

RESEARCH AND EDUCATION

Stress on implant-supported fixed prostheses with different numbers of abutments after the application of acrylic resin



Marina Rechden Lobato Palmeiro, DDS, MSc, PhD,^a Leonardo Hoffmann de Barcellos, DDS, MSc, PhD,^b Marcos Naconecy, DDS, MSc, PhD,^c Tomás Geremia, DDS, MSc, PhD,^d André Cervieri, DDS, MSc, PhD,^e and Rosemary Sadami Arai Shinkai, DDS, MSc, PhD^f

One of the most frequent causes of implant loss after the installation of a prosthesis is the development of excess tension in the system.¹ The planning, design, and production of the prosthesis should minimize tension to reduce initial bone loss and other complications. Thus, knowledge of the biomechanics associated with the implant-supported prosthesis is essential in designing the best treatment strategy for dissipating the occlusal forces.

Implant-supported prostheses are subjected to masticatory forces and to tension generated during the delivery and adaptation of the prosthetic structure.² The passive settlement of prosthetic structures, especially complete-arch fixed implant-supported prostheses, has been of concern since the discovery of osseointegration.^{1,3-5} Passivity in the metallic framework results from a meticulous process that includes clinical and laboratory procedures.⁶ This adaptation between both implant and abutment and between

ABSTRACT

Statement of problem. Clinical procedures and laboratory processing techniques inevitably induce stress in the implant/abutment/prosthesis system and may have negative effects when different numbers of implants are used.

Purpose. The purpose of the study was to evaluate the tension on the abutments of implant-supported fixed prostheses and to determine the effect of the application of an esthetic veneer (acrylic resin) and the number of abutments (5 or 4).

Material and methods. Four palladium-silver alloy cast bars were fabricated to simulate implant-supported fixed complete prostheses. Strain gauges were fixed on the abutments to measure the tension before and after the application of the esthetic veneer. The values of tension were measured in models with 5 or 4 abutments. Data were analyzed with a repeated measures ANOVA.

Results. No statistically significant differences were found for the main factors (esthetic veneer, $P=.22$; number of abutments, $P=.14$) despite the large effect size.

Conclusions. The results of this study suggest that the tension in the abutments of an implant-supported fixed prosthesis is not affected by the application of acrylic resin veneering or by reducing the number of abutments. (J Prosthet Dent 2015;113:323-328)

abutment and prosthetic structure is paramount for the long-term success of implant-supported prostheses.⁴ Similar to conventional fixed prostheses, the cause of a nonfitting prosthetic structure is multifactorial.¹ Distortion may occur in the x-, y-, and z-axis dimensions, resulting from one or more of the following factors: the positioning of the implants, the impression technique and material, the fabrication of the metallic framework, and the application of the esthetic veneer.^{2,5,7-14}

Partially supported by a scholarship from the Ministry of Education/CAPES, Brazil. Presented at the 27th Annual Meeting of the SBPqO (Brazilian Division of International Association of Dental Research), Águas de Lindóia, São Paulo, Brazil, September 2010.

^aAssistant Professor, Department of Prosthodontics, Pontifical Catholic University of Rio Grande do Sul, Rio Grande do Sul, Brazil.

^bAssistant lecturer, Postgraduate Program in Dentistry, Pontifical Catholic University of Rio Grande do Sul, Rio Grande do Sul, Brazil.

^cPrivate practice, Porto Alegre, Rio Grande do Sul, Brazil.

^dAssistant Professor, Department of Prosthodontics, Pontifical Catholic University of Rio Grande do Sul, Rio Grande do Sul, Brazil.

^eAssociate Professor, Department of Engineering, Lutheran University of Brazil, Rio Grande do Sul, Brazil.

^fProfessor, Department of Prosthodontics, Pontifical Catholic University of Rio Grande do Sul, Rio Grande do Sul, Brazil.

Clinical Implications

Although the threshold for the stress magnitude needed for the long-term success of implants and prostheses is still unknown, adequate treatment planning and controlled laboratory processing techniques are necessary to limit negative effects. The use of 4 abutments rather than 5 resulted in reliable biomechanical behavior after veneering the metallic bar with acrylic resin, because in the current model the residual stress did not increase.

Extensive studies on the biomechanical behavior of osseointegrated implants began in 1983 with the work of Skalak.¹⁵ Since this time, the distribution of vertical and horizontal forces on a fixed implant-supported prosthesis has been known to be influenced by the number, distribution, and resistance of the implants and the form and resistance of the prosthetic structure itself.¹⁵

The technique that was initially developed by Brånemark to rehabilitate edentulous mandibles recommended that 5 implants be installed and that these be attached to a screwed implant-supported prosthesis.³ This protocol of placing 5 implants in the region between the mental foramen, also known as the Brånemark protocol, continues to be reviewed. Regarding the number and distribution of the implants, an increasing number of studies have proposed altering the technique, which was initially developed for edentulous patients. These studies recommend the use of 4 implants for the same prosthetic solution, and this recommendation has become widespread because the tension distribution is similar when either 4 or 5 implants are used.¹⁶⁻²⁰

The distribution of the implants in the bone arch has been indicated as a more important factor than the number of implants because distribution is the predominant factor in forming an appropriate support polygon.^{19,21} Studies have demonstrated that the distribution of tension is similar when either 5 or 4 implants are used.^{16,17,20,22} Thus, the fixation of 4 implants has been increasingly used to rehabilitate patients with an edentulous arch.¹⁸⁻²⁰

The design and material of the prosthetic structure also influence the load of the dental implants and the deformation of the bone tissue. The prosthesis, which is applied over the implant, may consist of different materials, such as gold alloy, ceramic fused to a noble alloy, porcelain, composite resin, reinforced composite resin, and acrylic resin. Recently, studies have examined the materials in an effort to minimize the impact forces that are transmitted to the implant. These studies indicated that acrylic resin was the best esthetic veneering material for implant-supported prostheses.^{2,3,9,23-25}

Several techniques have been used to analyze the distribution of tension and deformations. Electrical resistance extensometry is an experimental method that measures deformation around a point in a body by means of strain gauges.^{12,13,20} Electrical strain gauges are sensors that are used to evaluate deformations that occur in a given area and a given direction in a piece of equipment.¹² Therefore, the use of strain gauges for biomechanical evaluation can determine both in vitro and in vivo real-time tension measurements in implants and metallic structures that are subjected to static or dynamic loads.^{12-14,20,26-30}

This study aimed to evaluate the tension in implant-supported fixed prostheses due to the effect of the application of an esthetic veneer and the number of implants (5 or 4) with electrical resistance extensometry. The null hypothesis was that no difference in tension would occur with the application of acrylic resin over the metallic framework and with the reduction of the number of implants from 5 to 4.

MATERIAL AND METHODS

Five screw implants measuring 4 mm in diameter and 15 mm in length and containing an external hexagonal platform (OSS 415; 3i Implant Innovations) were affixed to the parallel perforations in an epoxy resin base. Five straight, standard 7-mm abutments (AB700; 3i Implant Innovations) were screwed into the implant platform with an internal hexagon key (RASA3; 3i Implant Innovations). The abutments were numbered clockwise from 1 to 5. A torque of 20 Ncm was applied with an electronic torque control (DEC 600-1 Osseocare Drilling Equipment; Nobel Biocare) as recommended by the manufacturer.^{13,20}

Four silver-palladium bars (Porson 4; Degussa) were produced in an arc shape with a rectangular section. These had a width of 3 mm in the buccolingual direction, a height of 4 mm in the occlusal-cervical direction, and a cantilever length of 20 mm on the left side (Fig. 1). The passive adjustment of each bar was verified visually with a single screw, and no gaps were identified in any of the abutments. This procedure was performed individually for the 5 screws of each bar.

Each of the 4 bars was waxed with the PKT wax drip system (Duflex; SSWhite) to standardize the esthetic veneer. The waxing over the bar measured 3 mm in the buccolingual direction, 3 mm in the occlusal-cervical direction, and 20 mm on the left side of the cantilever, as measured with digital calipers (Mitutoyo Sul Americana Ltd), and flaked.

The acrylic resin (Lucitone 550; Dentsply Intl) was polymerized for 3 hours and 30 minutes at 70°C and 3 hours and 30 minutes at 98°C, followed by gradual cooling. After the application of the veneer, the

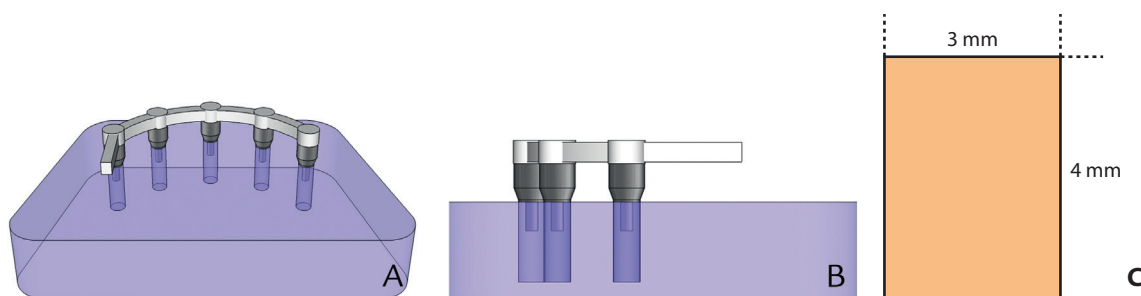


Figure 1. Silver-palladium bar. A, Posterior view. B, Lateral view. C, Transverse section.



Figure 2. Veneer. A, Occlusal view. B, Thickness measurement. C, Transverse section.

specimens showed the approximate shape of an implant-supported prosthesis with a 20-mm cantilever on the left side. Discrepancies in thickness were balanced by grinding with tungsten carbide burs (Heraeus Kulzer) rotating at 15 000 rpm. The thickness was periodically checked with the digital calipers. A thickness variation of ± 0.05 mm was accepted (Fig. 2).

Strain gauges (KFG 02-120C1-11N15C2; Kyowa Electronic Instruments Co Ltd) with a grid length of 0.2 mm were glued to the smooth metal band of each abutment (Fig. 3). Each electric resistance strain gauge measured a value of deformation in a given direction. This deformation value was obtained by reading the appropriate channel in the data-gathering equipment used in this experiment.

Each metal bar was screwed into the abutments of the master model to register the initial deformation of the system. In the model, the implants were numbered from 1 to 5 in a clockwise direction. Tightening of the gold retention screws (GSH30; 3i Implant Innovations) followed the sequence of 2, 4, 3, 1, 5 for all bars.³¹ First the screws were tightened with a manual hexagon driver (3i Implant Innovations) until the operator perceived any resistance. Then, the channels that read the deformations were reset to capture only those deformations that resulted from a tightening of the screws with a controlled torque. After that, a torque of 10 Ncm was applied by using a digital torque control (DEC 600-1 Osseocare Drilling Equipment; Nobel

Biocare) and a hexagon driver for controlled torque (RASH3N; 3i Implant Innovations). The same type of screws was used for each bar so that fatigue was similar.

The procedure described above was performed on the 4 bars: without the esthetic veneer and attached (screwed) on 5 abutments model; without the esthetic veneer and attached (screwed) on 4 abutments model; with the esthetic veneer and attached (screwed) on 5 abutments model; and with the esthetic veneer and attached (screwed) on 4 abutments model. In order to obtain the 4 abutments model, the central abutment (number 3) was removed.

Two conditions were tested: metallic bars without the esthetic veneer installed on either the 5 or 4 abutment model, and metallic bars with the esthetic veneer were installed on either the 5 or 4 abutment model. For each specimen (metallic bar), a deformation versus time graph was generated in an electronic data sheet. From each graph, the point where the signal had stabilized after the application of a 10-Ncm torque was selected. The readings obtained with the strain gauges were measured in units of deformation (mm/m) and converted by equations to units of tension (MPa).

Quantitative data were described by using mean and standard deviations. Data were analyzed with a repeated measures ANOVA, where the number of abutments (5 versus 4) was considered the within-subject factor and the esthetic veneer was considered the between-subject

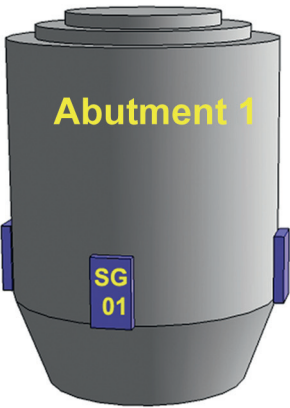
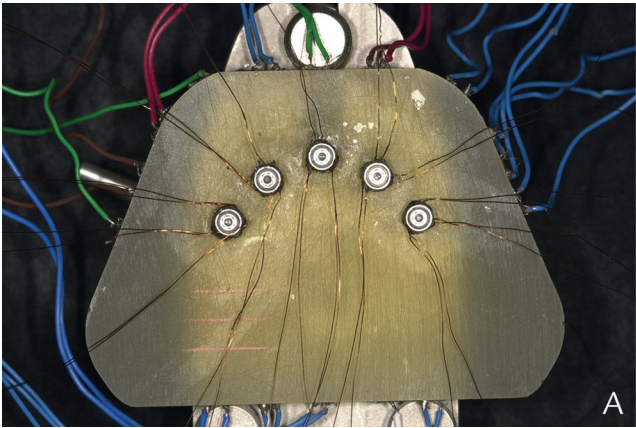


Figure 3. Strain gauges. A, Experimental scheme. B, Strain gauge position.

Table 1. Mean (standard deviation) for tension (MPa) stratified by abutment systems and esthetic veneer

Esthetic Veneer	4-Abutment System	5-Abutment System	Difference	P	d*
No	14.3 ±3.9	13.8 ±2.8	0.5	.74	0.18
Yes	21.3 ±10.1	17.1 ±8.8	4.2	.19	0.86

*Cohen effect size interpretation: 0-0.20 = slight; 0.21 to 0.6 = small; 0.6 to 1.2 = medium; 1.2 to 2.0 = large; 2.0 to 4.0 = very large; more than 4.0 = perfect agreement.

factor. The ANOVA model also included an interaction factor. In order to evaluate effect size, the eta-square statistic was used. Additionally, a stratified analysis was conducted to evaluate the number of abutments in the model (as within factor) by esthetic veneer presence by using the Cohen d statistic to evaluate effect size ($\alpha=.05$). All analyses were performed with a statistical software package (SPSS v.21.0; IBM Corp).

RESULTS

The statistical analysis with repeated measures ANOVA showed a difference between abutment systems (5 versus 4); however, despite the large effect size ($\eta^2=.32$), it did not achieve statistical significance ($P=.14$). In addition, the esthetic veneer seemed to be an interaction effect intensifying the difference in tension within the abutment systems and did not reach statistical significance either ($P=.22$).

Table 1 shows stratified analysis data of the tension values by abutment systems and esthetic veneer. After the application of the veneer, the variability in the tension values increased. Figure 4 demonstrates the variation factors (abutment systems and esthetic veneer).

DISCUSSION

This in vitro study did not demonstrate any statistical differences in the tension values for the abutments of fixed implant-supported prostheses before or after the application of an esthetic veneer in models with 5 and 4

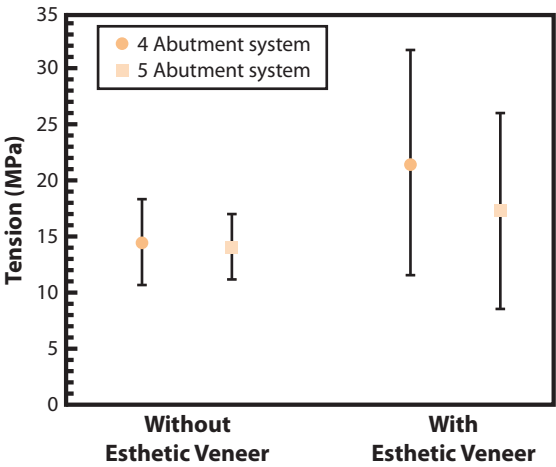


Figure 4. Results of tension (MPa) in abutment systems without and with esthetic veneer.

abutments. These results for the veneer factor provide positive evidence for the laboratory and clinical aspects once the application of an esthetic veneer is an essential step in the process of manufacturing dental prostheses. The use of acrylic resin, a widely used material, did not significantly increase tension in the entire system of abutments and a metal bar.

Even with the constant introduction of new materials, thermopolymerizable-acrylic resin is still the material of choice for the esthetic veneer for metal structures in implant-supported prostheses.⁹ Acrylic resin provides some absorption of masticatory forces, which could impede the integral transfer of adverse tensions for the implants and bone tissue. This material also has a low cost and an application protocol that is accessible to laboratory technicians.^{3,9,23,25,26} As a result of the close contact between the implant and bone tissue, between the implant and abutment, and between the bone tissue and prosthesis, the transmission of tension essentially occurs directly. The initial incidence of the masticatory

force is over the veneering material. This situation justifies the importance of using materials that better absorb and distribute the loads, like acrylic resin.^{9,15,24-26} In addition, when subjected to a static load, the metal structure better supports stress when veneered with acrylic resin.⁹

The application of the esthetic veneer on the prosthesis seemed to affect the level of tension distribution in the metallic framework. A previous study with mathematical models showed that the stress tends to remain concentrated in the marginal area of the prosthesis.⁹ Improving the clinical procedures and the prosthetic stages associated with the correct evaluation method for adaptation optimized the settling of the prosthesis and decreased the tension in this system.^{1,30}

Although the results of this study cannot be directly extrapolated to a clinical situation, they suggest that the application of the esthetic veneer may be more critical than the fabrication of the metal framework. After the application of the esthetic veneer, a greater variability among the tension values was found than for the values without a thermopolymerizable acrylic resin veneer. Therefore, a controlled technique for the application of the veneer is needed so that an eventual increase in tension generated in the system remains within clinically acceptable parameters. The use of composite resins has been suggested and tested. Photopolymerizable resin can absorb tension, but it has a higher cost than acrylic resin and demands a lengthier and more thorough production technique.^{9,25}

No statistical difference was found between the models with 5 and 4 abutments. The results of the current study are consistent with recent publications.¹⁶ The classic protocol of placing 5 implants in the interforaminal region of the mandible has been replaced by the use of 4 implants for the fixation of complete prostheses.¹⁶⁻²⁰ However, further investigation is needed to determine if clinical and/or biomechanical failures and complications, such as cracks in the esthetic veneer and/or loosening of the screws will occur in the long term.¹⁶ According to some authors, a decrease in the number of abutments from 5 to 4 does not significantly increase the tension; however, the use of 5 implants allows for greater predictability in the case of an eventual failure of one of the implants.^{16,17} In addition, the distribution of the implants in the bone arch may be more important than the number of implants because it is the predominant factor in the formation of an appropriate support polygon.^{18,21}

In this study, less variability in tension was found in the group with 5 abutments without veneer. The lack of homogeneity in the results in the other groups of this experiment can be explained by the processing method of the specimens.⁴

Currently, extensometry is a widely used method for measuring tension in systems composed of implant-supported prostheses. Biomechanical evaluation using extensometry can determine tension measurements both in vitro and in vivo and in real time in the implants and metal framework subjected to static or dynamic loads.^{12-14,20,26-28} The electrical resistance strain gauges are sensors; when they are affixed to the surface of a material, they record the deformation to which the material is subjected, which alters the passage of the low-intensity electrical current that runs through these sensors. In in vitro biomechanical studies of implant-supported prostheses, these devices may be placed in the master model, in the abutments, and/or in the prosthetic structure.^{4,5,16,27} In this study, the strain gauges were placed in the abutments, following the example of recently published studies.^{13,14,20,29}

Because the current study was an in vitro experiment, many simplifications were made in the design and the production of the metal framework. The metal bars used were arc shaped with a rectangular section and uniform dimensions of width, length, and height for all parts. This does not match clinical reality, where the metal framework is not uniform because the anatomy of the borders, the positioning of the implants, and maxillomandibular relations dictate the dimensions.^{13,16,20} However, the results of this research, along with previous studies completed by the same research group,^{11,13,20} contribute to the establishment of production protocols that can minimize the introduction of tension in the laboratory phase of fixed implant-supported prostheses.

Additional studies must be performed to better understand the influence of other types of esthetic veneers (thermopolymerizable acrylic resin, composite resin, and porcelain) on metal frameworks with different designs and alloys. Furthermore, the development of tension during load application in the system must be studied in vitro and in vivo. The distribution of tension in the osseointegrated complex depended on functional and parafunctional loads, on the passive settling of the prosthesis, on the length of the cantilever, and on the mechanical properties of the materials used. Thus, despite the inherent limitations of laboratory and experimental research, biomechanical studies of implant-supported prostheses such as the current study can help increase the predictability of function and the success of treatments.

CONCLUSIONS

According to the methodology used, the results of the current study revealed that in simulations with fixed implant-supported prostheses, the application of a thermopolymerizable acrylic resin veneer did not generate a significant variation in the tension of the abutments. In this experimental model, the number of

abutments (5 or 4) did not affect the tension in the system with or without the acrylic-resin veneer.

REFERENCES

- Kan JY, Rungcharassaeng K, Bohsali K, Goodacre CJ, Lang BR. Clinical methods for evaluating implant framework fit. *J Prosthet Dent* 1999;81:7-13.
- Jemt T, Lekholm U. Measurements of bone and frame-work deformations induced by misfit of implant superstructures. A pilot study in rabbits. *Clin Oral Implants Res* 1998;9:272-80.
- Brånemark PI. Osseointegration and its experimental background. *J Prosthet Dent* 1983;50:399-410.
- Watanabe F, Uno I, Hata Y, Neuendorff G, Kirsch A. Analysis of stress distribution in a screw-retained implant prosthesis. *Int J Oral Maxillofac Implants* 2000;15:209-18.
- Sahin S, Cehreli MC. The significance of passive framework fit in implant prosthodontics: current status. *Implant Dent* 2001;10:85-92.
- Chee W, Felton DA, Johnson PF, Sullivan DY. Cemented versus screw-retained implant prostheses: which is better? *Int J Oral Maxillofac Implants* 1999;14:137-41.
- Nicholls JL. The measurement of distortion: concluding remarks. *J Prosthet Dent* 1980;43:218-23.
- Tan KB, Rubenstein JE, Nicholls JL, Yuodelis RA. Three-dimensional analysis of the casting accuracy of one-piece, osseointegrated implant-retained prostheses. *Int J Prosthodont* 1993;6:346-63.
- Ciftçi Y, Canay S. The effect of veneering materials on stress distribution in implant-supported fixed prosthetic restorations. *Int J Oral Maxillofac Implants* 2000;15:571-82.
- Murphy WM, Absi EG, Gregory MC, Williams KR. A prospective 5-year study of two cast framework alloys for fixed implant-supported mandibular prostheses. *Int J Prosthodont* 2002;15:133-8.
- Naconecy MM, Teixeira ER, Shinkai RS, Frasca LC, Cervieri A. Evaluation of the accuracy of 3 transfer techniques for implant-supported prostheses with multiple abutments. *Int J Oral Maxillofac Implants* 2004;19:192-8.
- Assunção WG, Barão VAR, Tabata LF, Gomes EA, Delben JA, Santos PH. Biomechanics studies in dentistry: bioengineering applied in oral implantology. *J Craniofac Surg* 2009;20:1173-7.
- Geremia T, Naconecy MM, Mezzomo LA, Cervieri A, Shinkai RS. Effect of cantilever length and inclined implants on axial force and bending moment in implant-supported fixed prostheses. *Rev Odonto Ciênc* 2009;24:145-50.
- Suedam V, Souza EA, Moura MS, Jacques LB, Rubo JH. Effect of abutment's height and framework alloy on the load distribution of mandibular cantilevered implant-supported prosthesis. *Clin Oral Implants Res* 2009;20:196-200.
- Skalak R. Biomechanical considerations in osseointegrated prostheses. *J Prosthet Dent* 1983;49:843-8.
- Davis DM, Zarb GA, Chao YL. Studies on frameworks for osseointegrated prostheses: part 1. The effect of varying the number of supporting abutments. *Int J Oral Maxillofac Implants* 1988;3:197-201.
- Becker W, Becker BE, Huffstetler S. Early functional loading at 5 days for Brånemark implants placed into edentulous mandibles: a prospective, open-ended, longitudinal study. *J Periodontol* 2003;74:695-702.
- Kronström M, Widbom T, Löfquist LE, Henningson C, Widbom C, Lundberg T. Early functional loading of conical Brånemark implants in the edentulous mandible: a 12-month follow-up clinical report. *J Prosthet Dent* 2003;89:335-40.
- Maló P, Rangert B, Nobre M. "All-on-four" immediate-function concept with Brånemark System implants for completely edentulous mandibles: a retrospective clinical study. *Clin Implant Dent Relat Res* 2003;5:2-9.
- Naconecy MM, Geremia T, Cervieri A, Teixeira ER, Shinkai RS. Effect of the number of abutments on biomechanics of Brånemark prosthesis with straight and tilted distal implants. *J Appl Oral Sci* 2010;18:178-85.
- Morgan MJ, James DF. Force and moment distributions among osseointegrated dental implants. *J Biomech* 1995;28:1103-9.
- Brånemark PI, Svensson B, Van Steenberghe D. Ten-year survival rates of fixed prostheses on four or six implants ad modum Brånemark in full edentulism. *Clin Oral Implants Res* 1995;6:227-31.
- Adell R, Lekholm U, Rockler B, Brånemark PI. A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. *Int J Oral Surg* 1981;10:387-416.
- Davis DM, Rimrott R, Zarb GA. Studies on frameworks for osseointegrated prostheses: part 2. The effect of adding acrylic resin or porcelain to form the occlusal superstructure. *Int J Oral Maxillofac Implants* 1988;3:275-80.
- Gracis SE, Nicholls JL, Chalupnik JD, Yuodelis RA. Shock-absorbing behavior of five restorative materials used on implants. *Int J Prosthodont* 1991;4:282-91.
- Duyck J, Van Oosterwyck H, Vander Sloten J, De Cooman M, Puers R, Naert I. Magnitude and distribution of occlusal forces on oral implants supporting fixed prostheses: an in vivo study. *Clin Oral Implants Res* 2000;11:465-75.
- Bassit R, Lindström H, Rangert B. In vivo registration of force development with ceramic and acrylic resin occlusal materials on implant-supported prostheses. *Int J Oral Maxillofac Implants* 2002;17:17-23.
- Eser A, Akça K, Eckert S, Cehreli MC. Nonlinear finite element analysis versus ex vivo strain gauge measurements on immediately loaded implants. *Int J Oral Maxillofac Implants* 2009;24:439-46.
- Jacques LB, Moura MS, Suedam V, Souza EA, Rubo JH. Effect of cantilever length and framework alloy on the stress distribution of mandibular-cantilevered implant-supported prostheses. *Clin Oral Implants Res* 2009;20:737-41.
- Karl M, Graef F, Heckmann S, Taylor T. A methodology to study the effects of prosthesis misfit over time: an in vivo model. *Int J Oral Maxillofac Implants* 2009;24:689-94.
- Jemt T. Failures and complications in 391 consecutively inserted fixed prostheses supported by Brånemark implants in edentulous jaws: a study of treatment from the time of prosthesis placement to the first annual checkup. *Int J Oral Maxillofac Implants* 1991;6:270-6.

Corresponding author:

Dr Marina R. Lobato Palmeiro
Av. Ipiranga, 6681-Prédio 6
Porto Alegre, RS 90619-900
BRAZIL
Email: marina.lobato@pucrs.br

Acknowledgments

The authors thank Cedenir Albani, CDT, and Cristiano Friederichs, CDT, Porto-Dent Dental Laboratory, and Telmo Strohaecker, Eng, PhD, from the Federal University of Rio Grande do Sul, who was the coordinator of the laboratory where the experimental data were collected.

Copyright © 2015 by the Editorial Council for *The Journal of Prosthetic Dentistry*.