

Effect of cantilever length and inclined implants on axial force and bending moment in implant-supported fixed prostheses

Efeito do *cantilever* e de implantes inclinados na força axial e momento fletor em próteses fixas implantossuportadas

Abstract

Purpose: To assess the magnitude and distribution of axial forces and bending moments in abutments as a function of cantilever length and inclination of implants.

Methods: Ten metallic bars simulated frameworks of fixed implant-supported prosthesis over two master models with five implants: one with all implants straight and parallel ($n=5$) and one with the two distal implants tilted ($n=5$). Strain gauges were fixed on abutments to measure deformation when a 50N-load was applied on the cantilever at 10, 15, and 20 mm-distance from the distal abutment. Deformation values were transformed into axial force and bending moment and analyzed by ANOVA and Tukey test ($\alpha = 5\%$).

Results: Comparing 10 mm- to 20 mm-cantilever, there was an increase of approximately 50% for axial force and of 70% for sagittal bending moment. On the abutment adjacent to the cantilever, the axial force in the inclined model was 70% lower than in the straight model, and bending moments did not vary.

Conclusion: The results suggest that the inclination of distal implants does not have any deleterious biomechanical effect on abutments of the tested models and may reduce the cantilever effect on force magnitude.

Key words: Biomechanics; cantilever; implant-supported prostheses; strain gauges; tilted implants

Resumo

Objetivo: Avaliar a magnitude e a distribuição de forças axiais e momentos fletores em pilares em função da extensão do cantilever e da inclinação dos implantes.

Metodologia: Dez barras metálicas simularam infraestruturas de prótese fixa implantossuportada sobre dois modelos mestre com 5 implantes: um modelo com todos os implantes retos e paralelos ($n=5$) e um com os dois implantes distais inclinados ($n=5$). Extensômetros foram fixados nos pilares para medir sua deformação quando uma carga de 50N foi aplicada no cantilever a 10, 15 e 20 mm do implante distal. Os valores de deformação foram convertidos em força axial e momento fletor e analisados por ANOVA e teste de Tukey ($\alpha = 5\%$).

Resultados: Comparando-se as distâncias de 10 e 20 mm, houve um aumento de aproximadamente 50% da força axial e de 70% do momento fletor sagital. No pilar adjacente ao cantilever, a força axial no modelo com implantes inclinados foi 70% menor que no modelo com implantes retos, e os momentos fletores não variaram.

Conclusão: Os resultados sugerem que a inclinação dos implantes distais não promoveu nenhum efeito deletério sobre os pilares nos modelos testados e pode reduzir o efeito do cantilever na magnitude da força.

Palavras-chave: Biomecânica; extremidade livre; prótese implantossuportada; extensometria; implantes inclinados

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Received: January 12, 2009
Accepted: March 2, 2009

Introduction

Surgical techniques with inclination of distal implants have been increasingly used in atrophic maxilla (1-3) with short- and medium-term clinical success (4-6). The biomechanical rationale for using inclination of distal implants is based on the reduction of cantilever length and increase of the polygonal area for prosthesis support (4,7). Clinically the inclination of posterior implants is usually performed with distalization of the implant emergency sites. In the maxilla, the presence of large sinuses may require the installation of implants parallel to the anterior sinus walls with distal inclination (1,4,6): The 'apex' of this implant and the rotation fulcrum are located in the canine region, and the implant platform emerges in the first or second premolar region. In the mandible, the further the mental foramina are from the alveolar crest, the greater the distal implant inclination can be, and, consequently, the implant platform is located more distally. In both situations there are two variables: inclination of implant body and reduction of cantilever length due to implant distalization. Furthermore, there is an inherent increase of length of the prosthesis segment between the tilted distal implant and its immediate anterior implant. These characteristics change the prosthesis design and potentially complicate the predictability of cantilever models.

Little experimental or long-term clinical evidence is available regarding the effect of tilting distal implants on stresses generated in prosthetic components and implant/bone interface. Finite element analyses have shown contradictory results on stresses developed at cervical bone and implant neck with tilted distal implants and different cantilever configurations (8,9). One recent experimental study using strain gauges found that the inclination of distal implants provides better distribution of axial forces and bending moments in fixed prostheses supported by four or five abutments in comparison with three abutments (10). In that study the emergency sites of the distal implants were kept constant, and a static load was applied at a fixed cantilever distance to evaluate the isolated effect of implant inclination on the magnitude and distribution of force and bending moment. Therefore, that study showed that for the same cantilever extension tilted distal implants provided better general biomechanical behavior than straight implants in fixed prosthesis. Nevertheless, even with distal implant inclination fixed prosthesis design may require cantilever to some extent. Yet no previous experimental study quantified the combined effect of posterior cantilever length and inclined distal implants on bone, implants, or prosthetic components stresses.

Therefore, the present study aimed to evaluate the magnitude and distribution of axial forces and bending moments in abutments of fixed implant-supported prostheses for an edentulous mandibular arch as a function of cantilever length and inclination of distal implants.

Methods

Fabrication of the master models and metallic frameworks

Two master models were fabricated in epoxy resin: one model with straight implants and another with the distal implants inclined. The arch (curve of 134.30° and radius of 17.61 mm) of a human mandible for training in dental implants (ETH 0301-10 Nobel Biocare, Gothenburg, Sweden) was transposed to the master models for the perforation of the implant sites. In the model with straight implants, five perforations were made with 4 mm-diameter and 17 mm-length, parallel and 1 cm apart from each other. In the model with tilted implants, the three central perforations were made straight, and the two posterior perforations were inclined using an index with a 27-degree inclination plane. Ten 4.0×15-mm screw-type implants (OSS 415, 3i Implant Innovations, Palm Beach Gardens, FL, USA) were fixed into the perforations with fluid epoxy resin. The two models were placed in a pressure chamber at 4 bars for 40 min. After 12 hours, ten 7-mm standard abutments (AB700, 3i Implant Innovations, Palm Beach Gardens, FL, USA) were attached with 20 Ncm torque.

The frameworks were waxed up with rectangular section, 3-mm width, 4-mm height, and 20-mm cantilever at the left side. Around the entrance of the prosthetic screws the bars had thickness of 2 mm corresponding to the original thickness of a gold coping (CGC30, 3i Implant Innovations, Palm Beach Gardens, FL, USA) with addition of 1 mm of wax. Over each master model, five bars were waxed up 1 mm above the epoxy base. The cantilever was placed on the left side beginning at the emergency point of the posterior implant. The wax patterns were sectioned into five segments and cast with a Pd-Ag alloy (Porson 4, Degussa, Dusseldorf, Germany) following standard procedures. After finishing, the segments of each bar were laser-welded (EV LASER 900, Bergamo, Italy) using a stone index previously prepared to guarantee the accurate transfer of the abutment positions. To check the passivity of fit of the welded framework, one screw (WSK15, 3i Implant Innovations, Palm Beach Gardens, FL, USA) was tightened manually with the bar positioned on the respective index, and no gap should be visually detected in any of the other four abutments. This procedure was performed for all five screws of each bar, one by one.

The loading point on the cantilever was standardized at 10, 15, and 20 mm from the posterior emergency of the distal implant. With a milling machine, a concave notch was made with half-depth of a round tungsten bur of 2-mm diameter to mark the three loading sites per bar. This notch matched the load applicator tip (2-mm diameter) of a customized mechanical device used to deliver the 50 N static load during the tests. A schematical illustration of the framework attached to the master model with straight implants and with tilted distal implants is shown in Figure 1.

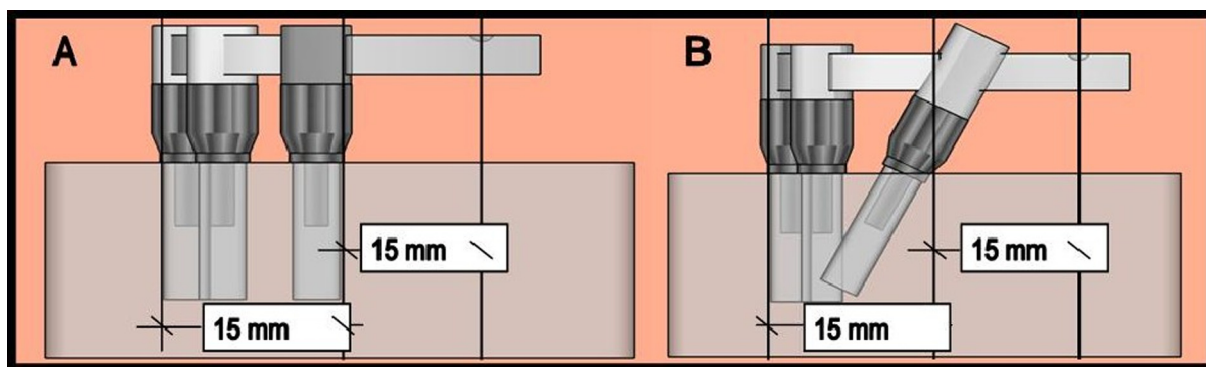


Fig. 1. Scheme of the lateral view of the assembly with straight (A) and tilted distal (B) implants. For both models, the sagittal distance between the most anterior and posterior points of the implant platform was 15 mm. The cantilever loading site was 10, 15 (as seen in the figure), and 20 mm from the distal implant emergency.

Strain gauge setup

Each abutment received three strain gauges (KFG02-120C1-11N15C2, Kyowa Electronic Instruments Co Ltd, Tokyo, Japan) attached to cylinder surface, 120° apart, in the following geometric disposition: one anterior, one posterior to the right, and one posterior to the left. The 0.2-mm grid was placed 1 mm above the implant platform in parallel with the axes of the cylinders. One strain gauge formed one channel for recording deformation (1/4 of a Wheatstone bridge); therefore, 15 recording channels were set for each master-model (three per abutment). Each strain gauge was connected to two cables transmitting the signals to a 15-channel strain gauge conditioner (MGC Plus, HBM Inc, Berlin, Germany). The analogic signal of electric resistance variation was transformed into a digital signal via a 12-byte resolution converter (MGC Plus, HBM Inc, Berlin, Germany). These signals were software-processed (MGC Plus, HBM Inc, Berlin, Germany), and channel signals originally measured in millivolts were converted into microstrain units ($\mu\text{m}/\text{m}$).

Test procedures and data collection

Each bar framework was screwed (GS300-3i Implant Innovations, Palm Beach Gardens, FL, USA) onto the respective master model under a torque of 10 Ncm (DEC 600-1 Ossecare Drilling Equipment, and DIA 189-0, Nobel Biocare AB, Gothenburg, Sweden). The abutments were numbered clockwise (#1 to #5; abutment #1 was adjacent to the cantilever), and the tightening sequence was 2, 4, 3, 1, and 5 (11). A different set of screws was used for each framework to avoid screw fatigue.

After the strain gauges were calibrated to zero, a 50 N static load was applied on the cantilever generating a graphic of deformation for the 15 reading channels. In this graphic the point of greater stabilization of the signals was selected, and the 15 deformation values were extracted. For each tested cantilever length (10, 15, and 20 mm), the test procedure was performed for all five frameworks on the master model with

straight implants, then repeated with the five frameworks on the model with tilted implants.

The strain gauge data (deformation in microstrain unit) were transformed into a numerical representation of the normal axial force and the bending moments around the X- and Y-axis using the calibration method and equations described by Duyck et al. (12,13). This calibration procedure was performed by loading a custom-cast disc fixed to each abutment in five standardized positions so that we could compute the axial force and bending moments (sagittal and lateral) separately. For axial force values, a positive signal was conventionally adopted for compressive force and a negative signal for tensile force but all calculations were performed using the absolute values.

Statistical analysis

Axial force, sagittal and lateral bending moments data were analyzed by ANOVA for random blocks design, followed by pairwise comparisons using Tukey tests for all abutments. Linear regression analysis was used to predict axial force and bending moments on abutment adjacent to the cantilever (abutment #1) as a function of cantilever length (10, 15, and 20 mm) and model (straight and tilted), and the slopes of the regression lines were compared with univariate ANOVA (interaction model* cantilever). A two-tailed significance level of 0.05 was set for all tests.

Results

Figure 2 displays the mean values for axial force, sagittal bending moment, and lateral bending moment in each abutment of the straight and tilted models for the 10, 15, and 20 mm-cantilever loading. Overall, the axial force in the inclined model was 70% lower than in the straight model with no increase of bending moments; the cantilever distance affected the axial force and sagittal bending moment but not the lateral moment. With the increase of cantilever distance there was an increase of axial force and sagittal bending moments; the largest effects occurred in the abutment #1.

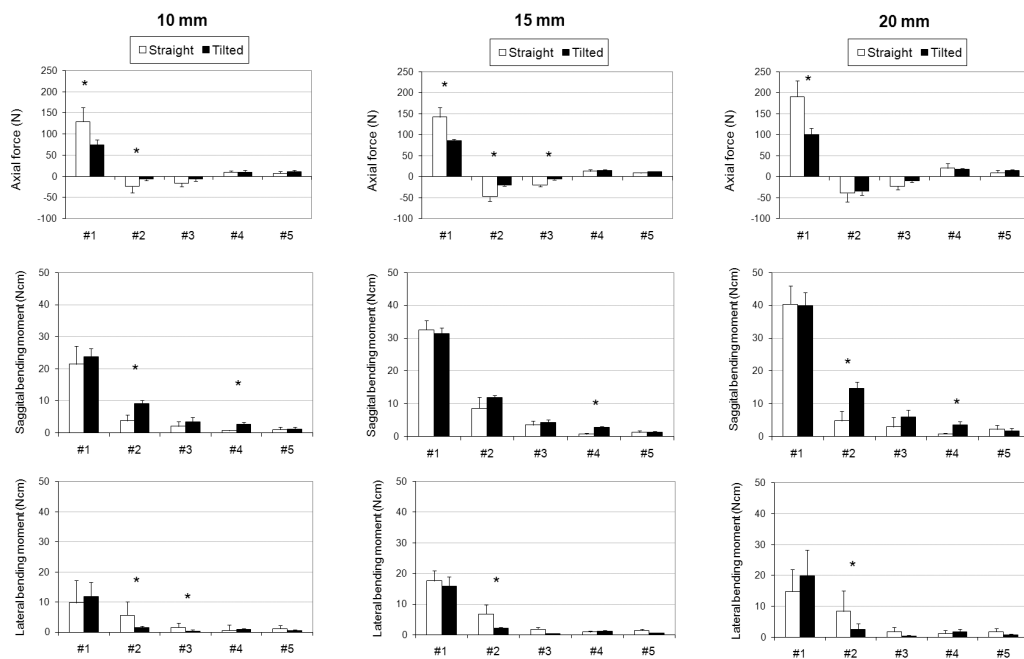


Fig. 2. Models with 10, 15, and 20mm-length cantilever: axial force, saggital bending moment, and lateral bending moment for each abutment (#1, 2, 3, 4, 5). Error bars are standard deviation of the mean. For force values, a positive signal means compressive force and a negative signal means tensile force. Asterisks indicate statistical difference between means ($P < 0.05$).

Figure 3 shows the linear regression results of axial force, saggital bending moment, and lateral bending moment as a function of cantilever length and model for abutment #1. The slopes of the regression lines were not statistically different (axial force: $P=0.187$; saggital bending moment: $P=0.519$; lateral bending moment: $P=0.631$). For the main effects of

the univariate ANOVAs, model was not significant (axial force: $P=0.749$; saggital bending moment: $P=0.499$; lateral bending moment: $P=0.774$), and cantilever had a significant effect for axial force ($P=0.003$) and saggital bending moment ($P < 0.001$), but was marginally non-significant for lateral bending moment ($P=0.051$).

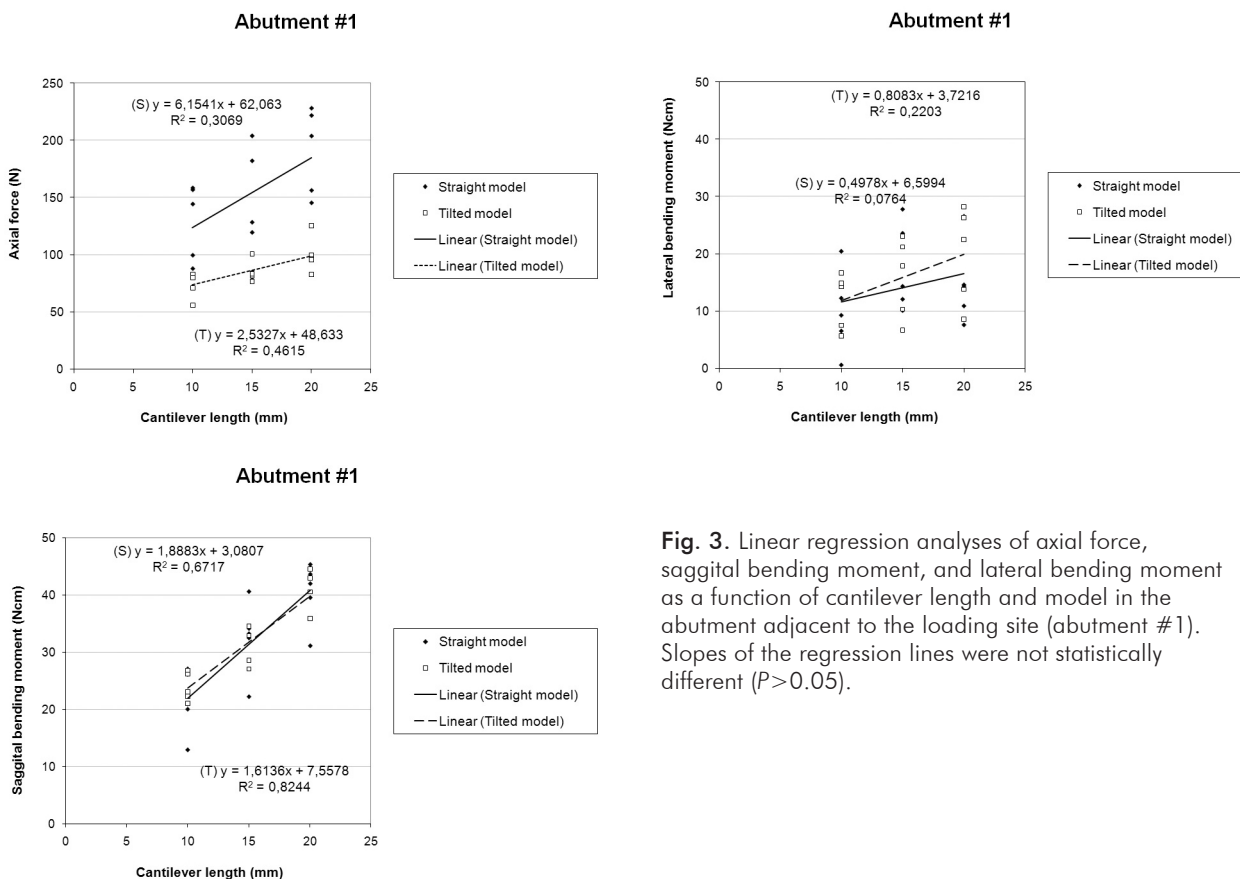


Fig. 3. Linear regression analyses of axial force, saggital bending moment, and lateral bending moment as a function of cantilever length and model in the abutment adjacent to the loading site (abutment #1). Slopes of the regression lines were not statistically different ($P > 0.05$).

Discussion

This study showed that cantilever length affected axial force and saggital bending moments in abutments of implant-supported fixed prostheses with straight and tilted distal implants. When the loading distance varied from 10 to 20 mm overall axial force increased by 50% and saggital bending moment by 70%. However, tilting distal implants reduced axial force magnitude with no detrimental effect on saggital bending moment in comparison with straight implants for any of the tested cantilever lengths. Naconey also found that inclination of the implant adjacent to cantilever decreased forces and bending moments in abutments independently from the number of implants (three, four, or five) (10).

In the present study the distal implants were inclined with the rotation fulcrum at the implant platform; therefore, the emergency of the implants were not displaced distally. One may argue that the use of standard abutments with 7 mm-length distalized 2.84 mm the prosthesis support over the abutments in the model with tilted implants and, consequently, reduced the free-standing bar. If the reduction of the cantilever length was achieved by inclining the implants and also distalizing the implant emergency to the posterior end, it would be difficult to isolate their effect on abutments. Nevertheless, the results showed that force on abutment #1 of the tilted model with loading at the maximum cantilever distance (20 mm) was even lower than the straight counterpart with loading at 10 mm. At the same time, saggital and lateral bending moments showed similar increase with variation of cantilever length for both models, which suggests that there was not any significantly different force vector on abutments #1 of the straight and tilted models.

Differences of force values also were detected between the two models for the abutments closer to abutment #1. The application of a static load on the cantilever beam generated compressive forces on distal abutments and tensile forces on medial abutments. This pattern of force distribution was previously reported *in vitro* and *in vivo* (14) due to a hinge effect of the prosthesis supported by multiple implants (12). As the implant/abutment/prosthesis system is not completely rigid because of microscopic gaps and elastic deformation, a static vertical load on the cantilever promotes a chain reaction in the abutments supporting the prosthesis. The abutment loading results in axial force and potential implant intrusion, generating bending moment on adjacent abutments (15). In general, axial force on the abutment adjacent to cantilever (abutment #1) was three to four-fold higher than on its immediate anterior abutment (abutment #2). Other studies also reported that the most distal implant receives high compressive forces and bending moments, being at least twice the load applied on the cantilever due to a lever effect (7,13-19).

The present study showed that axial force and saggital bending moment proportionally increased with cantilever length on abutment #1, but lateral bending moment was less affected. When a force is applied on the cantilever

the abutment located closer to the loading site receives compressive axial force and function as a rotation fulcrum for the implants/abutments/prosthesis system (13). The mode of load transmission and stress distribution in each system component are directly proportional to the distance from the loading site. The larger the ratio cantilever/potency arm, the larger the compressive forces on the abutments. A reduced cantilever has been shown to have more favorable biomechanical resultant of maximum stresses at the most distal implant/bone interface (9,19), yet the clinical cut-off length is unknown. Clinical guidelines usually recommend that the cantilever should not be longer than 2.5 times the anteroposterior distance, and other variables should be considered to determine cantilever length, such as bone quality, number and diameter of implants, and opposing arch conditions. If a cantilever is inevitable, short distal implants may be an alternative to restrain the vertical movement of the cantilever end (17,20). Furthermore, when good anchorage to the prosthesis is mandatory and there are anatomical restrictions to place implants more distally, tilting distal implants has been recommended (3). Nevertheless, despite of unfavorable results of theoretical and *in vitro* studies, the *in vivo* influence of cantilever length on force magnitude and direction seems to be minor than expected (18).

In summary, the present experimental study found that the cantilever effect was significant for axial forces and saggital bending moments, with more pronounced impact on abutment #1 for both straight and tilted models, but the inclination of distal implants yielded a significant decrease of axial force. These findings suggest that the inclination of distal implants may be biomechanically more favorable to abutments of a fixed implant-supported prosthesis for the full edentulous jaw, and possibly to the implant/bone interface. However, it should be emphasized that the present results cannot be extrapolated directly to the clinical situation and the method used to measure deformation has experimental limitations due to positioning of strain gauges on the abutment surface. Further studies should investigate the influence of other variables, such as different loading conditions and fatigue of components. Additionally, longitudinal clinical studies should provide information on the predictability of alternative designs for implant-supported prosthesis.

Acknowledgments

The research project was partially supported by a scholarship from the Brazilian Ministry of Education and Culture/CAPES. We would like to thank Mr. Cedenir Albani, CDT, and Mr. Cristiano Friederichs, CDT, from the PortoDent Dental Laboratory, and Mr Eubirajara Medeiros, Eng, MSc, from the PROMM Surgical Materials Ltd., for their technical assistance to fabricate the study specimens. We also thank Dr. Telmo Strohaecker, Eng, PhD, from the Federal University of Rio Grande do Sul, coordinator of the laboratory where strain gauge data were collected.

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