FEM Analysis on Deformation and Stress Distribution in Fixed Metal-Reinforced Provisional Restorations of Immediately Loaded XiVE® Implants in the Edentulous Mandible

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Introduction

Although initial considerations in implant dentistry have claimed that the process of osseointegration requires on average an undisturbed healing of three months in the mandible and six months in the maxilla, an increasing interest has been noticed with regard to early and immediate loading of implants to expedite the restorative outcome. In spite of the lack of a consistent terminology on the definition of micro- and macromovements of immediately loaded implants, it has been suggested that a movement of 30 µm or less has no adverse effect on integration, while a movement of 150 µm or more results in soft connective tissue apposition to the implant. A successful, accelerated protocol for implant rehabilitation depends upon several interactive factors: Beside accurate pre-surgical diagnostics and treatment planning, implant macro- and microdesign, the adequate fixation and immobility of the implant are of utmost importance to prevent the risk of micromovements related to the surrounding bone. Rigid splinting seems to have a significant impact on the peri-implant tissue response since it is able to reduce the mechanical stress exerted on each implant. If rigidity is lost, implant failure is likely to occur due to uncontrolled masticatory forces. Consequently, the stability of the provisional restoration and the ability to keep the micromovements below the critical threshold are considerably increased by rigid splinting. Prosthetic concepts for immediate loading of multiple implants in the edentulous or partially edentulous mandible and maxilla reported in the literature involve bar-supported overdentures in the mandible, retrofitting of pre-existing prostheses to implants, or fabricating acrylic resin provisional restorations. A high predictability of immediate implant loading with fixed provisional restorations has been shown in several reports. This indicates that rigid acrylic resin provisional restorations are able to confine the occlusal forces applied to the bone-to-implant interface to a physiological range. Material stability and fracture strength are essential in maintaining the rigidity of provisional restorations on immediately loaded implants over a longer period of time. However, long-span acrylic resin restorations are subject to flexion and fracture under occlusal forces. This applies in particular for a cross-arch stabilization of multiple implants in the edentulous mandible. The human mandible presents a complex elastic biomechanical behavior under functional loading. This is a result both of its u-shaped anatomic conformation with posterior insertion sites of masticatory muscles, and of the complex structure and elasticity of the constituent bone. From a biomechanical point of view, a rigid splint of dental implants by means of a fixed cross-arch bridge could induce torsional stress that could be transmitted to the prosthetic superstructure, leading to fracture of the restoration and failure of the luting cement. All previously described techniques for reinforcement of acrylic resin provisional restorations involve either the use of a thin wire or fibers throughout the span, or a time consuming fabrication of a cast metal framework in the laboratory that covers the facial and/ or lingual surfaces of the provisional restoration. The objective of this poster was to evaluate the biomechanical effect of bite forces and mandibular functional flexure on stress build-up in temporary implant-supported fixed restorations. The relative deformations and stress distributions in metal-reinforced and non-metal-reinforced acrylic resin provisional restorations in the edentulous mandible were analyzed by a three-dimensional finite element model (FEM).

Name of element type	ANSYS-Name	Description
10-Node Quadratic Tetrahedron	Solid187	10-Node Tetrahedral Structural Solid
20-Node Quadratic Hexahedron	Solid186	20-Node Hexahedral Structural Solid
6-Node Quadratic Trianqular Contact	Conta174	Hi-order Surface to Surface Contact
6-Node Quadratic Triangular Target	Targe170	Surface Contact Target
8-Node Quadratic Quadrilateral Contact	Conta174	Hi-order Surface to Surface Contact
8-Node Quadratic Quadrilateral Target	Targe170	Surface Contact Target

Tab. 1: Overview of elements used in FEM

	Young's Modulus GPa/ Reference			
	Melo C et al 1995	*Bratu E & Steimann M 2003*	*O'Brien WJ 1997*	*Zarone F et al 2003*
Cortical bone	13.7	13.7	14.7	15
Cancellous bone	2.5	1.37	0.5	1.5
Titanium	107	110	117	110

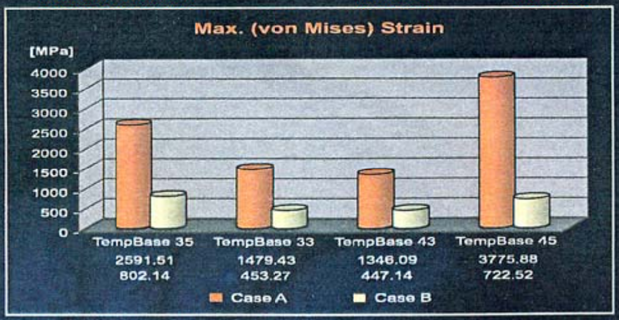
Tab. 2: Physical material properties of bone and titanium with corresponding references

Object	Max. (von-Mises) strain [MPa]	Max. deformation [mm]
Acrylic resin restoration	57.74	0.16
Titanium bar	- / -	- / -
TempBase abutment 35	2,591.51	0.0189
TempBase abutment 33	1,479.43	0.00747
TempBase abutment 43	1,346.09	0.00748
TempBase abutment 45	3,775.88	0.0188

Tab. 3: Strain and deformation values for mere (non-metal-reinforced) acrylic resin provisional restoration

Object	Max. (von Mises) strain [MPa]	Max. deformation [mm]	Strain reduction %
Acrylic resin restoration	103.74	0.1	+79
Titanium bar	162.64	0.0991	- / -
TempBase abutment 35	802.14	0.02	-323
TempBase abutment 33	453.27	0.00876	-326
TempBase abutment 43	447.14	0.00878	-301
TempBase abutment 45	722.54	0.0184	-525

Tab. 4: Strain and deformation values for titanium-framework reinforced acrylic resin provisional restoration and its strain reduction compared to non-metal-reinforced provisional restorations



Tab. 5: Reduction of strain and deformation in titanium-framework reinforced acrylic resin provisional restorations in %. A: Non-metal reinforced, B: Titanium-framework reinforced

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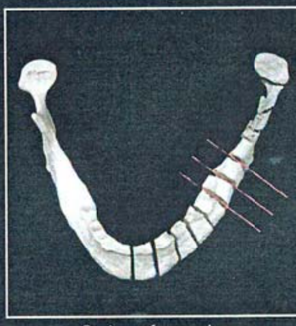
Material and Methods

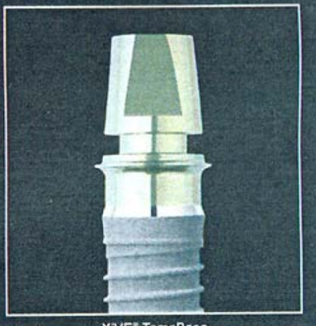
A mandibular three-dimensional (3D) Finite Element Model (FEM) was created by sequential sectioning, scanning and imaging of a solid-foam edentulous mandible (SAWBONES, Pacific Research Laboratories, Inc., Washington, USA). The mandibular section profiles were collected at 8 mm increments. The intercondylar dimension was 8 mm. The height of the mandibular bone in the symphysis was 30 mm, and 18 mm in the left, respectively 15 mm in the right first molar region. Al traces were assembled into a 3D wireframe model by means of an ordinary 3D CAD. Four threaded cylindrical titanium implants (XiVE®, DENTSPLY Friadent, Germany) with a total length of 13 mm and a diameter of 3.8 mm were incorporated into the model. Each implant was fully inserted into the bone and temporary titanium abutments (TempBase, DENTSPLY Friadent, Germany) were mounted. Two implants were placed in each quadrant of the mandible in the center of the mandibular crest, symmetrically to the midsagittal plane, within the region of the canine and second premolar. Three-dimensional mandible models of an implant-supported, cross-arch provisional restoration on four implants with, and without metal-reinforcement was analyzed and compared. Both prosthetic superstructures were conceived as fixed, acrylic resin, symmetrical bridges with a section of 7 by 9 mm. One model was additionally reinforced by a metal framework fabricated of titanium implant abutments, intraoraly welded to a titanium bar of 2 mm in diameter. In accordance to FEM accuracy requirements of using a model over 30,000 degrees of freedom, the final FEM model was designed linearly, using 90,000 solid elements. The specific element types used in the analysis are listed in Table 1. Subsequently, a virtual masticatory load was chosen according to clinical conditions in the oral cavity. Apart from individual anatomic and physiologic characteristics, previous studies have shown that maximal bite forces vary according to the region in the oral cavity 57-60. While the greatest bite force was found in the first molar region, incisors only bear about one third to one fourth of that force in the posterior region. Mean values varying from 180 to 847 N for the maximum force level could be shown, whereas smaller values ranging from 94 to 250 N have been reported for the incisal region. Consequently, masticatory forces in the present FEM were simulated using average external loads of 300 N in the anterior region (incisors to canines), and 900 N in the posterior region (premolars to molars). FEM was carried out by Ansys 8.0 software (ANSYS Inc., Canonsburg, USA) comparing van-der-Mises and maximum stress levels obtained from the calculation. The following assumptions were made in order to simulate the mechanical behavior of mandibular bone:

- Total bonding between bone and implants (complete implant osseointegration).
- Considering an atrophied edentulous mandible, bony tissue was simulated by assuming solely cortical bone with a Young's modulus of 13.7 GPa. A Young's modulus of 115 GPa was assumed for the titanium implant (grade 2). The choice of the applied Young's modules for cortical bone and titanium was within the range of values reported in the literature. Literature references and reported physical properties are itemized in Table 3. A Young's modulus of 96 GPA was assumed for the implant abutment (titanium alloy) and 3.2 GPa for the autopolymerizing polymethylmethacrylate (PMMA).
- Cortical bone thickness was considered consistantly throughout the mandibular body.
- An arbitrary load of 10 N was applied in the x-direction on the mandible, simulating previously reported forces of the lateral pterygoid muscles pulling medially on the condyles.
- The structural analysis was assumed linear and static.

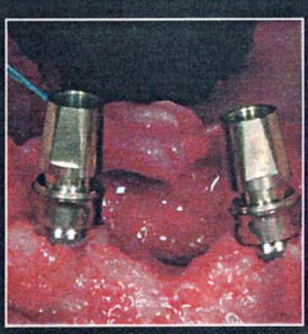
Sequential sectioning at 8 mm increments of sawbones



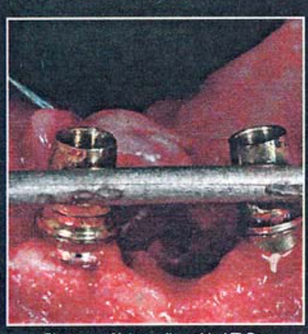
Sawbones for scanning



XiVE® TempBase

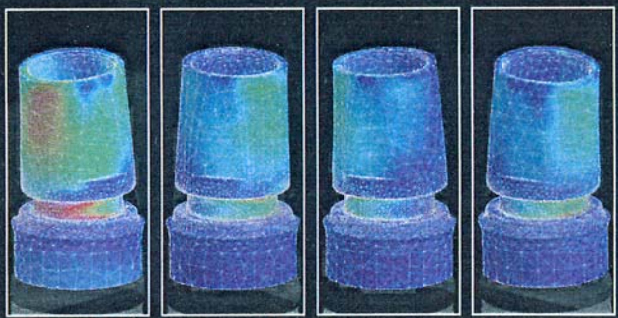


Close-up of XiVE® TempBases in mandible

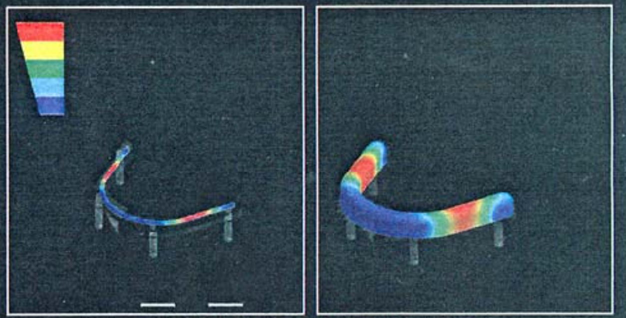


Close-up of intraorally welded Ti-Bar

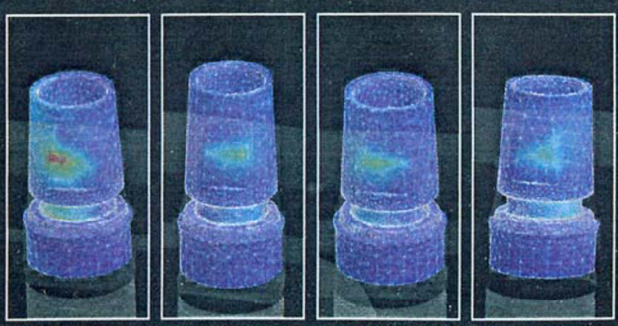
Case A: Acrylic resin provisional



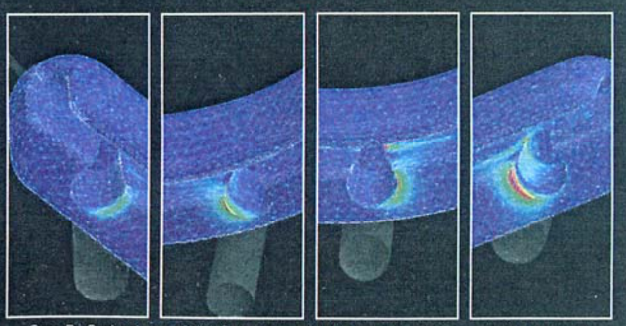
Case A: XiVE® TempBase provisional titanium abuments with acrylic resin restoration



Case B: Titanium-bar reinforced acrylic provisional



Case B: XiVE® TempBase provisional titanium abuments with titanium bar reinforced restoration



Case B: Occlusal view of XiVE® TempBases with titanium-bar reinforced acrylic provisional

Results

In comparison to mere acrylic superstructures, a significant reduction of deformation and strain within metal-reinforced acrylic resin provisional restorations could be detected in FEM analysis. The titanium framework reinforced provisional restorations investigated in the current study exhibited a reduction of maximum von-Mises strain values of 300 to 500 % at external loads of 300 N in the anterior, and 900 N in the posterior region. The strain values measured at the implant abutments and along the provisional spans are given in Table 4 to 6. With regards relationship between stress distribution and implant location along the mandibular arch, maximum stress values were located at the level of the most distal implants.

Summary

An optimal biomechanical stress distribution, both at the level of the provisional superstructure and at the level of the implant infrastructure, is the primary aim of the rigid temporization of multiple immediately loaded implants. Stress distribution in mandibular, fixed, implant-supported restorations is greatly influenced by many variables, including prosthetic design and material, occlusal scheme, bone structure, shape and activity of masticatory muscles, implant location, as well as design and material of implants and implant abutments. Although the present FEM analysis revealed a high decrease of deformation and maximum strain in titanium framework reinforced acrylic resin restorations, caution must be given when extrapolating FEM data to clinical situations, since multiple in vivo variables are excluded from a controlled computer analysis. The tendency of strain reduction was, however, obvious. Research in fixed implant prosthodontics on osseointegrated implants has advised to section the superstructure in multiple free-standing bridges, rather than designing one cross-arch rigid restoration. A rigid restorative system could not follow the flexure of the mandibular bone, generating high stress concentrations and increasing the rate of screw loosening and fractures. In the treatment concept of immediate implant loading, however, an adequate fixation and immobility of implants in the early stages of bone healing is a prerequisite to prevent micromovements in relation to the surrounding bone. After successful osseointegration of immediately loaded implants, splitting the final superstructure into multiple free-standing bridges should be taken into account, thereby allowing an adequate stress distribution and a better prosthetic fit as a result of fewer connected abutments.

References

1. Degidi M, Piattelli A: 7-year follow-up of 93 immediately loaded titanium dental implants. J Oral Implantol. 2005;31(1):25-31.
2. Degidi M, Piattelli A, Felice P, Carinci F. Immediate functional loading of edentulous maxilla: A 5-year retrospective study of 388 titanium implants. J Periodontol. 2005 Jun;76(6):1016-24.
3. Szmukler-Moncler S, Salama H, Reingewirtz Y, Dubruille JH. Timing of loading and effect of micromotion on bone-dental implant interface: Review of experimental literature. J Biomed Mater Res 1998;43:192-203.
4. Hobkirk JA, Schwab J.Mandibular deformation in subjects with osseointegrated implants. Int J Oral Maxillofac Implants. 1991;6(3):319-28.
5. Korioth TW, Romilly DP, Hannam AG. Three-dimensional finite element stress analysis of the dentate human mandible. Am J Phys Anthropol. 1992;88(1):69-96.
6. Melo C, Matsushita Y, Koyano K, Hirowatari H, Suetsugu T.Comparative stress analyses of fixed free-end osseointegrated prostheses using the finite element method. J Oral Implantol 1995;21(4):290-4.