A Preliminary Three-Dimensional Finite Element Analysis of Mandibular Implant Overdentures

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A treatment protocol that may lead to reduced mandibular posterior residual ridge resorption in patients with overdentures retained and supported by two interforaminal implants was investigated. The treatment included the addition of short implants in the posterior edentulous mandible for the presumed purpose of favorable provision of mechanical load stimulus to alveolar bone. Three-dimensional finite element analysis was used to model cited effective strains that may stimulate bone remodeling in two selected models. Based on this laboratory study, the addition of posterior short implants has a favorable effect in maintaining bone mass under implant-retained overdentures. *Int J Prosthodont 2014;27:70–72. doi: 10.11607/ijp.3425*

Patients wearing maxillary complete dentures opposed by mandibular implant overdentures may exhibit posterior mandibular ridge reduction and other signs of the so-called "combination syndrome".[1–3] Since dental implants are believed to assist in the reduction of residual ridge resorption by providing favorable mechanical stimuli,[4,5] it was hypothesized that the management of edentulous patients with maxillary complete dentures and mandibular implant overdentures retained by two interforaminal implants would benefit from placing two additional bilateral implants in posterior edentulous mandibles. The presumed benefit would be a more favorable stress distribution in sites that are otherwise vulnerable to ridge reduction.

Materials and Methods

A commercial finite element program (LS-DYNA, Livermore Software Technology) was used to create two three-dimensional (3D) models of a human edentulous mandible. The two models were identified as IMP2 and IMP4 (Figs 1 and 2) and differed only in the number of endosseous implants inserted into the model (IMP2 contained two implants and IMP4 contained four). Material properties for the different model parameters are shown in Table 1. A mandibular overdenture was created for both models and provided load to the alveolar bone and to the implants. The connection between the overdenture and anterior implants simulated ball-socket attachments providing direct prosthesis retention, whereas no attachments were assumed between the posterior implants and the overdenture, thereby only ensuring support. The posterior implants were of minimum height to compensate for anatomical limitations (minimal available bone height and proximity of the inferior alveolar nerve) and were presumed to transfer some of the mechanical loads to their supporting bone. Six bilateral oblique loads of 70 N were applied on locations that are clinically relevant with a mandibular overdenture (Fig 2).

An automatic mesh generation process (Abaqus/CAE) and four-node tetrahedron elements were used for meshing. The mesh of IMP2 contained 127,347 elements, whereas the mesh of IMP4 contained 128,406 elements.

Table 1 Material Properties Used in Both Implant Models

	Elastic modulus (MPa)	Poisson ratio
Cortical bone	13,700	0.3
Cancellous bone	1,379	0.3
Mucosal layer	1	0.3
Implant (Ti-6Al-4V)	103,400	0.3
Acrylic resin (overdenture)	2,000	0.3

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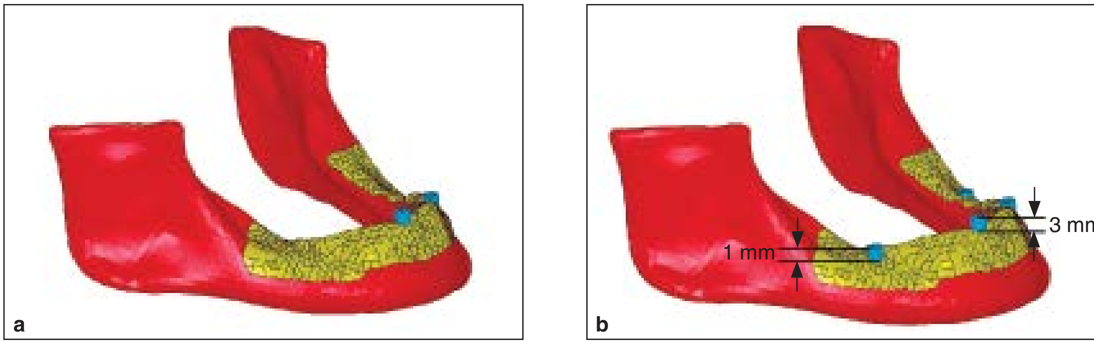

Fig 1 **(a)** Implant model with two endosseous implants (IMP2) and **(b)** implant model with four implants (IMP4). Cortical bone is shown in red, mucosal layer in yellow, and endosseous implants in blue. Only the abutments are shown, with heights of 3 mm and 1 mm for the anterior and posterior abutments, respectively.

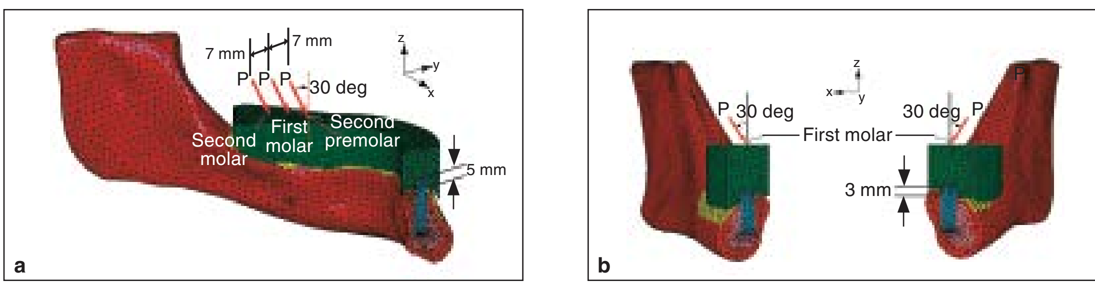

Fig 2 Cross section of the mandible showing the finite element mesh. **(a)** Cross section at the anterior implant location modeling cortical and cancellous bone, implants, mucosal layer, and overdenture (shown in green). **(b)** Cross section at the posterior implant location (mandibular first molar). Abutments over the implants are shown: 5 mm in height for the anterior implants and 3 mm in height for the posterior implants. The anterior implants were modeled as cylinders with 4 mm diameter and 12 mm length, whereas posterior implants were 4 mm in diameter and 8 mm in length. Loads (P) applied on the overdenture are shown as red arrows directed from buccal to lingual over selected tooth locations.

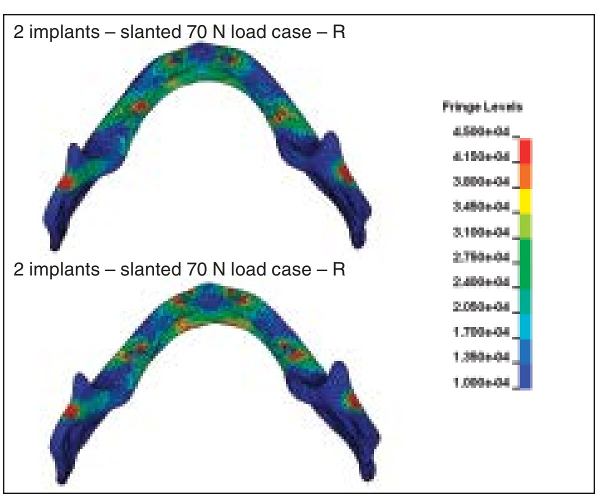

Fig 3 von Mises strain contour plots and mesh of the cortical bone for the IMP2 and IMP4 models. Higher strains occurred in more locations and over larger areas in the IMP4 model.

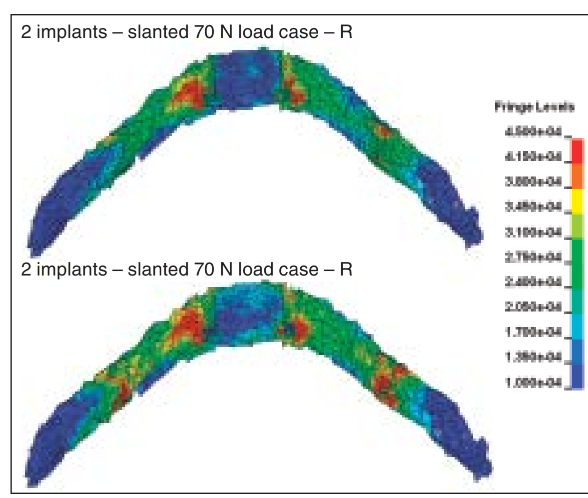

Fig 4 von Mises strain contour plots and mesh of the cancellous bone for the IMP2 and IMP4 models. Higher strains occurred in more locations and over larger areas in the IMP4 model.

Results

Strain distributions of von Mises strains were analyzed over the entire models in both cortical and cancellous bone (Figs 3 and 4). More locations with higher/effective von Mises strains were observed in the IMP4 model compared with the IMP2 model in both cortical bone (Fig 3) and cancellous bone (Fig 4).

Table 2 Comparison of Maximum von Mises Strains in Microstrains

	Implant model	
	IMP2	IMP4
Cortical bone	1,788 (A)	1,739 (A)
	1,367 (P)	1,194 (P)
Cancellous bone	931	867

A = maximum strains around the anterior implant; P = maximum strains around the posterior implant.

The recorded strains in the IMP4 model were within the range of the stimulus window for bone remodeling and turnover, which have been reported to be in the range of 200 to 2,000 $\mu\varepsilon$.[4,5] In the IMP2 model, overall von Mises strains throughout the model were less than 250 $\mu\varepsilon$. In the posterior edentulous area in the IMP2 model, only microstrains less than 250 $\mu\varepsilon$ were observed, which are less than the physiologic value required for bone remodeling.

Maximum values of von Mises strains are presented in Table 2. Interestingly, peak von Mises strains for both cortical and cancellous bone occurred in the IMP2 and not in the IMP4 model. These high strains were recorded around the anterior implants and can potentially exceed the bone's hyper-physiologic limit.

Discussion

The authors readily accept the inherent limitations of finite element analysis when applied to biologic systems. The complex spectrum of biologic bone behavior in the context of its response to diverse magnitudes, durations, and qualities of applied forces tends to preclude simple conclusions when this experimental approach is used. On the other hand, this technique has proven to be a useful adjunctive educational and research tool for a diversity of research scenarios, since it provides scope for visualizing hypothetical questions such as the one posed in this preliminary study.[5] The observations suggest that the employed model of adjunctive placement of posterior implants may indeed serve as a means of stimulating favorable bone remodeling and possibly result in maintaining bone mass. The posterior implants tested in this investigation were of minimum height (8 mm) to compensate for potential anatomical limitations, but nevertheless appeared to provide adequate strain for bone remodeling.

The preliminary observations may be interpreted as providing the desired mechanical bone stimuli necessary for bone modeling, as previously reported.[4,5] The effective strains were observed at the bone-implant interfaces and dissipated into the surrounding bone. The results agree with previous findings[3] that when only two interforaminal implants are used to retain a mandibular overdenture, high strains are observed in the bone surrounding the implants, whereas the addition of posterior implants appears to reduce the harmful potential of otherwise hyper-physiologic strains.

Conclusion

These preliminary observations underscore the merit of clinical investigations and long-term studies of the proposed change in implant overdenture treatment protocol.

Acknowledgments

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