dental implants with different implant/abutment joint design and their respective titanium abutments were divided into two groups (n = 10): DSP implant 5 x 5.5 mm with straight platform and frictional intermediate (Dental Special Products, Campo Largo, PR, Brazil); and Kopp Implant 5 x 6.0 mm implant with angled (30°) platform and frictional intermediate (Kopp, Curitiba, PR, Brazil) (Fig.

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Figure 1. A. DSP Implant. B. Kopp Implant.

Source: Authors.

The implant features are described in Table 1.

Table 1. Technical information of studied implants.

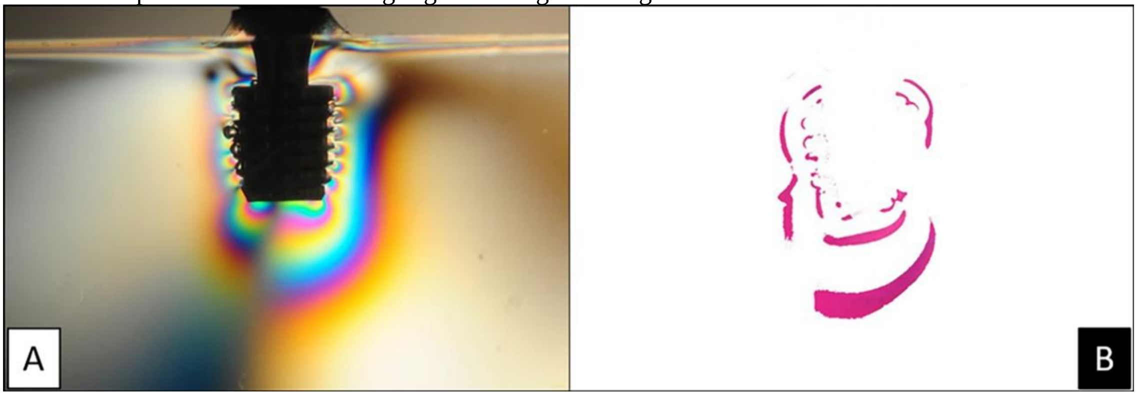
Features	G1 (DSP)	G 2 (Kopp)
Implant diameter	5 mm	5 mm
Implant length	5.5 mm	6 mm
Thread shape	"V" – shaped – cervical third Square – middle and apical	Square
Implant wall thickness	1.25 mm	1mm
Implant wall angulation	5.5°	9°
Taper angle	1.5°	1.5°
Joint diameter	2.5 mm	3 mm

Source: Authors.

The implant-intermediates were placed in molds (10 mm wide, 40 mm high, and 60 mm long) filled with epoxy (photoelastic) resin (Resin rigid, Polipox, São Paulo, SP, Brazil). The sets were then taken to the polariscope (Optovac, Osasco, SP, Brazil) attached to a universal test machine (DL30000, Emic, São José dos Pinhais, PR, Brazil). Axial loads of 100 N, 200 N, and 400 N were applied at the center of the occlusal surface of the abutment. During the load application, images were captured using a digital camera (D5000, Nikon, Tokyo, Japan / 105 mm DG Macro EX, Sigma, Ronkonkoma, NY, USA) with the following parameters: manual mode, speed 1/40, aperture f.16, and ISO 200.

The dimension of the STAs corresponding to the magenta fringes were measured (considering pixel number) using Image J software (NIH, USA). The disclosure of the magenta areas was obtained by image processing with Photoshop CS5.1 software (Adobe Systems Incorporated, San Jose, CA, USA) as described in previous studies (Zielak *et al.*, 2013; 2015) (Fig. 2).

Figure 2. (A) Original image obtained from axial 100 N load application. (B) Edited image after processing on Photoshop CS 5.1 software to highlight the magenta fringes.



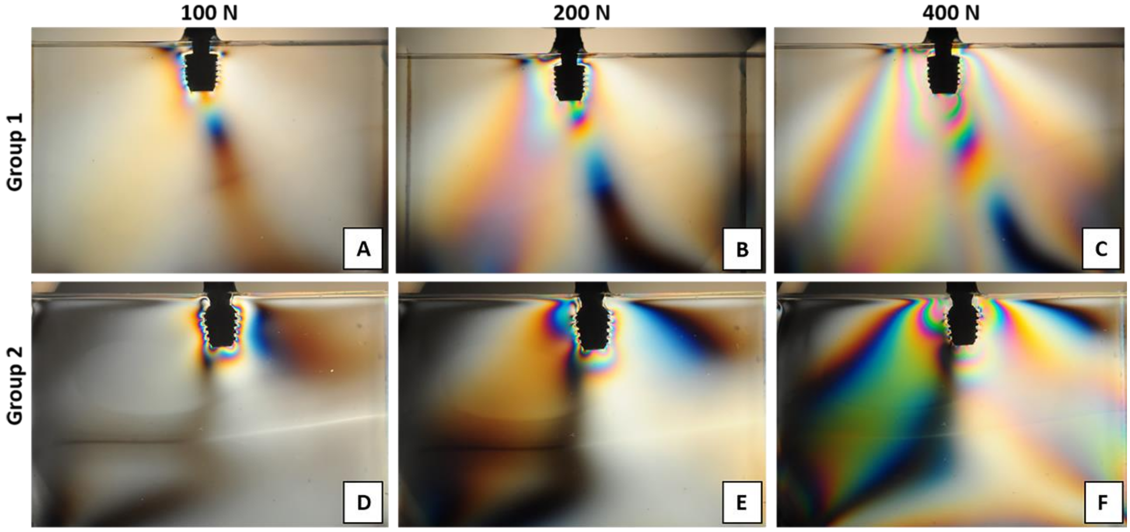
Source: Authors.

The quantitative analysis in the same implants with different was compared by One-way ANOVA with repeated measures, followed by Tukey's test; and the data of different implants, with the same forces, were compared by Mann-Whitney U test, using the STATISTICA software (Quest Software Inc., Aliso Viejo, CA, USA).

3 RESULTS

Both short implants used in this study demonstrated similar biomechanical behavior, with higher stress concentration occurring around the apical region (Fig. 3).

Figure 3. Original images of the samples showing the stress distribution around implants. (A) DSP, 100 N. (B) DSP, 200 N. (C) DSP, 400 N. (D) Kopp, 100 N. (E) Kopp, 200 N. (F) Kopp, 400 N.



Source: Authors.

The numerical results among the groups showed significant difference only in group Kopp, with the 400 N of axial load (*P* < .05) (Table 2).

Table 2. Total area of magenta fringes (STA), in pixels, for groups under axial loads of 100, 200, and 400 N (mean ± standard deviation)

Load (N)	G1 (DSP)	G2 (Kopp)
100	30030 ± 1670 a,A	29471 ± 7501 a,A
200	72342 ± 13995 b,A	48005 ± 11900 b,B
400	203027 ± 64180 c,A	211879 ± 68074 c,A

Note: The means followed by the same lowercase letter in the column and upper case in the row do not differ statistically from each other (Mann-Whitney test; p < 0.05).
Source: Authors.

4 DISCUSSION

Considering the qualitative analysis, the biomechanical behavior of both implant types was similar, with the higher stress concentration occurring around the apical third of the implants. However, the quantitative analysis showed a difference in the stress distribution when a 400 N axial load was applied in group Kopp, while DSP presented higher stress areas. It could be attributed to some differences in the implant and abutment designs, such as threads shape and size, and the convergence degree of implant body and implant abutment joint design. There are previous studies demonstrating better biomechanical behavior of square threads when compared to the "V"-shaped threads (Mosavar *et al*., 2015; Trisi *et al*., 2015). It could be one of the reasons for the difference in stress intensity between the groups. Recent *in vivo* studies showed the key-role of threads design in osseointegration (Trisi *et al*., 2015; Vivan *et al*., 2015).

The qualitative results for stress distribution obtained in this study are in accordance with the previous studies, which evaluated the stress distribution around locking taper implants under axial loads and found stresses generated mainly in the apical third of the implant (Batista *et al*., 2015; Galvão *et al*., 2016).

Clinically, higher stress concentration around implants can lead to micro cracks in the peri-implant bone causing bone resorption (Frost, 1960; Misch *et al*., 2001; Shmetov-Yona and Rittel, 2015). In short implants the crown/implant ratio is biomechanically unfavorable (Cinar and Imirzalioglu, 2016), since these have a shorter length and receive the same load of conventional implants, hence, an overload would inevitably lead to the loss of the implanted element (Toniollo *et al*., 2012). De Souza Rendohl and Brandt (de Souza and Brandt, 2020), evaluating extra-short implants with Morse taper connections, concluded that the abutment had higher stress concentrations with an angled abutment on oblique loads, damaging the peri-implant bone. However, despite the theoretical biomechanical disadvantage of short implants, some clinical studies reported reliable success rate for this type of treatment (Annibali *et al*., 2012).

According to Akça and Cehreli, (2008), internal conical connection implants, with or without an internal screw, have similar characteristics in stress distribution at the implant/abutment interface. However, the type of implant/abutment connection determines the joint strength, joint stability, and anti-rotational stability. The most used system is the screwed one, but screw loosening and fracture has also been reported (Goodacre *et al*., 1999). Thus, the frictional system was designed as an alternative. The friction increases the retention between the parts, which depends on the friction force (activation).

The implant/abutment joint of the implants used in the present study follows the platform-switching concept, where the prosthetic components have a smaller diameter than the implant platform, to reduce or eliminate bone loss around the implants (Prasad *et al*., 2011). This can explain the reduction in stress concentration around the cervical region of the implants.

From the results obtained, it is suggested that with an increasing load, short frictional implants with straight or angled switching platform promote a better voltage distribution. The short implants with the conical internal connection (DSP and Kopp) analyzed in the present study, with straight or inclined cervical platforms, demonstrated similar biomechanical behavior; however, the straight cervical may present a higher concentration of stress in its periphery.

In search of clarifications of the phenomena that occur at the bone/implant interface, the photoelastic analysis proves to be an excellent method to study complex cases where the understanding of biomechanics is fundamental. Several laboratory studies used photoelastic analysis to qualitatively evaluate the stress distribution around dental implants (Akça *et al*., 2008; Galvão *et al*., 2016; Burgoa-la-Forcada *et al*., 2018; Geramizadeh *et al*., 2018; Pirmoradian *et al*., 2020; Borges *et al*., 2021).

However, there are only few photoelastic studies reporting the quantitative evaluation of stress around implants, as it needs complex calculations and is very time consuming. The quantification of stress makes comparative analysis possible and allows evaluation of the influence of different parameters on the stress distribution (Zielak *et al*., 2015).

This study presents a simple method for the quantitative analysis of stress distribution in the peri-implant region, based on the images obtained from the photoelastic analysis as shown in previous studies distribution (Zielak *et al*., 2013, 2015). The original images were edited for evidential magenta fringes, which were measured to determine the amount of stress concentration. As magenta fringes are considered regions of transition of stress (red to blue), it can be assumed that a higher number and larger areas of magenta color represents higher stress concentration. This study evaluated the morphometry inherent to the magenta color (transition color between the stress fringes) for a comparative discussion between the two groups. Therefore, the total area of magenta (TTA) was considered.

The results of the present study must be interpreted with caution, as there are some limitations in the experiment. The number of specimens may have influenced the standard deviation and, therefore, also the statistical results of the study. Additionally, only static axial loads were applied to the specimens, which do not reproduce the clinical conditions where oblique and cyclic loads are also present. Another limitation is the absence of restoration, as the load was applied directly to the occlusal surface of the abutment, therefore, it does not consider the key-role of the restorative materials on the stress distribution (Burgoa-la-Forcada *et al*., 2018). Finally, the differences in implant macro-geometry and abutment design were not detailed in the present study.

The success of the treatments and the predictability that the surgeon has using previous biomechanical studies, do not exempt the professional from taking care that the success is even greater. Good planning and considering the ideal choice of implant (prosthetic fitting, implant size, ideal design) is a part of such care, with impacts on individual's quality of life (Schimunda *et al*., 2021).

5 CONCLUSION

The photoelastic evaluation of the locking taper short implants submitted in this study, as per the analysis of the magenta color, showed differences in the stress distribution in group Kopp only for the axial load of 400 N showing some influence of the implant design on its biomechanical behavior. In both groups, the area of greatest stress distribution was at the apical region.

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