Short Communication

Three-Dimensional Finite Element Analysis of Load Transmission Using Different Implant Inclinations and Cantilever Lengths

Marco Bevilacqua, DDS[a]/Tiziano Tealdo, DDS, MS, DT[b]/Francesco Pera, DDS[a]/Maria Menini, DDS[a]/
Alexei Mossolov, ENG[c]/Carl Drago, DDS, MS[d]/Paolo Pera, MD, DDS, PhD[e]

Many clinical studies have reported high survival rates for tilted implants. However, tilted implants transmit increased stress to bone when compared to vertically placed implants. Theoretical (computer-based), laboratory, and clinical studies are warranted to effectively address this issue. In this study, a 3-dimensional finite element analysis was performed to analyze the stress values surrounding tilted versus vertical implants. The results revealed laboratory and biomechanical evidence that distal tilting of implants, splinted in full fixed prostheses without cantilevers, reduced the amount of stress generated around the peri-implant bone when compared to the levels of stress seen in peri-implant bone with vertical implants and cantilevered segments in similar full fixed prostheses. *Int J Prosthodont 2008;21:539–542.*

The presence of the maxillary sinus or the mental foramen/inferior alveolar nerve usually precludes insertion of long implants (> 10 mm) in the distal areas of resorbed maxillae and mandibles. Short implants (< 10 mm) may also inhibit high levels of initial primary stability, considered one of the most important factors for successful osseointegration of dental implants in immediate loading protocols.[1] Long, tilted implants (≥ 13 mm) have been advocated by some researchers to obtain high levels of initial primary stability. Additionally, tilting implants can optimize the anterior/posterior spread of the implants to provide satisfactory molar support for a full fixed prosthesis (FFP) of 12 masticatory units. This FFP design also eliminates the use of cantilever extensions generally seen with vertical implants to obtain the same number of masticatory units (Fig 1). Several clinical studies have reported high survival rates for tilted implants.[2,3] However, questions remain relative to the amount of stress generated at the bone surrounding tilted implants. Theoretical (computer-based), laboratory, and clinical studies are warranted to effectively address this issue.

The purpose of this laboratory study was to evaluate the load transmission using different implant inclinations and cantilever lengths with 3-dimensional (3D) finite element analysis.[4] The null hypothesis was that there would be no differences in stresses to peri-implant bone between vertical and tilted implants.

Materials and Methods

A 3D edentulous jaw model was created using customized computer software (FEMAP 8.3, UGS). The mesh value was 140,000 units. The elastic moduli were set to 103,400 MPa for titanium implants, 13,700 MPa for cortical bone, 1,370 MPa for cancellous bone, and 210,000 MPa for the metal framework of the FFP. The Poisson ratio of titanium and bone was considered equal to 0.3.

In the first test performed (test 1), a single parallel wall screw implant (4 × 13 mm) with varying inclinations (0, 15, 30, and 45 degrees) was virtually inserted into the molar area and vertically loaded with 150 N. Then, von Mises stress values of peri-implant bone were evaluated in compact and cancellous bone.

[a]Lecturer, Department of Prosthetic Dentistry, University of Genoa, Genova, Italy.
[b]Professor, Department of Prosthetic Dentistry, University of Genoa, Genova, Italy.
[c]Director, ITERA, Castelletto Stura, Italy.
[d]Director, Dental Research, Biomet 3i, Palm Beach Gardens, Florida.
[e]Professor and Head, Department of Prosthetic Dentistry, University of Genoa, Genova, Italy.

Correspondence to: *Dr Marco Bevilacqua, Reparto di Protesi Dentaria, Largo R. Benzi 10, Padiglione 4, Ospedale S. Martino, Genova, Italy. Fax: +39-0103537584. E-mail: garibaldi4@ libero.it*

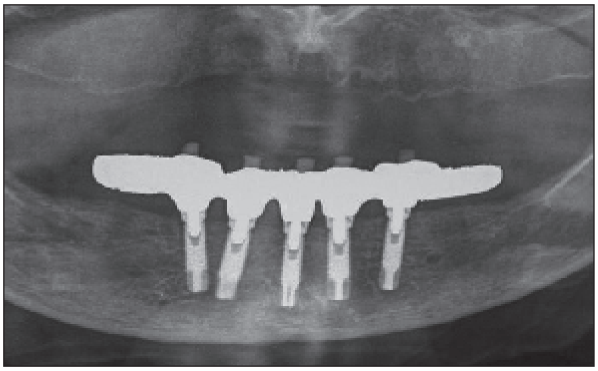

Fig 1a Panoramic radiograph of an edentulous jaw with a conventional FFP supported by vertical implants placed in the intraforaminal area of the mandible. Note the length of the distal cantilevered segments.

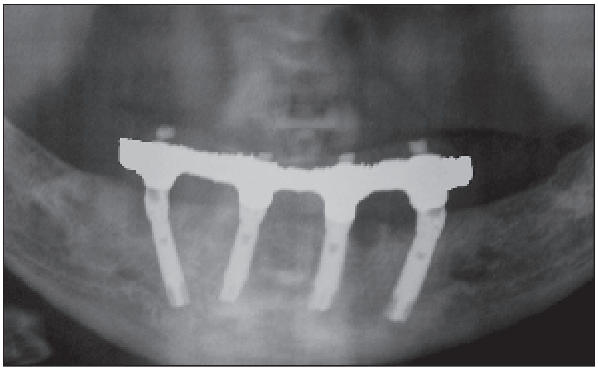

Fig 1b Panoramic radiograph of an FFP supported by tilted distal implants. Note the reduced length of the cantilevered segments without a significant reduction in the occlusal surface of the prosthesis.

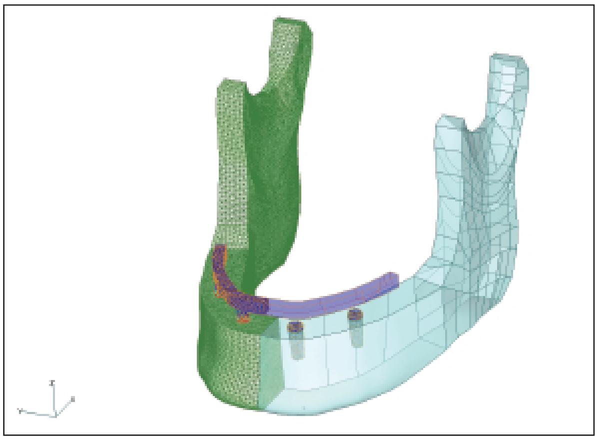

Fig 2 Edentulous jaw 3D model. Four parallel wall screw-type implants were placed in the interforaminal area of the mandible, simulating the clinical treatment of an edentulous patient with an FFP. The first analyzed configuration had vertical bilateral distal implants and cantilevers of 15 mm.

In the second test (test 2), 4 parallel wall screw-type implants (4 × 13 mm) were virtually placed in the interforaminal area of the mandible, simulating clinical treatment of an edentulous patient with an FFP. The FFP, with a virtual metal framework (10 mm^2 in cross-section), was designed with first molar occlusion and splinted all of the implants. The connections between the superstructure and the implants were projected as rigid. A vertical load (150 N) was applied on a distal cantilevered segment to simulate biting force. The von Mises stress values of the peri-implant bone of the FFP were evaluated according to 4 configurations, with the framework length held constant. In the first configuration, the bilateral distal implants were placed vertically and the cantilevers were 15 mm long (Fig 2). In the second, third, and fourth configurations, the posterior implants were inclined 15, 30, and 45 degrees distally and the cantilever extensions were 11.6, 8.3, and 5 mm, respectively.

Results

In each test, the highest von Mises value in the peri-implant bone was used for comparison.

In test 1, the single tilted implant, submitted to a vertical load, demonstrated higher peri-implant bone stress than the single vertical implant submitted to the same vertcal load. The stresses increased as the tilt of the single implants increased (Figs 3 and 4). Test 2 results are illustrated in Table 1. When the implants were splinted in a rigid FFP, the use of tilted distal implants, with reduced cantilever lengths, resulted in lower mechanical stresses on the peri-implant bone with respect to the vertical implants with longer cantilevers (Figs 5 and 6). A reduction of stress around anterior implants was observed with the tilted distal implants compared to the vertical implant FFP design. With regard to the FFP framework stress, lower von Mises values were observed with tilted implants than with vertical implants.

Table 1 Results of Test 2: Stress Values in MPa (% Stress Variation*) in Splinted Implant Model

Angulation of distal implant	Cantilever length (mm)	Compact bone			Cancellous bone		
		Distal implant	Anterior implant	Metal framework	Distal implant	Anterior implant	Metal framework
0 deg	15	75.0	22.0	100.0	82.0	27.0	110.0
15 deg	11.6	63.0 (–16%)	14.0 (–36.4%	88.0 (–12%)	68.0 (– 17%)	18.0 (– 33.3%)	98.0 (–10.9%)
30 deg	8.3	36.0 (– 52%)	11.5 (– 47.7%)	76.0 (–24%)	43.0 (– 47.6%)	14.0 (–48.1%)	84.0 (–23.6%)
45 deg	5	25.0 (–66.7%)	10.0 (– 54.5%)	59.0 (–41%)	36.0 (– 56%)	12.0 (–55.5%)	63.5 (–42.3%)

*Refers to distal vertical implants.

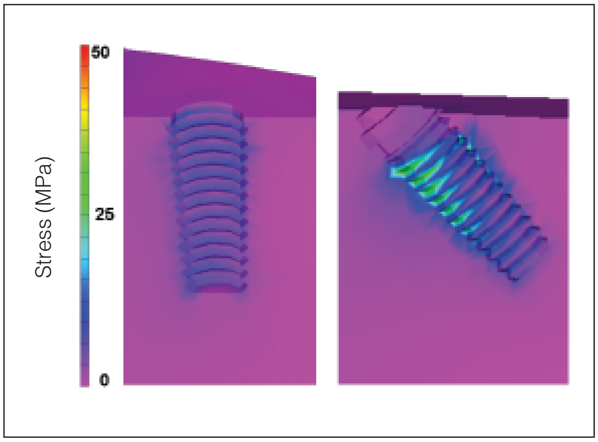

Fig 3 Von Mises stresses (MPa) around single implants submitted to a vertical load of 150 N in cortical bone. (*left*) The 0-degree model (max stress: 10.6 MPa). (*right*) The 45-degree tilted model (max stress: 25 MPa).

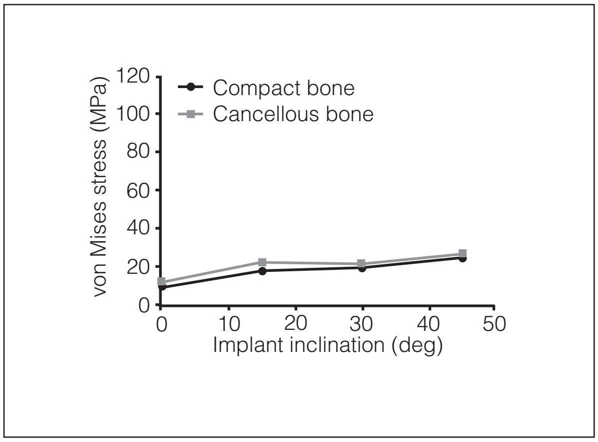

Fig 4 Test 1 results. Stress values (in MPa) in the single implant model submitted to a vertical load of 150 N.

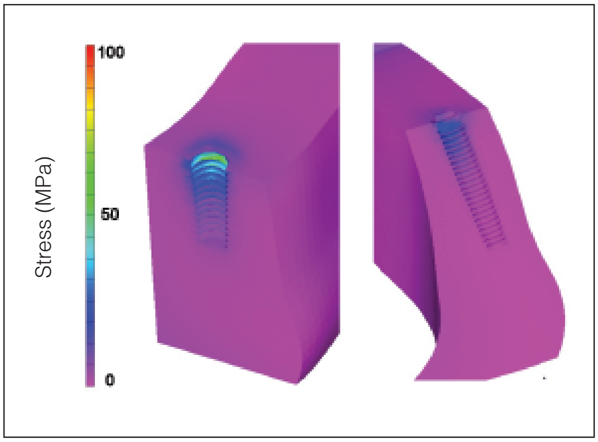

Fig 5 Von Mises stresses (MPa) around splinted distal implants submitted to a vertical load of 150 N in cortical bone. Details are shown without framework visualization. (*left*) The 0-degree model with cantilever extensions of 15 mm (max stress: 75 MPa). (*right*) The 45-degree tilted model with cantilever extensions of 5 mm (max stress: 25 MPa).

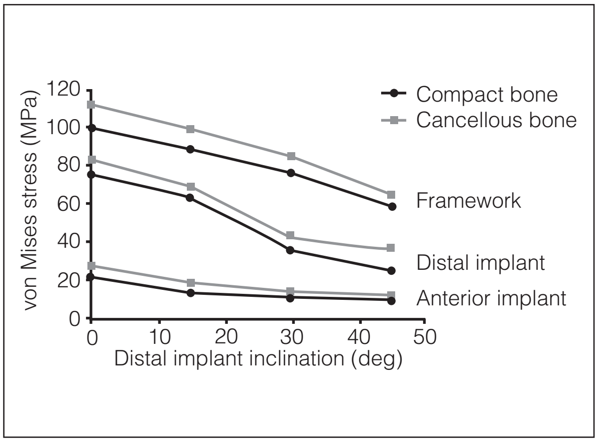

Fig 6 Graphic representation of stress reduction observed in the peri-implant bone surrounding distal and anterior implants splinted in a rigid FFP submitted to a vertical load of 150 N. Implant inclinations, cantilever lengths, and cancellous/compact bone values are plotted. Metal framework stresses have also been plotted.

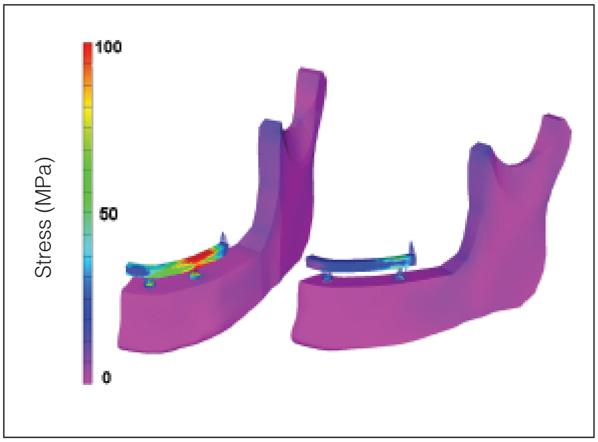

Fig 7 FFP framework stresses (MPa) in cortical bone. (*left*) Vertical distal implants configuration with cantilever extensions of 15 mm (max stress: 100 MPa). (*right*) Model with distal implants tilted by 45 degrees with cantilever extensions of 5 mm (max stress: 59 MPa).

Discussion

Within the limitations of this 3-D virtual analysis, the results of this study demonstrated that loading and tilting single implants increased peri-implant bone stresses, compared to the stresses observed around vertical implants. In contrast, the tilting of distal implants supporting decreased cantilevered segments rigidly splinted in an FFP, decreased peri-implant bone stresses and FFP framework stress compared to vertical implants supporting cantilevered segments (Fig 7). The cantilever length reduction associated with the FFP design on tilted implants played a key role in decreasing the peri-implant stresses seen around the implants.

References

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Literature Abstract

Retention and marginal leakage of provisional crowns cemented with provisional cements enriched with chlorhexidine diacetate

This study evaluated the effects of incorporating chlorhexidine diacetate (CHDA) salt into Temp Bond, Temp Bond NE, and Freegenol provisional cements, on the retention and marginal leakage of provisional crowns in vitro. Duralay was used to fabricate provisional crowns for 12 intact molars. These crowns were luted individually with and without incorporation of CHDA salt. Each test group included the same 12 specimens. Twelve specimens were left with no luting agent to act as the controls. Crowns were thermal cycled 100 times, stored in 100% humidity at 37°C for 6 days, and then immersed in a 0.5% basic fuchsin at 37°C for 6 h. Seven days after cementation, a removal test was done with a universal testing machine at a crosshead speed of 5 mm/min. Marginal leakage was assessed with a 5-level dye penetration scale and a 2-way ANOVA test was performed. A Bonferroni test was used to compare the means. The nonparametric Wilcoxon signed ranks test was used to evaluate the leakage. While the addition of CHDA had no effect on the retention of Temp Bond and Temp Bond NE, there was a 3-fold increase in retention with Freegenol cemented crowns. CHDA incorporation had no significant effect on the marginal leakage of all cements. Addition of CHDA salts could help increase the retention of temporary crowns cemented with Freegenol when needed. Moreover, the addition would improve the antimicrobial properties of the provisional cements with no negative effect on retention.

ILewinstein I, Chweidan H, Matalon S, Pilo R. *J Prosthet Dent* 2007;98:373-78. **References:** 26. **Reprints:** Dr Israel Lewinstein, Department of Oral Rehabilitation, The Maurice and Gabriela Goldschleger, School of Dental Medicine, University of Tel Aviv, Tel Aviv, Israel. Fax: 972-3-640-9250. E-mail: lewins@post.tau.ac.il—*Majd Al Mardini, Hamilton, Ontario, Canada.*