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ORIGINAL ARTICLE

# Photoelastic analysis of the influence of residual ridge inclination in conjugated class I mandibular prostheses with different attachment systems

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**Abstract**

***Objectives:*** The aim of this study was to evaluate the stress distribution in mandibular free-end removable partial dentures (RPD) associated with FPD in the abutment teeth considering different inclinations of the residual ridge: (1) horizontal and (2) distal descending ridges and two designs of free-end RPD with different attachment systems were tested: (1) clasp and (2) system ERA. ***Methods.*** Axial loads (100 N) were applied on the teeth of the RPD. The images were recorded and the stress distribution was evaluated through photoelastic fringes. ***Results.*** In general, the distal descending ridge presented more photoelastic fringes in the region of the roots of the abutment teeth while the horizontal ridge exhibited higher compression in the base of the prosthesis. In the horizontal ridge, the denture with clasp presented more favourable stress distribution than the denture with the system ERA. In the distal descending ridge, the denture with the system ERA relieved the region of the abutment teeth and overloaded the residual ridge. ***Conclusion:*** The horizontal ridge presented more favourable performance; the dentures with clasp exhibited better performance for both ridges evaluated; the denture with the system ERA presented better results in the distal descending ridge.

**Key Words:** *biomechanics, prosthodontics, precision attachment*

## Introduction

The use of RPD for rehabilitation of patients with distal extension (Kennedy Class I and II) is complex [1] due to the difference of resilience from 1–13 between the periodontal ligament of the abutment teeth and the mucosa on the residual ridge [2–5]. This difference of resilience generates rotational movement when occlusal loads are applied on the base of the free-end removable partial denture (FERPD) [5,6] that may induce unfavourable forces to the supporting tissues and generate resorption of the distal residual ridge and damage to other structures [5–12].

The residual ridge is also responsible for support of the FERPD to absorb and neutralize vertical, horizontal and oblique functional loads since its anatomy may influence the stability of the assembly and integrity of the abutment teeth through distribution of the occlusal loads [13].

Elbrecht [14] classified the anatomic design of the residual ridges in the sagital direction and the influence of its inclination on rehabilitations with FERPD. The alveolar bone crest can present four designs in relation to the occlusal plane:

(1) horizontal ridge—distal inclination of 0°, the prosthesis maintains its position when vertical loads are applied on the base and the load is perpendicularly transferred to the ridge in the long axis of the tooth adjacent to the edentulous area;
(2) distal descending ridge—the prosthesis is positioned on an inclined plane and the FERPD moves to distal following the ridge inclination when vertical forces are applied;
(3) distal ascending ridge—occlusal loads applied on the prosthesis base generate movement to distal in the direction of the abutment teeth; and

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(4) concave or ascending-descending ridge—combination of descending and ascending inclinations, respectively.

According to a study [15], the distal descending ridge was more frequent among 64 hemi-arches analysed through two periapical radiographies to determine the angle generated by bone resorption, where the highest levels of resorption of the residual ridge were found.

Some studies [16,17] applied mechanical tests to evaluate the influence of residual ridge inclination in the sagital direction on movement of the distal abutment tooth in Kennedy Class I mandible rehabilitated with FERPD. The researches revealed that the direction and magnitude of movement of the abutment tooth adjacent to the prosthetic area are affected by the sagital angulation of the residual ridge.

In cases of rehabilitation with FERPD and fixed prostheses in the distal abutment teeth, the attachment systems are important mainly for aesthetics. Several attachment systems have been studies including the traditional extracoronal clasps [2,6,8] and intra- and extra-coronal precision and semi-precision attachment systems [4,5,18–24]. The clasps present better results considering the attachment systems [21]. For the rigid attachment systems, the transference of the loads applied on the distal extension of the RPD to the abutment teeth is higher [22]. The majority of the studies did not consider the use of resilient attachments that allow movement of parts of the system when loads are applied on the base of the FERPD and act as a stress breaker [24], decreasing the loads transferred to the abutment teeth.

Thus, the aim of this study was to evaluate the influence of two residual ridge inclinations (horizontal and distal descending) on stress distribution to the supporting structures of the mandibular FERPD associated with FPD using clasps and resilient attachments ERA through photoelasticity.

## Materials and methods

For the confection of photoelastic models, were used a dental mannequin (Odontofix Ind. Com. Ltda. Ribeirão Preto, São Paulo, Brazil), the teeth that had no relevance in this study were removed, resulting in bilateral posterior edentulous model, keeping the incisors, canines and first premolars, the dimensions of the teeth were of average sizes and shapes [25]. The mannequin was duplicated with silicone (Sapeca Artesanato, Bauru, SP, Brazil) to obtain a silicone mould poured with dental stone type IV (Durone, Dentsply, Petrópolis, Rio de Janeiro, Brazil).

The canine and first premolar teeth were used as support and were prepared to receive metal crowns. The model with the prepared teeth was duplicated with silicone to obtain another silicone mould. This mould was poured with dental stone type IV to obtain four models that were sent to a laboratory for confection of the prostheses.

For the confection of photoelastic teeth were used silicone moulds of incisors, canines and first premolars prepared and poured with photoelastic resin (PL-1, Vishay, Micro-Measurements Group, Inc., Raleigh, NC) manipulated according to manufacturers' instructions. Photoelastic teeth were positioned into the silicone mould and filled with photoelastic resin (PL-2, Vishay, Micro-Measurements Group, Inc.) to simulate the alveolar bone. After pouring, the models were kept under pressure at 40 lbf/pol$^2$ for removal of bubbles.

The fixed prostheses were made with Ni-Cr (Fit Cast-SB Plus, Talladium Brazil, Curitiba, PR, Brazil) with the corresponding attachment to be analysed. Four metallic frameworks of removable partial dentures were made with Co-Cr alloy (Degussa SA, Sao Paulo, Brazil), all in the same laboratory using standardized methods and conditions. The major connector was the lingual bar. Table I illustrates the models used in the present study.

The fixed partial prostheses were cemented on prepared teeth with provisional cement (Temp Bond, Kerr Corp., CA) to facilitate the removal of the crowns after the tests. To simulate the alveolar mucosa a soft lining material was used (Dentusoft, DMG Industria Argentina, Argentina).

The assembly was positioned lying on a device in a circular polariscope for a 100 N-axial load that was applied in standardized points on the occlusal surface of teeth (pre-molars and molars) during 10 s, through a metal rod associated to the universal testing machine (EMIC-DL 3000, São José dos Pinhais, Paraná, Brazil).

The stresses represented by photoelastic fringes were recorded with a digital camera (Nikon D80, Nikon Corp, Japan) and visualized using graphic software (Adobe Photoshop CS3, San Jose, CA) for qualitative analysis, as Caputo and Standlee [25], Çehreli et al. [26] and Pellizzer et al. [27]. This analysis established that: (1) the higher the number of fringes, the greater the stress; and (2) the closer the fringes, the greater the stress concentration.

## Results

The results were observed in four regions: apexes of the roots of the distal abutment teeth, cervical-distal region of the distal tooth, area between the abutment teeth and distal residual ridge (Figure 1).

Table I. Models.

| Model | Retention system | Residual ridge |
|---|---|---|
| 1 | Clasps | Horizontal |
| 2 | Clasps | Distal descending |
| 3 | System ERA | Horizontal |
| 4 | System ERA | Distal descending |

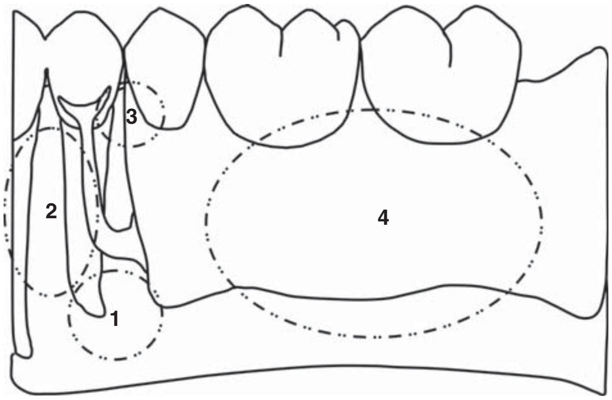


Figure 1. Design of the areas evaluated in the models by qualitative analysis.

### *Horizontal ridge*

*Loading on the second premolar. Apex of the roots* Four fringe orders were observed in Model 1 (Figure 2), while Model 3 (Figure 3) presented three orders.

*Cervical-distal region of the distal tooth*. Model 1 exhibited lower stress concentration than Model 3, which presented two orders of fringe.

*Area between the abutment teeth*. Models 1 (Figure 2) and 3 (Figure 3) showed similar stress distribution.

*Residual ridge*. Similar formation of fringes was observed for both models, but there was a larger area of fringes in Model 3.

*Loading on the first molar*

*Apex of the roots*. Three orders of photoelastic fringes were observed in Models 1 and 3, with highest fringes concentration in the second model.

*Cervical-distal region of the distal tooth*

There were three orders of fringes in Model 3, with higher formation in comparison to Model 1.

*Area between the abutment teeth*

A similar stress pattern and distribution as observed for Models 1 (Figure 2) and 3 (Figure 3), but Model 1 was more favourable.

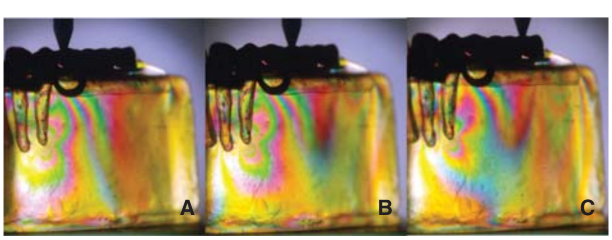


Figure 2. Axial load on model 1: (A) 1st premolar; (B) 1st molar; (C) 2nd molar.

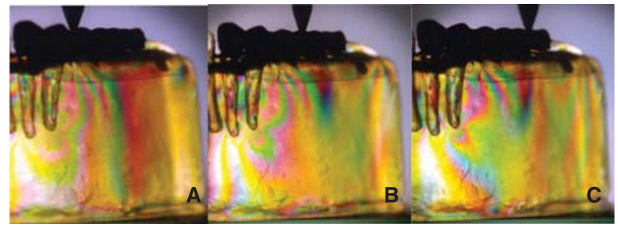


Figure 3. Axial load on model 3: (A) 1st premolar; (B) 1st molar; (C) 2nd molar.

*Residual ridge*

Model 3 presented lower formation of photoelastic fringes in the distal region of the ridge and Model 1 exhibited a high number of fringes.

### *Loading on the second molar*

*Apex of the roots*

Two orders of fringes were observed in both models, but Model 3 (Figure 3) showed a higher concentration of the photoelastic fringes.

*Cervical-distal region of the distal tooth*

Model 3 presented three orders of fringes, with less favourable performance in this region in comparison to Model 1 (Figure 2).

*Area between the abutment teeth*

Model 1 showed more fringes than Model 3.

*Residual ridge*

Model 3 presented fewer fringes in the ridge, while Model 1 showed three orders of fringes.

### *Distal descending ridge*

*Loading on the second premolar*

*Apex of the roots*. There were similar stress distributions in Models 2 (Figure 4) and 4 (Figure 5) with similar amount of fringes orders but higher stress concentration in Model 4.

*Cervical-distal region of the distal tooth*. Similar stress distribution was found, but Model 4 exhibited a larger area of stress.

*Area between the abutment teeth*. Model 4 (Figure 5) presented less favourable performance, while Model 2 exhibited more fringes.

*Residual ridge*. Model 2 showed more red fringes in the distal extension of the ridge in comparison to Model 4.

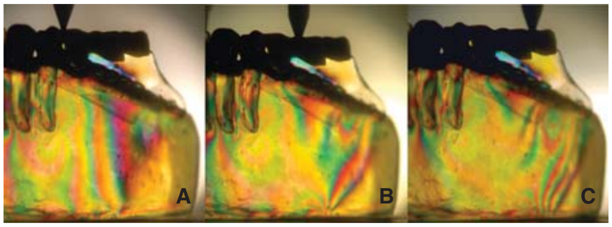


Figure 4. Axial load on model 2: (A) 1st premolar; (B) 1st molar; (C) 2nd molar.

*Loading on the first molar*

*Apex of the roots*. Model 4 (Figure 5) exhibited more favourable performance with two orders of fringes, while Model 2 (Figure 4) showed three orders of fringes.

*Cervical-distal region of the distal tooth*. Larger area of stress were observed in Model 4 (Figure 5) and fewer fringes in Model 2 (Figure 4).

*Area between the abutment teeth*. Model 2 presented less favourable performance with more fringes.

*Residual ridge*. Model 2 showed a more favourable situation with only one order of fringe.

*Loading on the second molar*

*Apex of the roots*. There were two orders of fringes in Model 2 (Figure 4) and one order of fringe in Model 4 (Figure 5), with lower solicitation of the abutment teeth.

*Cervical-distal region of the distal tooth*. Model 2 presented few fringes in the cervical region of the distal abutment tooth. Model 4 exhibited large area of fringes in the ridge near the distal abutment tooth.

*Area between the abutment teeth*. Model 2 showed a higher level of stress between the roots of the abutment teeth in comparison to Model 4 (Figure 5).

*Residual ridge*. Higher stress concentration was observed in Model 4, with more fringes in the distal region. Model 2 (Figure 4) presented fewer fringes.

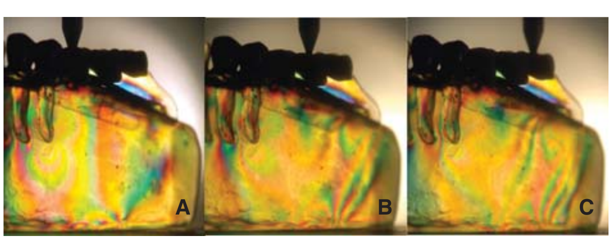


Figure 5. Axial load on model 4: (A) 1st premolar; (B) 1st molar; (C) 2nd molar.

## Discussion

The horizontal and distal descending residual ridges were evaluated in the present study. Theoretically, the horizontal ridge distributes the forces perpendicularly to the ridge and toward the long axis of the abutment tooth, absorbs forces and improves the stress distribution without damage to the supporting structures. The distal descending ridge was evaluated since this inclination is commonly reported [15].

Some research used mechanical tests to evaluate the influence of the ridge of patients wearing FERPD on movement of the distal abutment teeth [16,17] and concluded that the direction and magnitude of forces are affected by the ridge. Similar results were observed in the present study since the distal descending ridge exhibited unsatisfactory stress distribution between the roots of the distal abutment teeth and their apexes, which indicates that the FERPD pulls the abutment teeth with this type of ridge.

A high number of fringes and compressive areas were observed in the region of the residual ridge that was represented by extensive red bands in the models with horizontal ridge. This indicates that this type of ridge absorbs the resultant forces, while the descending ridge allows displacement of the FERPD to distal pulling the distal tooth.

The clasp was analysed in this study since it is the best biomechanical option for cases of mandibular Class I [5,18–20,24]. The retention system ERA was also evaluated since it is a resilient attachment with easy manipulation and versatility [23].

It was observed that the clasp was more favourable for distribution of the forces applied on the FERPD to the supporting structures. This is in agreement with Chou et al. [19] that used photoelasticity to analyse the stress transference to the supporting tissue with six different types of mandibular FERPD without resilient attachments as the system ERA. However, comparing prostheses with precision and semi-precision attachment systems and prostheses with clasps submitted to several simulations of occlusal loads, the RPD with attachments generated higher stress on the abutment tooth than the dentures with clasps with the highest levels for the precision attachment system Stern G/L.

The same author [20] conducted a complementary study after 2 years using the three-dimensional technique of stereophotogrammetry to analyse the same designs of FERPD and determine the movement of the abutment teeth and the RPD submitted to occlusal loading. It was concluded that the prostheses with clasps exhibited reduced movement in comparison to the prostheses with precision and semi-precision attachment systems.

However, Berg and Caputo [22] used photoelasticity and demonstrated that the prosthesis with system ERA generated better results than the prosthesis with clasps type 'I' and the prosthesis with semi-precision attachment system. The dentures with attachment systems were tested with and without splinted abutments. However, a maxillary model was used with periodontally compromised teeth, concluding that the prosthesis with clasp type 'I' presented intermediary result when teeth were not splinted. The best results were obtained for the attachment system ERA with splinting of the remaining teeth.

In the present study, the denture with the system ERA was more efficient in the model with distal descending ridge. This ridge inclination allowed higher movement of the FERPD, which would be compensated by the resilience of the system. In the horizontal ridge, which presents higher stability of the assembly, the denture with the system ERA overloaded the cervical-distal region of the distal abutment tooth, probably due to the movement of parts of the attachment system.

## Conclusion

According to the present methodology, it was concluded that:

- The horizontal ridge presented more favourable performance;
- The dentures with clasp exhibited better performance for both ridges evaluated; and
- The denture with the system ERA presented better results in the distal descending ridge.

***Declaration of interest:*** The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

## References

[1] Itoh H, Caputo AA, Wylie R, Berg T. Effects of periodontal support and fixed splinting on load transfer by removable partial dentures. J Prosthet Dent 1998;79:465–71.
[2] Preiskel HW. Impression techniques for attachment-retained distal extension removable partial dentures. J Prosthet Dent 1971;25:620–8.
[3] Tebrock OC, Rohen RM, Fenster RK, Pelleu GB Jr. The effect of various clasping systems on the mobility of abutment teeth for distal-extension removable partial dentures. J Prosthet Dent 1979;41:511–16.
[4] Reitz PV, Caputo AA. A photoelastic study of stress distribution by a mandibular split major connector. J Prosthet Dent 1985;54:220–5.
[5] Igarashi Y, Ogata A, Kuroiwa A, Wang CH. Stress distribution and abutment tooth mobility of distal-extension removable partial dentures with different retainers: an *in vivo* study. J Oral Rehabil 1999;26:111–16.
[6] Shohet H. Relative Magnitudes of stress on abutment teeth with different retainers. J Prosthet Dent 1969;21:267–82.
[7] Kratochvil FJ, Caputo AA. Photoelastic analysis of pressure on teeth and bone supporting removable partial dentures. J Prosthet Dent 1974;32:52–61.
[8] El Charkawi HG, Goodking RJ, Delong R, Douglas WH. The effect of the resilient-layer distal-extension partial denture on movement of the abutment teeth: a new methodology. J Prosthet Dent 1988;60:622–30.
[9] Morikawa M, Masumi S, Kido H, Kosono Y. Analysis of abutment tooth movement utilizing mandibular kinesiograph (MKG). Dent Mater J 1989;8:56–64.
[10] Thompson WD, Kratochvil FJ, Caputo AA. Evaluation of photoelastic stress patterns produced by various designs of bilateral distal-extension removable partial dentures. J Prosthet Dent 2004;91:105–13.
[11] Mizuuchi W, Yatabe M, Sato M, Nishiyama A, Ohyama T. The effects of loading locations and direct retainers on the movements of the abutment tooth and denture base of removable partial dentures. J Med Dent Sci 2002;49:11–18.
[12] Kelly E. Changes caused by a mandibular removable partial denture opposing a maxillary complete denture. J Prosthet Dent 1972;27:140–50.
[13] Rebossio AD. Prótesis parcial removible. Buenos Aires: Editorial Mundi; 1963.
[14] Elbrecht A. De la prótesis y de su construcción. Trib Odontol 1943;31:15–32.
[15] Guedes CG, Zanetti AL, Feltrin PP. Analysis of the prevalence of different topographical characteristics of the residual ridge in mandibular free-end arches. Braz Oral Res 2004;18: 29–34.
[16] Cecconi BT, Asgar K, Dootz E. Removable partial denture abutment tooth movement as affected by inclination of residual ridges and type of loading. J Prosthet Dent 1971;25:375–81.
[17] Feingold GM, Grant AA, Johnson W. The effects of partial denture design on the mobility of abutment tooth movement. J Oral Rehabil 1988;15:379–84.
[18] Kratochvil FJ, Thompson WD, Caputo AA. Photoelastic analysis of stress patterns on teeth and bone with attachment retainers for removable partial dentures. J Prosthet Dent 1981; 46:21–8.
[19] Chou TM, Caputo AA, Moore DJ, Xiao B. Photoelastic analysis and comparison of force transmission characteristics of intracoronal attachments with clasp distal-extension removable partial dentures. J Prosthet Dent 1989;62:313–19.
[20] Chou TM, Eick JD, Moore DJ, Tira DE. Stereophotogrammetric analysis of abutment tooth movement in distal-extension removable partial dentures with intracoronal attachments and clasps. J Prosthet Dent 1991;66:343–9.
[21] Berg T, Caputo AA. Load transfer by a maxillary distal-extension removable partial denture with cap and ring extracoronal attachments. J Prosthet Dent 1992;68:784–9.
[22] Berg T, Caputo AA. Maxillary distal-extension removable partial denture abutments with reduced periodontal support. J Prosthet Dent 1993;70:245–50.
[23] Williamson RT. Removable partial denture fabrication using extracoronal resilient attachments: a clinical report. J Prosthet Dent 1993;70:285–7.
[24] El Charkawi HG, El Wakad MT. Effect of splinting on load distribution of extracoronal attachment with distal extension prosthesis *in vitro*. J Prosthet Dent 1996;76:315–20.
[25] Berkovitz BKB, Holland GR, Moxham BJ. Oral anatomy, embryology and histology. 3rd ed. St Louis - MO: MOSBY International Limited; 2002.
[26] Caputo AA, Standlee JP. Biomechanics in clinical dentistry. Chicago, IL: Quintessence Publishing Co; 1987.
[27] Çehreli M, Duyck J, De Cooman M, Puers R, Naert I. Implant design and interface force transfer: a photoelastic and strain-gauge analysis. Clin Oral Implants Res 2004;15: 249–57.
[28] Pellizzer EP, Ferraço R, Tonella BP, Oliveira BJ, Souza FL, Falcón-Antenucci RM. Influence of ridge type on mandibular distal extension removable partial denture. Acta Odontol Latinoam 2010;23:68–73.