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# **Prótese Parcial Removível com extensões distais – avaliação crítica do papel da Retenção Indireta**

*Distal extension Removable Partial Denture – a critical  
evaluation of the role of indirect retention*

Susana João Cunha Oliveira

- Monografia de Investigação -

Porto, 2016

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Mestrado Integrado em Medicina Dentária

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the role of indirect retention*

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## ACKNOWLEDGEMENTS

Uma tese mais não é do que um sinergismo de competências, valências e mestrias. Prova desse esforço coletivo é o vasto leque de pessoas que se envolveu neste trabalho e o tornou viável. Esta secção é a elas dedicada.

À Professora Helena Figueiral, agradeço a gentileza com que aceitou ser minha orientadora, a simpatia e afabilidade com que sempre me recebeu e, sobretudo, a total liberdade “criativa” que me concedeu neste projeto.

Ao Professor Mário Vaz, que desde a primeira hora tomou como seu este trabalho, agradeço toda a disponibilidade, empenho e entusiasmo com que coorientou esta tese.

Ao Professor Reis Campos, que “não sendo nada” foi tudo, agradeço toda a confiança (por vezes excessiva, arrisco dizer) que deposita em mim e por ter sempre o contacto certo na hora certa.

Ao Doutor Jaime Monteiro, quero agradecer a partilha de conhecimentos e a generosidade demonstrada... obrigada por ter emprestado uma nova “ótica” ao trabalho!

Ao Engenheiro Nuno Viriato, elemento “infinito” nesta caminhada, o meu sincero obrigada pelas horas “roubadas”, pela dedicação e amabilidade. Sem ele este projeto simplesmente não existiria!

Ao Sr. Américo e ao Sr. Torres, os meus protésicos favoritos, agradeço a paciência com que acolheram os meus pedidos: das vossas mãos nasceu a matéria-prima para que este projeto pudesse acontecer.

Aos meus compinchas Petra, Zé, Diogo e Bruno, agradeço todas as horas de boa disposição, a companhia e camaradagem que entre nós nasceu. Que a nossa amizade perdure!

Paulo, lamento que este percurso não tenha sido traçado mais de perto... agradeço-te, porém, toda a confiança, incentivo e motivação transcontinentais!

Pais, a vocês agradeço TUDO! Por me terem acompanhado neste devaneio que foi voltar a estudar, por constantemente me incentivarem e apoiarem (em todos os significados que a palavra encerra), pelo Amor incondicional, o meu mais profundo Obrigada!

## ABSTRACT

**Introduction/Objectives:** The clinical success of removable partial denture (RPD) relies on the widely established biomechanical principles of retention, stability and support. In contemporary approaches, however, open prosthetic designs with minimal oral tissues coverage have been advocated. Longstanding conflicting opinions regarding the indirect retention concept have arisen, although robust scientific evidence is still scarce. To shed some light on this issue, the current work aims at *in vitro* analyzing the influence of indirect retainers in the forces transmitted to abutment teeth of a unilateral distal extension mandibular RPD.

**Material and Methods:** Using a Kennedy class II mandibular RPD placed on a standard acrylic model simulating a mandibular arch, Electronic Speckle Pattern Interferometry (ESPI) measurements were performed. The 3D out-of-plane displacements were recorded in the two experimental groups – presence or absence of an indirect retention element – when tensile forces perpendicular to the occlusal plane were applied on the distal aspect of the free-end saddle.

**Results:** Once challenged by a dislodging force, abutment teeth contralateral to the distal extension were subjected to higher deformations in the presence of an indirect retention element. Regarding the principal abutment contiguous to the edentulous area, deformation values depend on the magnitude of the tensile force applied: while the indirect retainer decreased the deformation events under low intensity forces, the opposite was observed when higher force magnitude was delivered.

**Discussion/Conclusions:** Our findings reinforce the notion that indirect retention facilitates stress distribution along the dental arch. The forces transmitted to the tooth supporting the indirect retainer were also uncovered in our experimental model. Concerning the original objective, this work suggests that using indirect retainers to protect the abutment teeth against hazardous torque forces might be fallacious. Whereas requiring additional experimental and clinical validation, the preliminary results herein presented encourage the updating of the indirect retention principles with contemporary methodology.

**Keywords:** Partial Removable Denture, Distal extensions, Indirect retainers, Electronic Speckle Pattern Interferometry (ESPI)

## RESUMO

**Introdução/Objetivos:** O sucesso clínico da Prótese Parcial Removível (PPR) depende dos amplamente estabelecidos princípios biomecânicos de retenção, estabilidade e suporte. Nas abordagens contemporâneas, porém, desenhos protéticos abertos com o mínimo recobrimento dos tecidos orais têm sido preconizados. Opiniões divergentes acerca do conceito de retenção indireta têm emergido desde há muito, embora evidência científica robusta continue a ser escassa. Como contributo para a clarificação deste assunto, o presente trabalho pretende analisar *in vitro* a influência dos retentores indiretos nas forças transmitidas aos dentes pilar de uma PPR mandibular com extensão distal unilateral.

**Material e Métodos:** Utilizando uma PPR mandibular classe II de Kennedy colocada sobre um modelo acrílico *standard* simulando a arcada inferior, foram realizadas medições com *Electronic Speckle Pattern Interferometry* (ESPI). Os deslocamentos 3D fora do plano foram registados nos dois grupos experimentais – presença e ausência de um elemento de retenção indireta – quando forças de tração perpendiculares ao plano oclusal eram aplicadas na porção distal da sela livre.

**Resultados:** Face a uma força de desinserção, os dentes pilar contralaterais à extensão distal foram submetidos a maiores deformações na presença do retentor indireto. Relativamente ao pilar contíguo à área desdentada, os valores de deformação dependem da magnitude da força de tração aplicada: enquanto o retentor indireto diminui os eventos de deformação sob forças de baixa intensidade, o oposto foi observado quando magnitudes mais elevadas foram usadas.

**Discussão/Conclusões:** Os nossos resultados corroboram a noção de que a retenção indireta facilita a distribuição de tensões ao longo da arcada dentária. As forças transmitidas ao dente que suporta o retentor indireto foram também evidenciadas no nosso modelo experimental. No que concerne ao objetivo original, este trabalho sugere que a incorporação de retentores indiretos para proteger os dentes pilar de forças de torque potencialmente nocivas pode ser falacioso. Apesar de exigirem validação experimental e clínica adicional, os resultados preliminares aqui apresentados encorajam a atualização dos princípios de retenção indireta com metodologia contemporânea.

**Palavras-chave:** Prótese Parcial Removível, Extensões distais, Retentores indiretos, *Electronic Speckle Pattern Interferometry* (ESPI)

## **LIST OF ABBREVIATIONS**

CCD – Charge-Coupled Device

DIC – Digital Image Correlation

ESPI – Electronic Speckle Pattern Interferometry

FEA – Finite Element Analysis

IR – RPD with Indirect Retention

noIR – RPD without Indirect Retention

PZT – Piezoelectric device

RPD – Removable Partial Denture

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**Figure 2** – Model duplication and casting. A, Alginate impression of the mandibular model. B and C, Working cast (different views).

**Figure 3** – Fabricated RPDs placed on the acrylic mandibular model. A and B, RPD with an indirect retainer on teeth 44 (IR, different views). C and D, RPD without indirect retention elements (noIR, different views).

**Figure 4** – Experimental ESPI setup for measurement of the surface displacements (out-of-plane displacement field). A, Photograph of the experimental setup. B, Detail of the experimental system showing the point of application of traction forces in the RPD. C, Schematic representation of the experimental setup. PZT - Piezoelectric device.

**Figure 5** – ESPI measurements for the indirect retention (IR) group upon application of a tensile force in the free-end saddle (out-of-plane displacement field). Raw fringe pattern, with tooth numbers depicted (left); filtered phase map image, color-coded (middle): red – highest displacement; blue – lowest displacement; graphical representation of the final 3D displacement values (right). A and B, Records for the third quadrant (3<sup>rd</sup> Q.). C and D, Records for the fourth quadrant (4<sup>th</sup> Q.).

**Figure 6** – ESPI measurements for the group without indirect retention (noIR) upon application of a tensile force in the free-end saddle (out-of-plane displacement field). Raw fringe pattern, with tooth numbers depicted (left); filtered phase map image, color-coded (middle): red – highest displacement; blue – lowest displacement; graphical representation of the final 3D displacement values (right). A and B, Records for the third quadrant (3<sup>rd</sup> Q.). C and D, Records for the fourth quadrant (4<sup>th</sup> Q.).

**Figure 7** – Indirect retention principle. A, Indirect retainer as the fulcrum of a Class 2 lever. (F) *Fulcrum* – indirect retainer; (R) *Resistance* – direct retainer clasp; (P) *Power* – occlusally-directed force; (PA) Power arm; (RA) Resistance arm. B, Mandibular Kennedy class II RPD showing the clasp axis and the relative position of the indirect retainer element (perpendicular to the former). *Adapted from [14, 34].*

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# 1. INTRODUCTION

In the context of a rising life expectancy, a widespread access to oral healthcare services and more conservative treatment philosophies, several surveys have anticipated a declining percentage of total tooth loss, with growing incidence of partial edentulism in developed countries [1-3]. Despite attractive, fixed prosthetic approaches remain unaffordable for lower socioeconomic classes, precisely those more severely affected by tooth loss [2, 4, 5]. It comes as no surprise, therefore, that removable partial denture (RPD), although not always in the limelight of prosthodontic literature, still plays a pivotal role in conventional oral rehabilitation [6].

Attempting to restore oral functions and aesthetics in harmony with the remaining natural teeth and supporting structures, RPD represents a noninvasive and less expensive treatment option in comparison to other current solutions [5]. The success of RPD can be measured by the patient satisfaction and acceptance [7], which largely depends on accurate diagnostic assessment, treatment planning and technical execution [8]. Meeting fabrication standards, however, does not necessarily correlates with improved patient satisfaction scores [9].

Classical theories and rules for RPD design have mainly focused on biomechanical aspects related to force distribution, support, stability and retention [10, 11]. Despite their wide dissemination among prosthodontic experts and textbooks, the majority of such traditional biomechanical principles lacks scientific evidence [5, 6]. The importance of adequate plaque control and protection of oral tissues, previously regarded as secondary prophylactic aspects [12], has been advocated by contemporary RPD strategies. Accordingly, simple and open designs that reduce framework components to the strictly required for biomechanical standards, also minimizing the surface area covered by the prosthesis, have been encouraged in recent years [13]. A paradigm shift in RPD concepts is thus mandatory. Such an endeavor must rely on experimental and clinical research that unequivocally supports or disrupts the existing consensus.

While routinely used in free-end saddle dentures, indirect retainers are not without criticism. Primarily designed to counteract the rotational displacement of distal extensions about a fulcrum axis (an imaginary line connecting the two occlusal rests on the terminal abutment on each side of the arch) [14], these elements play complementary functions related to increased stability against horizontal movements, additional guiding surfaces, reduced anteroposterior lever action on abutment teeth and stress distribution [11]. Nonetheless, a set

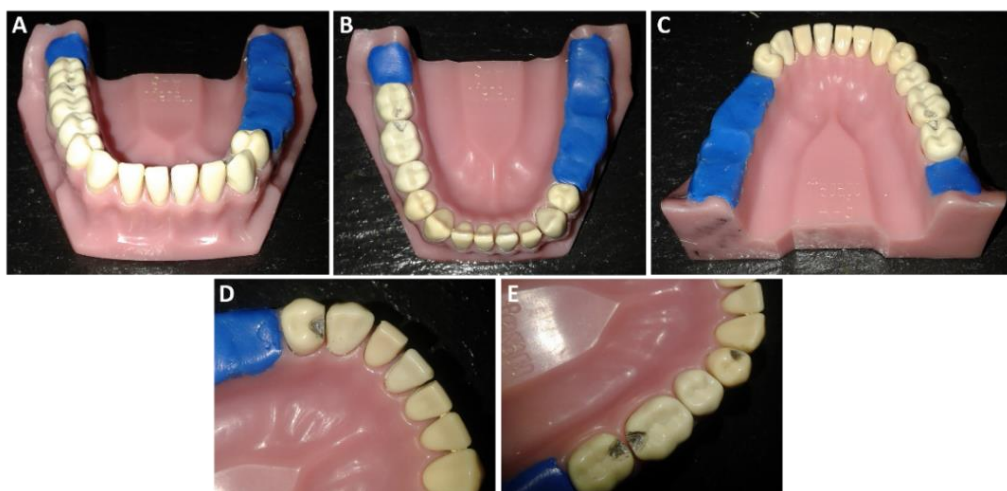
of arguments questioning the value of indirect retention has been presented elsewhere. It can be summarized as follows: i) the idea of a fulcrum line depends on the hypothesis that rests of the two posterior-most direct retainers are not dislodged during function. The accuracy of this assumption deserves further investigation, although previous studies have suggested that “during normal function distal extension dentures do not always rotate around the supporting rests when occlusally loaded” [11]; ii) the effectiveness of indirect retainers in preventing the lifting of distal bases under masticatory forces has not yet been completely confirmed. In fact, movements of distal extensions despite the presence of indirect retainers have been reported elsewhere [15]; iii) the rationale that torque forces transmitted to the abutment teeth must be prevented through indirect retention might be a misconception, deserving experimental assessment. One cannot anticipate to which extension the physiologic tolerance of periodontium will be able to cope with those challenges, thus relativizing the need of indirect retainers [16] ; iv) potentially adverse side-effects of indirect retainers on abutment teeth cannot be neglected. These include tooth movement and impingement of supporting tissues [17]; v) from a biological perspective, indirect retainers lead to more complex, less “hygienic” framework constructions, thus potentiating the risk of gingival inflammation and root caries [13].

Collectively, the paradigm shift and the arguments described above prompted us to experimentally appraise the importance of indirect retention on the biomechanical performance of a distal extension RPD. Using an *in vitro* model of a mandibular Kennedy class II prosthesis and taking advantage of an Electronic Speckle Pattern Interferometry (ESPI) setup, this work aims at investigating the forces transmitted to the abutment teeth – of both direct and indirect retainers – in the presence and absence of indirect retention.

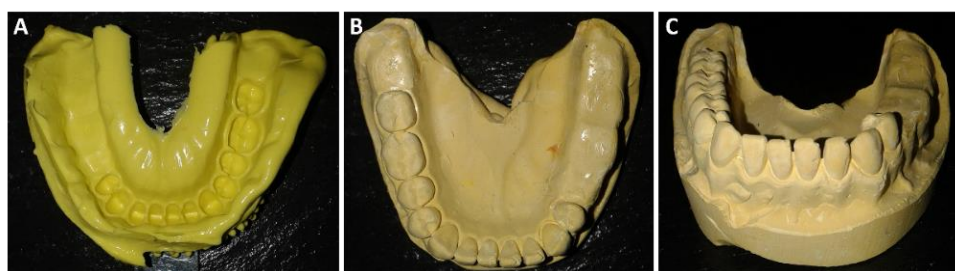
## 2. MATERIAL AND METHODS

### 2.1. Mandibular model

To simulate the mandibular arch, a standard acrylic model (Frasaco, Tettngang, Germany) was used. Teeth 35, 36, 37, 38 and 48 were removed and the corresponding regions covered with a thin layer of putty addition silicone (Virtual Fast Set, Ivoclar Vivadent, NY, USA; Fig. 1A-C). Spoon-shaped occlusal rests, designed as *per* the Principles, Concepts and Practices in Prosthodontics (1994) guidelines [10], were prepared in teeth 35 (*mesial*), 46 (*distal*) and 47 (*mesial*). A small rest seat was cut in the 44 mesial marginal ridge to accommodate (if necessary) the indirect retainer (Fig. 1D, E). All teeth preparations were performed with 016 and 018 diamond round burs used with a high-speed handpiece. The model was duplicated using a standard impression tray loaded with alginate material, being the gypsum cast immediately obtained (Fig. 2A-C).



**Figure 1** – Mandibular acrylic model. **A – C**, Teeth 35, 36, 37, 38 and 48 were removed and replaced by putty silicone (different views). **D** and **E**, Close-up of the occlusal rests prepared in teeth 35 (*mesial*), 46 (*distal*) and 47 (*mesial*).



**Figure 2** – Model duplication and casting. **A**, Alginate impression of the mandibular model. **B** and **C**, Working cast (different views).

## 2.2. Mandibular RPDs

Two Kennedy class II RPDs fabricated of acrylic resin with a cobalt-chromium alloy framework were casted on the acrylic model. Both prostheses consist of the following components: a) a lingual bar (major connector); b) a circumferential clasp in tooth 34 and a double Akers clasp in 46 and 47 (direct retainers); c) three occlusal rests on the abutment teeth 34 (*mesial*), 46 (*distal*) and 47 (*mesial*) to support direct retainers and d) prosthetic teeth 35, 36, 37 and 48. The two RPD frameworks were only distinguished by the presence (IR model) or absence (noIR model) of an indirect retainer on tooth 44 (Fig. 3).



**Figure 3** – Fabricated RPDs placed on the acrylic mandibular model. **A** and **B**, RPD with an indirect retainer on teeth 44 (IR, different views). **C** and **D**, RPD without indirect retention elements (noIR, different views).

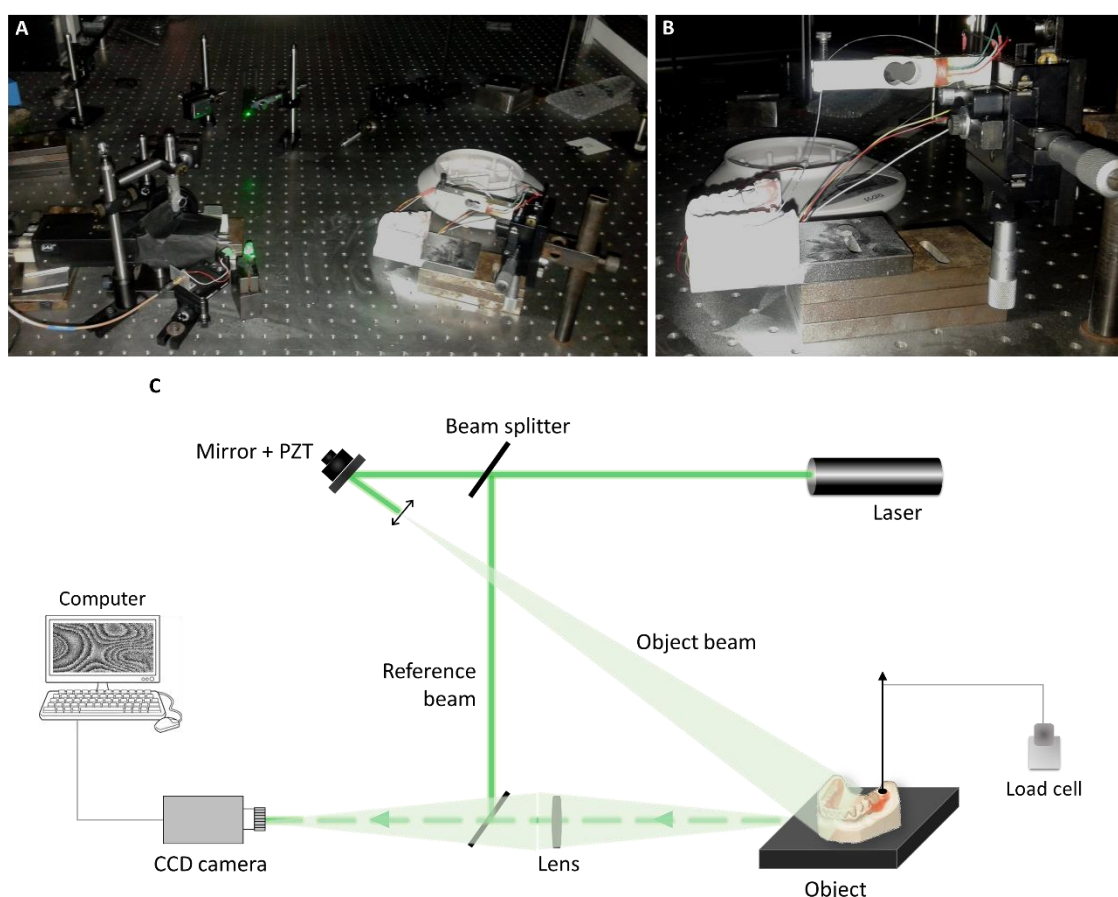
## 2.3. ESPI model system

To analyze the displacement pattern induced by an applied load to the abutment teeth in the presence and absence of indirect retention, an ESPI-based setup was developed. Using coherent light illumination, the ESPI technique enables interferometric measurements of surface displacements or strains, with no direct contact with the object and submicrometer resolution [18].

Upon immobilization of the mandibular model, tensile forces perpendicular to the occlusal plane ranging from 0,15 to 0,70 N, were delivered on the distal aspect of the free-end saddle. Fig. 4 shows the ESPI setup used to measure the out-of-plane displacement field. Briefly,

a Coherent Verdi 532 nm laser (2 W) beam was split into two beams of equal intensity (reference and object beams). The interference between the two wave fronts results in a set of interferometric fringes corresponding to a holographic recording, what means the registration of the amplitude and phase of the wave front coming from the object. This means that the difference between an initial state (no load) and a final state (load) results in a fringe pattern, being these fringes related to the displacement isocurves. Using a phase shift element (mirror + Piezoelectric device - PZT) and with an appropriated algorithm it is possible to calculate the phase maps, suitable for data post-processing. From these phase maps is possible to assess the displacement field knowing the laser wavelength and the setup geometry.

Upon confirming the reproducibility of the tensile forces applied, a single measurement was recorded for each experimental condition. To minimize potential confounding variables, the indirect retention element was removed from the RDP after concluding the IR-related assays, and thus used as noIR model.



**Figure 4** – Experimental ESPI setup for measurement of the surface displacements (out-of-plane displacement field). **A**, Photograph of the experimental setup. **B**, Detail of the experimental system showing the point of application of tensile forces in the RPD. **C**, Schematic representation of the experimental setup. PZT – Piezoelectric device. CCD – Charge-Coupled Device.

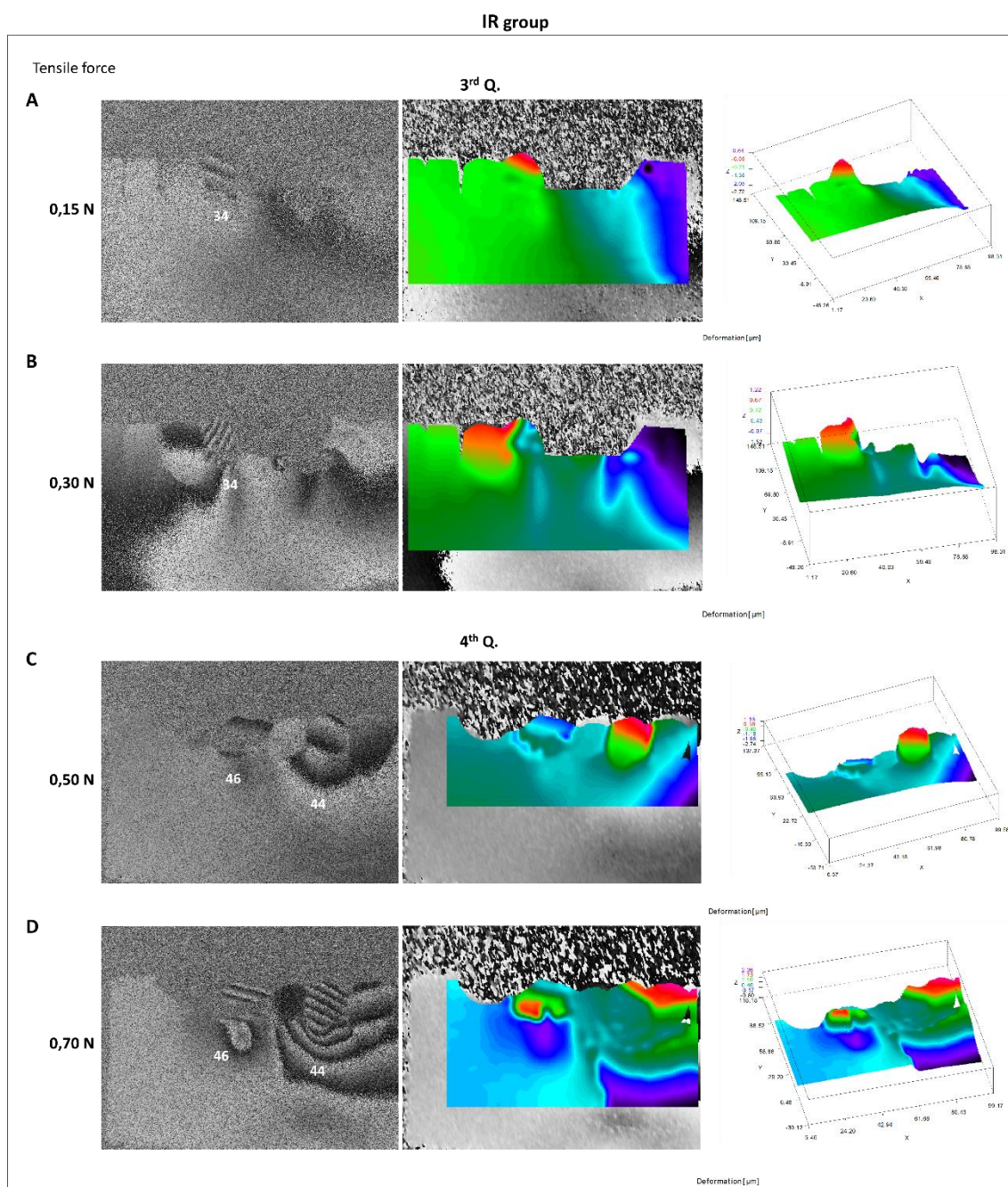
## 3. RESULTS

### *ESPI analysis*

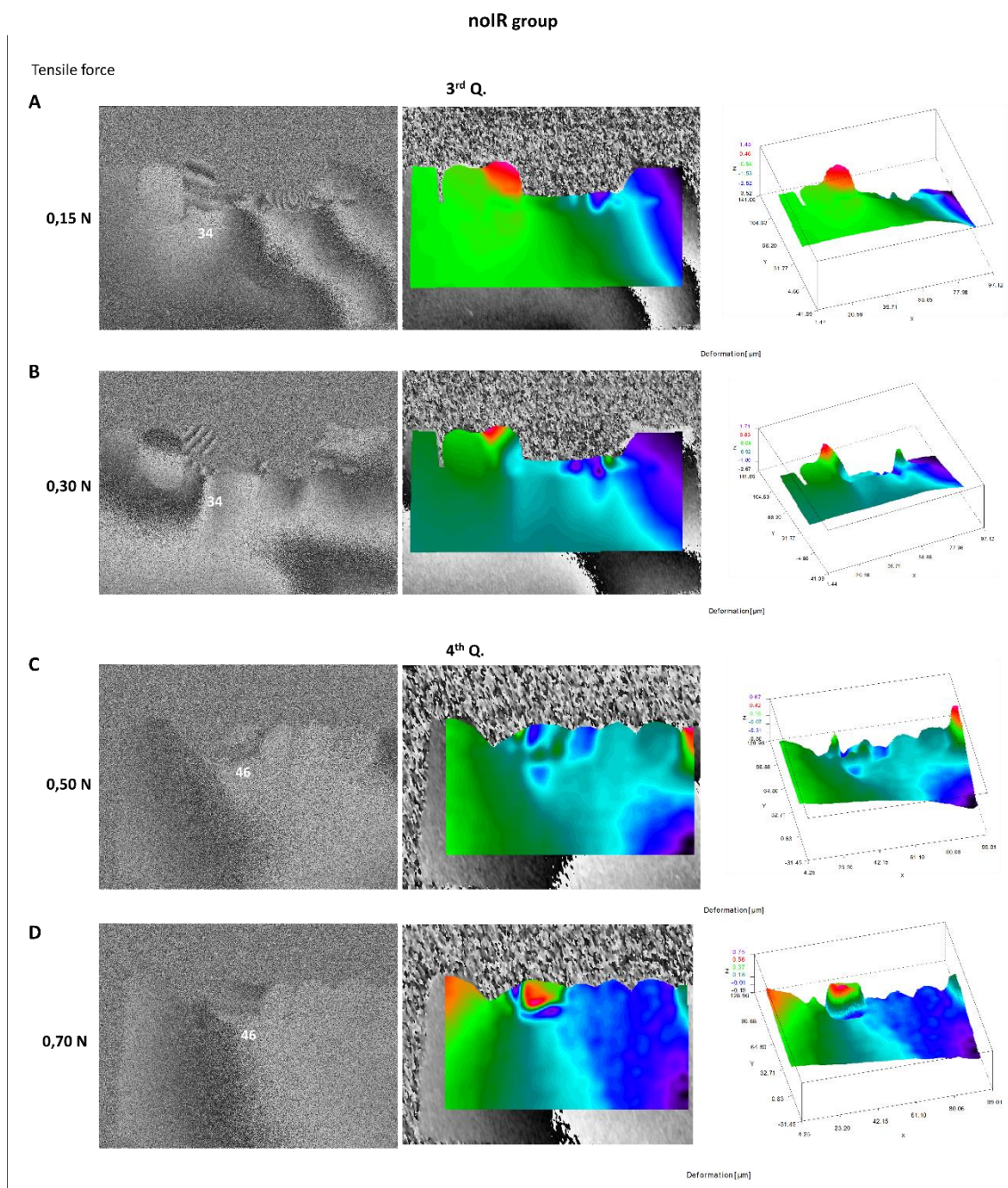
Since interferometric measurements are obtained upon illuminating the surface of the test object with laser light, data from the third and fourth quadrants was separately collected. The out-of-plane displacements registered for each experimental group and condition are summarized in Figs. 5 and 6. An increased number of black and grey fringes and the appearance of red shaded areas are both indicative of high intensity deformations. The maximum tensile load applied to the distal extension was 0,70 N because above this value measurements could not be recorded. Owing to the high sensitivity of the method, relatively large displacements make the fringe pattern indiscernible for the system, which triggers the former observation. One last consideration: during the post-processing some incongruences were produced (black and grey vs colored images). Since the RPD clasps display considerable mobility, the information relative to the underlying tooth surface cannot be accurately integrated by the algorithm. Nevertheless, raw data analysis allows a satisfactory qualitative interpretation of the results.

Regarding the fourth quadrant, displacements associated to the tooth 46 and the surrounding area increased as higher magnitude of tensile load is applied, both in the presence (Fig. 5C-D) and absence (Fig. 6C-D) of the indirect retention element. Comparing the two experimental groups, however, when no indirect retainer is provided the displacements suffered by the tooth 46 were considerably lower than those observed with indirect retention (compare Fig. 6C vs Fig. 5C and Fig. 6D vs Fig. 5D). As anticipated, tooth 44 which supported the indirect retainer in the IR group, was the most affected by deformation events upon the tensile testing.

Concerning the third quadrant, good quality speckle interferograms for the tooth 34 could only be obtained using lower intensity tensile forces (0,15 and 0,30 N). Beyond this level, the measurement range of ESPI was exceeded. Interestingly, the tested forces of 0,15 and 0,30 N triggered different direction patterns of the dark and bright fringes around 35 (Fig. 5A vs B and Fig. 6A vs B). Under low intensity pulling forces (0,15 N), the abutment tooth 34 appears to be more protected from deformation in the IR model (Fig. 5A vs Fig. 6A). On the contrary, when the force magnitude raises, increased deformation was recorded around teeth 34 and 33 in the presence of an indirect retainer (Fig. 5B vs Fig. 6B).



**Figure 5** – ESPI measurements for the indirect retention (IR) group upon application of a tensile force in the free-end saddle (out-of-plane displacement field). Raw fringe pattern, with tooth numbers depicted (left); filtered phase map image, color-coded (middle): red – highest displacement; blue – lowest displacement; graphical representation of the final 3D displacement values (right). **A** and **B**, Records for the third quadrant (3<sup>rd</sup> Q.). **C** and **D**, Records for the fourth quadrant (4<sup>th</sup> Q.).



**Figure 6** – ESPI measurements for the group without indirect retention (noIR) upon application of a tensile force in the free-end saddle (out-of-plane displacement field). Raw fringe pattern, with tooth numbers depicted (left); filtered phase map image, color-coded (middle): red – highest displacement; blue – lowest displacement; graphical representation of the final 3D displacement values (right). **A** and **B**, Records for the third quadrant (3<sup>rd</sup> Q.). **C** and **D**, Records for the fourth quadrant (4<sup>th</sup> Q.).

## 4. DISCUSSION

### *RPD: an obsolete concept?*

The more globalized access to oral care services and the conservative practices of modern dental medicine have determined a progressive decline of total tooth loss, with rising prevalence of partially dentate population [1, 19]. The clinical management of such condition relies on conventional fixed and removable prostheses or implant-supported/retained dentures. Regardless of the adopted strategy, any prosthetic rehabilitation intends to restore normal function of the stomatognathic system (mastication, deglutition and speech), in harmony with aesthetic-related criteria [5]. According to de Van [20], efforts in prosthodontics should be directed toward the perpetuation and preservation of the remaining structures, rather than the mere replacement of missing elements.

A review of the literature suggests that oral comfort is more effectively accomplished by tooth- or implant-supported fixed dentures [5, 21]. The invasiveness and financial costs associated with these modalities, however, often preclude their use as first-line therapies [6, 22]. Accordingly, conventional removable prosthodontic treatment still the most common alternative for the restoration of edentulous areas in general practice [23, 24]; conversely, cutting-edge research focused on RPD has been scarce in the last decades. More than in any field of prosthetic dentistry, removable partial prosthodontics is primarily ruled by cultural and subjective clinical experience, rather than standardized procedures. Likewise, albeit largely accepted, most of classical concepts for RPD construction lack scientific evidence [6, 13].

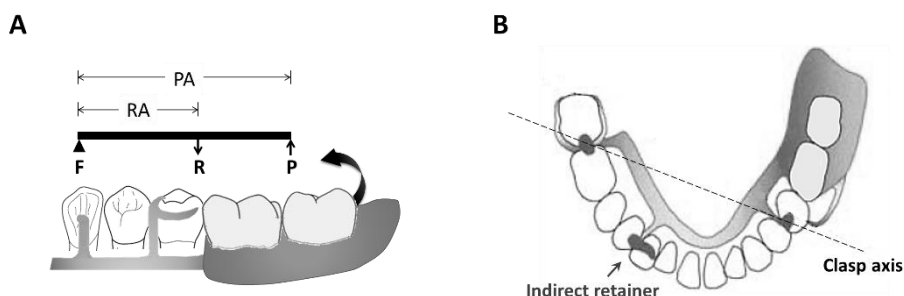
### *Shifting paradigms in RPD*

Traditional principles governing metal-based RPD design emphasize the biomechanical aspects of support, retention and stability. Besides these mechanical tenets, the so called “hygienic principles” are of uttermost importance [13]. According to Jacobson [25], contemporary RPD should focus on simple and open frameworks, with minimal coverage of both hard and soft oral tissues. As documented elsewhere, avoiding redundant or unnecessary structural components enhances plaque control while decreases impingement of the periodontium [13]. Marginal gingiva deserves particular attention, since its coverage elicits crevicular temperature rise, plaque accumulation, gingival inflammation and increased probing depth [26, 27], also potentiating root caries [5, 28].

In light of the topics discussed above, a triad of arguments can be envisaged. First, the significant number of RPDs rejected upon fabrication due to discomfort, practical constraints or patient's unmet expectations [29, 30]. Second, the increased risk of detrimental effects for the remaining oral structures, namely caries and periodontal problems, likely exacerbated by inappropriate or complex RPD designs [27, 28, 31]. Third, the paucity of updated scientific foundations supporting most of the basic concepts of traditional biomechanical RPD construction [5, 6]. According to this triad, a critical reappraisal of classical concepts for RPD design is needed. As part of this endeavor, to examine the importance of indirect retention in distal extension RPDs was defined as the central aim of the current work.

### Indirect retention revisited

The static-dynamic aspects underlying free-end saddle prostheses, particularly in the mandible, constitute a major challenge in the RPD framework design. Aside from the discrepant resiliency of oral mucosa and teeth that determines different viscoelastic responses under occlusal loads, the putative rotation of the denture when lifting forces are present (eg. gravity on maxillary prosthesis, sticky food or functional forces) should be considered as well [32]. To circumvent some of these clinical concerns, the indirect retention principle, first proposed by Cummer [33], has been advocated by specialized prosthodontic literature [10, 11]. The rationale of indirect retention can be illustrated by a Class 2 lever, as follows: the *resistance* (R), represented by the retentive arm of the direct retainer clasp, locates between the *fulcrum* (F), defined by the indirect retainer resting on a tooth, and the *power* (P), representing any occlusally-directed force (Fig. 7A) [14]. To maximize the length of the resistance arm and thus decrease the mechanical advantage of the displacing force, the clasp axis (also referred to as fulcrum line) should be positioned as close as possible to the saddle, with the indirect retainer placed as far to the denture base as feasible (Fig. 7B) [34].



**Figure 7** – Indirect retention principle. **A**, Indirect retainer as the fulcrum of a Class 2 lever. (F) *Fulcrum* – indirect retainer; (R) *Resistance* – direct retainer clasp; (P) *Power* – occlusally-directed force; (PA) *Power arm*; (RA) *Resistance arm*. **B**, Mandibular Kennedy class II RPD showing the clasp axis and the relative position of the indirect retainer element (perpendicular to the former). *Adapted from* [14, 34].

Notwithstanding this apparent consensus, indirect retention remains a controversial issue, whose benefits and drawbacks should be carefully evaluated. Such divided opinions are well documented in the survey of Davenport *et al.* [34], where equal percentage of agreement and disagreement for the need of indirect retainers in distal extension RPDs was obtained among prosthodontic experts. Earlier, using an inferior bilateral distal extension RPD as model, Frank and Nicholls [35] reported little impact of the indirect retainer in counteracting dislodging forces.

The most common version of an indirect retainer consists on a rest coupled to the major connector through a minor connector [14]. Besides increasing the surface area covered by the prosthetic device, this design implies crossing the gingival margin, with all the aforementioned disadvantages [5, 13, 26-28]. To justify incorporating indirect retainers in the RPD metal framework it is, therefore, crucial to assess the effectiveness of those elements by contemporary experimental methods.

#### *(Re)evaluating indirect retention effectiveness*

In addition to prevent the displaceability of distal extension saddles from the supporting mucosa, indirect retainers are supposed to reduce torque forces, i.e., the anteroposterior leverage, on the principal abutment teeth [11]. In a review of 1985, Berg [16] challenged all the conventional assumptions about RPD-related periodontal tissue reactions. According to this author, the hypothesis that the physiologic limits of the periodontium are surpassed by such torque stresses deserves supplementary investigation [16]. In fact, the periodontal deterioration and abutment loosening commonly observed in RPD wearers are likely secondary to plaque accumulation and poor oral hygiene, rather than a direct consequence of detrimental forces transmitted to periodontal structures via RPD framework. These conclusions, pioneered by Bergman *et al.* [36], have been further supported by others [27, 37, 38].

Apparently, distal extension RPDs are no exception: there is no scientific evidence that torque forces transmitted to the abutment teeth can *per se* impair the periodontal status neither increase tooth mobility, as long as three criteria were met: i) rigorous plaque control; ii) favorable bone support; and iii) well-fitting denture saddle [16, 38]. One cannot ignore, however, that the coexistence of these conditions is rare. There remains the question: is the neutralization of torque forces through indirect retention elements worthwhile? To shed some light on this subject, the biomechanical perspective of the problem was experimentally addressed by a holographic approach.

The ESPI technique has been employed to codify the surface information and thus assess the deformation and displacement of an object upon loading conditions. As a non-contact and non-destructive method, ESPI enables repeated measurements on the same sample. Coupled to its high resolution (0,1  $\mu\text{m}$ ), those features turn ESPI into a powerful platform in the dental medicine field [18, 39].

According to the obtained results, the deformation magnitude of the abutment tooth adjacent to the edentulous ridge in the presence or absence of an indirect retainer depends on the intensity of the tensile force applied. Under low intensity dislodging forces able to trigger the retentive function of the direct retainer clasp, the presence of the indirect retainer guarantees an additional fulcrum point that might attenuate forces transmitted to the principal abutment. On the contrary, in the context of higher tensile forces, the deformation resistance of the clasp is likely surpassed. If no indirect retention were provided, the retentive portions of the direct retainers become the only rotation points for the RPD [14]. It is conceivable, therefore, that during the occlusally-directed rotation path, retentive clasps were displaced from the tooth, thus justifying the diminished deformation of the corresponding abutment.

The increased deformation of the contralateral abutment tooth in the IR group, corroborates the notion that indirect retainers facilitate stress distribution [11]. The herein presented findings also highlight the impact of dislodging forces on the tooth supporting the indirect retention element, whose long-term benefits and disadvantages should be carefully analyzed as suggested by others [13].

Although valuable qualitative information was provided by these holographic experiments, a direct *in vitro-in vivo* correlation for the estimated deformation values cannot be established. The accuracy of ESPI results would benefit from the use of dried human mandibles instead of the acrylic-based mandibular arcade here employed [40]. In view of the intrinsic diversity of natural anatomical specimens, however, confounding variables might compromise the interpretation of the results, since disparate deformation patterns could not be directly attributed to the indirect retention. To obviate the practical restrictions associated to large displacements during the ESPI assays, an alternative non-contact optical strategy relying on Digital Image Correlation (DIC) may be considered in future investigations [41].

*In vivo* clinical validation of the ESPI data would represent a major contribution to the research question. Intending to appraise the influence of occlusal rest location and saddle adaptation of a bilateral distal extension RPD on the forces transmitted to abutment teeth, Maxfield *et al.* [42] developed an intraoral strain-gauge device. More recently but with identical purpose, Kawata *et al.* [43] took advantage of a 3D-force measuring device including a piezoelectric transducer. With such an approach, the influence and effectiveness of indirect

retention could be addressed during masticatory function and with varied type of food (eg. hard vs sticky).

Not precluding clinical and experimental tests, the ESPI fringe data could be complemented by another *in vitro*, computerized method: Finite Element Analysis (FEA). FEA consists of a numerical method for modelling intricate structures and predict their biomechanical behavior, vastly used in prosthodontics [44]. The next stage of this work will encompass the development of a FEA model and the 3D CAD design was already set in motion. This strategy should provide important clues for the issues as follows: a) magnitude and direction of the forces transmitted to abutment teeth of both direct and indirect retainers; b) amplitude of movements of the distal extension evoked upon different points of application of the tensile force and c) efficacy of indirect retainers in preventing occlusally-directed movements of the free-end saddle.

## 5. CONCLUSIONS

Contemporary removable partial prosthodontics has evolved from the foundation principles of retention, stability and support, until the open and simple design concepts that reconcile oral hygiene and mechanical performance. Since each RPD framework component represents an additional site of biofilm accumulation, also impairing the self-cleaning action of the buccal mucosa and tongue, its presence should be worthwhile. In this regard, conflicting arguments about the relevance of indirect retainers have been presented elsewhere [13, 16], although robust scientific evidence is still lacking. In order to experimentally assess the impact of indirect retention on the forces transmitted to abutment teeth of a unilateral distal extension mandibular RPD, holographic interferometry data was collected. Taken together, the results herein presented: i) reinforce the empirical consensus that indirect retainers promote cross-arch stress distribution; ii) suggest that forces transmitted to the tooth engaging the indirect retainer should not be neglected, but rather weighed during the framework construction; iii) demonstrate that the ability of indirect retention in preventing torque forces on direct abutment teeth depends on the magnitude of the dislodging force. According to the data here reported, beyond certain limits, intending to protect the abutment tooth from hazardous deformation with indirect retainers might be a misconception.

Although conclusions drawn from *in vitro* models must be interpreted with caution, the current piece of work supports the notion that RPD, particularly with free-end saddles, should be evaluated on a case by case basis. The individualization of the framework design, respecting periodontal conditions, oral hygiene and patient's expectations, should be the gold standard of RPD. Whenever the risks of incorporating an indirect retention element surpass its putative advantages, alternative forms of resisting occlusally-directed forces should be considered. These include maximal base extension and adaptation to the residual ridge, altered-cast impression technique and reduction of the occlusal table area [34].

The validation of these preliminary results via clinical and complementary experimental approaches warrant further investigation that will likely uncover the indirect retention relevance and effectiveness.

## 6. REFERENCES

1. Fuller E, Steele J, Watt R, Nuttall N. 1: Oral health and function – a report from the Adult Dental Health Survey 2009. The Health and Social Care Information Centre. 2011.
2. Douglass CW, Watson AJ. Future needs for fixed and removable partial dentures in the United States. *J Prosthet Dent.* 2002;87(1):9-14.
3. Joshi A, Douglass CW, Feldman H, Mitchell P, Jette A. Consequences of Success: Do More Teeth Translate into More Disease and Utilization? *J Public Health Dent.* 1996;56(4):190-7.
4. Dolan TA, Gilbert GH, Duncan RP, Foerster U. Risk indicators of edentulism, partial tooth loss and prosthetic status among black and white middle-aged and older adults. *Community Dent Oral Epidemiol.* 2001;29(5):329-40.
5. Wostmann B, Budtz-Jorgensen E, Jepson N, Mushimoto E, Palmqvist S, Sofou A, et al. Indications for removable partial dentures: a literature review. *Int J Prosthodont.* 2005;18(2):139-45.
6. Waliszewski MP. Turning points in removable partial denture philosophy. *J Prosthodont.* 2010;19(7):571-9.
7. Knezovic Zlataric D, Celebic A, Valentic-Peruzovic M, Jerolimov V, Panduric J. A survey of treatment outcomes with removable partial dentures. *J Oral Rehabil.* 2003;30(8):847-54.
8. Hakestam U, Karlsson T, Soderfeldt B, Ryden O, Glantz PO. Does the quality of advanced prosthetic dentistry determine patient satisfaction? *Acta Odontol Scand.* 1997;55(6):365-71.
9. Frank RP, Brudvik JS, Leroux B, Milgrom P, Hawkins N. Relationship between the standards of removable partial denture construction, clinical acceptability, and patient satisfaction. *J Prosthet Dent.* 2000;83(5):521-7.
10. Principles, concepts, and practices in prosthodontics-1994. Academy of Prosthodontics. *J Prosthet Dent.* 1995;73(1):73-94.
11. McGivney GP, Castleberry DJ. McCracken's removable partial prosthodontics. 9th ed. St. Louis, MO: Mosby; 1995.
12. Marxkors R. The Partial Denture with Metal Framework. Bremen, Germany: BEGO; Bremer Goldschlägerei Wilhelm Herbst; 1984.
13. Owall B, Budtz-Jorgensen E, Davenport J, Mushimoto E, Palmqvist S, Renner R, et al. Removable partial denture design: a need to focus on hygienic principles? *Int J Prosthodont.* 2002;15(4):371-8.
14. Avant WE. Indirect retention in partial denture design. 1966. *J Prosthet Dent.* 2003;90(1):1-5.
15. Hedegard B, Lundberg M, Wictorin L. [Denture mobility during chewing; a study method]. *Swed Dent J.* 1966;59(7):403-15.
16. Berg E. Periodontal problems associated with use of distal extension removable partial dentures-a matter of construction? *J Oral Rehabil.* 1985;12(5):369-79.

17. Marxkors R. Mastering the removable partial denture. Part one: Basic reflections about construction. *J Dent Technol.* 1997;14(1):34-9.
18. Campos LMP, Parra DF, Vasconcelos MR, Vaz M, Monteiro J. DH and ESPI laser interferometry applied to the restoration shrinkage assessment. *Radiat Phys Chem.* 2014;94:190-3.
19. Muller F, Naharro M, Carlsson GE. What are the prevalence and incidence of tooth loss in the adult and elderly population in Europe? *Clin Oral Implants Res.* 2007;18 Suppl 3:2-14.
20. DeVan MM. The nature of the partial denture foundation: Suggestions for its preservation. *J Prosthet Dent.* 1952;2(2):210-8.
21. Jepson N, Allen F, Moynihan P, Kelly P, Thomason M. Patient satisfaction following restoration of shortened mandibular dental arches in a randomized controlled trial. *Int J Prosthodont.* 2003;16(4):409-14.
22. Scully C, Hobkirk J, D Dios P. Dental endosseous implants in the medically compromised patient. *J Oral Rehabil.* 2007;34(8):590-9.
23. Owen PC. Appropriatech: prosthodontics for the many, not just for the few. *Int J Prosthodont.* 2004;17(3):261-2.
24. Carlsson GE . Some issues related to evidence-based implantology. *J Indian Prosthodont Soc.* 2016;16:116-23.
25. Jacobson TE. Periodontal considerations in removable partial denture design. *Compendium.* 1987;8(7):530-4, 6-9.
26. Runov J, Kroone H, Stoltze K, Maeda T, El Ghamrawy E, Brill N. Host response to two different designs of minor connector. *J Oral Rehabil.* 1980;7(2):147-53.
27. Zlataric DK, Celebic A, Valentic-Peruzovic M. The effect of removable partial dentures on periodontal health of abutment and non-abutment teeth. *J Periodontol.* 2002;73(2):137-44.
28. Jepson NJ, Moynihan PJ, Kelly PJ, Watson GW, Thomason JM. Caries incidence following restoration of shortened lower dental arches in a randomized controlled trial. *Br Dent J.* 2001;191(3):140-4.
29. Jepson NJ, Thomason JM, Steele JG. The influence of denture design on patient acceptance of partial dentures. *Br Dent J.* 1995;178(8):296-300.
30. Graham R, Mihaylov S, Jepson N, Allen PF, Bond S. Determining "need" for a Removable Partial Denture: a qualitative study of factors that influence dentist provision and patient use. *Br Dent J.* 2006;200(3):155-8, discussion 47.
31. Radnai M SR, Gorzo I. Removable Partial Denture with Bar or Plate: How should We Decide? *Int J Experiment Dent Sci* 2013;2(2):104-9.
32. Nassani MZ, Tarakji B, Baroudi K, Sakka S. Reappraisal of the removable partial denture as a treatment option for the shortened dental arch. *Eur J Dent.* 2013;7(2):251-6.
33. Cummer W. Partial denture service. In Anthony LP, editor: *The American textbook of prosthetic dentistry.* 7th ed. Philadelphia: Lea & Feibiger; 1942. pp. 782-3.
34. Davenport JC, Basker RM, Heath JR, Ralph JP, Glantz PO, Hammond P. Indirect retention. *Br Dent J.* 2001;190(3):128-32.

35. Frank RP, Nicholls JI. An investigation of the effectiveness of indirect retainers. *J Prosthet Dent.* 1977;38(5):494-506.
36. Bergman B, Hugoson A, Olsson CO. Caries, periodontal and prosthetic findings in patients with removable partial dentures: a ten-year longitudinal study. *J Prosthet Dent.* 1982;48(5):506-14.
37. do Amaral BA, Barreto AO, Gomes Seabra E, Roncalli AG, da Fonte Porto Carreiro A, de Almeida EO. A clinical follow-up study of the periodontal conditions of RPD abutment and non-abutment teeth. *J Oral Rehabil.* 2010;37(7):545-52.
38. Budtz-Jorgensen E, Bochet G. Alternate framework designs for removable partial dentures. *J Prosthet Dent.* 1998;80(1):58-66.
39. Campos JC, Correia A, Vaz MA, Branco FJ. Holographic stress analysis in a distal extension removable partial denture. *Eur J Prosthodont Restor Dent.* 2009;17(3):111-5.
40. Campos TN, Adachi LK, Chorres JE, Campos AC, Muramatsu M, Gioso MA. Holographic interferometry method for assessment of static load stress distribution in dog mandible. *Braz Dent J.* 2006;17(4):279-84.
41. Tanasic I, Milic-Lemic A, Tihacek-Sojic L, Stancic I, Mitrovic N. Analysis of the compressive strain below the removable and fixed prosthesis in the posterior mandible using a digital image correlation method. *Biomech Model Mechanobiol.* 2012;11(6):751-8.
42. Maxfield JB, Nicholls JI, Smith DE. The measurement of forces transmitted to abutment teeth of removable partial dentures. *J Prosthet Dent.* 1979;41(2):134-42.
43. Kawata T, Kawaguchi T, Yoda N, Ogawa T, Kuriyagawa T, Sasaki K. Effects of a removable partial denture and its rest location on the forces exerted on an abutment tooth in vivo. *Int J Prosthodont.* 2008;21(1):50-2.
44. Trivedi S. Finite element analysis: A boon to dentistry. *J Oral Biol Craniofac Res.* 2014;4(3):200-3.

## DECLARAÇÃO

### Monografia de Investigação

Declaro que o presente trabalho, no âmbito na Monografia de Investigação, integrado no MIMD, da FMDUP, é da minha autoria e todas as fontes foram devidamente referenciadas.

Porto, 27 de maio de 2016

A investigadora,



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(Susana João Cunha Oliveira)

## **PARECER DO ORIENTADOR**

### **(Entrega do trabalho final de Monografia)**

Informo que o Trabalho de Monografia desenvolvido pela Estudante Susana João Cunha Oliveira com o título "Prótese Parcial Removível com extensões distais – avaliação crítica do papel da Retenção Indireta", está de acordo com as regras estipuladas na FMDUP, foi por mim conferido e encontra-se em condições de ser apresentado em provas públicas.

Porto, 27 de maio de 2016

A Orientadora,

Maria Helena Guimarães Figueiral da Silva

(Maria Helena Guimarães Figueiral da Silva)