Mandibular Implant-Retained Overdenture: Finite Element Analysis of Two Anchorage Systems

Giulio Menicucci, DDS*/Massimo Lorenzetti, MD, DDS*/Paolo Pera, MD, DDS*/
Giulio Preti, MD, DDS**

Transmission of masticatory load in mandibular implant-retained overdentures was evaluated using a three-dimensional finite element model. The reaction forces on the distal edentulous mucosa and the stress on the peri-implant bone were compared in overdentures retained either by two ball attachments or by two clips on a bar connecting two implants. In the finite element model, a 35 N load on the first mandibular molar induced a greater reaction force on the distal edentulous ridge mucosa of the nonworking side when the overdenture was anchored by ball attachments than with the clips/bar attachment. Stress on peri-implant bone was greater with the clips/bar attachment than with the ball attachment.
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Key words: ball attachment, clips/bar attachment, finite element model, implants, overdenture, reaction forces, stress

Masticatory load transmission in mandibular implant-retained overdentures differs substantially from that in implant-supported complete arch restorations. In an in vivo study, Jemt et al[1] found a reduction in compression/tension forces transmitted through the implants to the peri-implant bone in implant-retained overdentures compared to implant-supported complete arch rehabilitations, and they interpreted this to be a consequence of the mucosal resilience in the distal edentulous ridges. Although the masticatory loads in mandibular implant-retained overdentures are weaker than those in either natural dentition or implant-supported complete arch restorations,[2–4] studies have demonstrated that implants retaining the overdentures are subjected to both axial and transverse forces,[1,3] the latter being weaker but potentially more harmful.[5]

Finite element (FE) model analysis has been widely used to evaluate stresses on peri-implant bone in the edentulous mandible.[6–9] Meijer et al[7,9] used a three-dimensional FE model to represent internal stresses in the jaw under masticatory load. Mandibular implant-retained overdentures are generally retained by at least two implants placed in or slightly medial to the canine area[10]; commonly used forms of anchorage include ball attachments[11] and clips on a bar connecting the implants.[12]

The aim of this study was to use an FE model of mandibular implant-retained overdentures to relate peri-implant bone stress and reaction forces on the edentulous ridge mucosa to two types of anchorage: ball and clips/bar.

Materials and Methods

The FE model reproduced an edentulous human mandible with the mucosa, an overdenture, and two implants placed in the canine area 8 mm from the midline (Figs 1 and 2). Two widely used methods of anchorage were compared: ball attachments (Fig 1) (Nobel Biocare, Göteborg, Sweden) and clips on a golden bar (Fig 2) (Nobel Biocare). The type of implant chosen for modeling was a 3.75-mm-diameter, 8.5 mm titanium implant (Nobel Biocare); abutments were 5.5 mm standard abutments (Nobel Biocare); and anchorage was either by two ball attachments or by one straight bar and two clips 6 mm apart. The two implants were placed so that the axis connecting them was parallel to the terminal hinge axis.[2,13]

*Lecturer, Department of Prosthodontics, University of Turin, Turin, Italy.
**Professor and Chairman, Department of Prosthodontics, University of Turin, Turin, Italy.

Reprint requests: *Dr Giulio Menicucci, Università di Torino, Dipartimento di Fisiopatologia Clinica, Sezione di Riabilitazione Orale e Protesi Maxillo-Faciale, Cattedra di Protesi Dentaria, C.so Dogliotti 14, Torino, Italia. Fax: (+39) 011/6636489.*

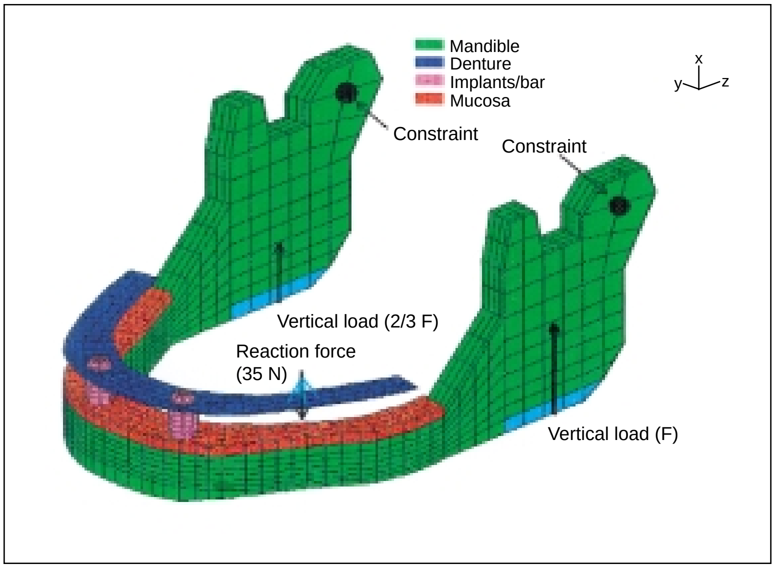


Fig 1 The mathematical model of the mandibular implant-retained overdenture (MIR-OVD) on ball attachment includes: mandible (cortical and cancellous bone), mucosa, implants, ball attachments, and denture.

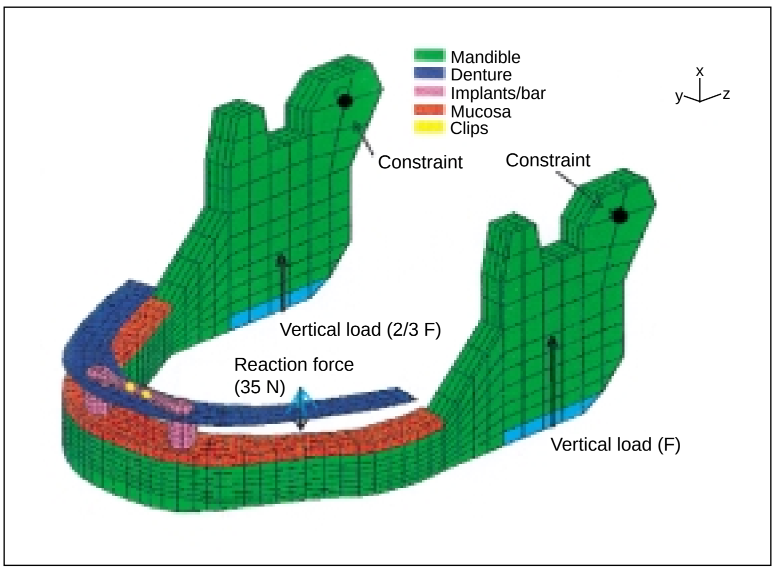


Fig 2 The mathematical model of the MIR-OVD on clips/bar attachment includes: mandible (cortical and cancellous bone), mucosa, implants, bar, and denture.

Bone, implants, and mucosa were simulated using a mesh of 3,171 three-dimensional (eight-node brick and six-node pentahedron) elements. The model was simplified by using 132 two-dimensional (four-node quad) elements to simulate the prosthesis. The mesh comprised a total of 3,528 grid points.

A Cartesian coordinate system was employed; the positive x-axis was to the back and the positive z-axis upward. A constraint was provided at either extremity of the jaw, to prevent displacement while allowing free rotation. The bone-implant connection was simulated by unilateral constraints: two-node radial gap elements all around the implant, and two-node axial gap elements at the bottom. This condition was intended to reproduce the ideal clinical situation of osseointegrated implants. As in other studies,[8,9] the jawbone was represented as a layer of cortical bone varying from 1 to 3 mm (3 mm at the neck, 2 mm at the apex and lingual side, 1 mm at the labial) with a cancellous bone interior. A uniform 3-mm-thick layer of mucosa[14,15] was assumed to support the denture by unilateral constraints (two-node gap elements). The denture was assigned a bending stiffness (Young's modulus multiplied by the section moment of inertia) that matched the values of actual dentures. The ball attachments were simulated by two hinge connections between the prosthesis and the implants, allowing zero relative displacement and free rotation.

The two nodes at the top of the bar simulating the clip attachments were given zero relative displacement along the x and z axes, and no rotation was allowed around the z-axis.

All the materials used in these models were considered to be isotropic, homogeneous, and linearly elastic[16,17]; elastic properties were assumed as follows:

Titanium:	E = 103,400 N/mm^2; Poisson's ratio 0.35
Cortical bone:	E = 13,700 N/mm^2; Poisson's ratio 0.30
Cancellous bone:	E = 1370 N/mm^2; Poisson's ratio 0.30
Resin:	E = 3,000 N/mm^2; Poisson's ratio 0.35
Mucosa:	E = 1 N/mm^2; Poisson's ratio 0.37
Gold alloy:	E = 100,000 N/mm^2; Poisson's ratio 0.30

These values are within the range of those reported in the literature,[6–9,18] except for mucosa: viscoelastic properties of mucosa are well known, but for the purposes of this study it was assumed to be an isotropic and linearly elastic material, and the Young's modulus of elasticity assigned was considered to be realistic.[19]

To simulate masticatory loading,[7–9] an upwards vertical force was assumed to act on the posterior lower margin of the horizontal branch of the mandible, as shown in Fig 1. The force on the nonworking side was two thirds of that acting on the working side, so as to reproduce the greater activity of elevator muscles on the working side during unilateral chewing.[20] The amplitude of these forces was such that the reaction force at a restrained point at the first molar of the prosthesis equaled 35 N vertical bite force.[21]

To increase the accuracy of the FE model, a convergence test was performed. As the series of meshes became finer, ie, more grid points and elements, the approximate solution improved, and this was judged by looking at the curve "node displacements versus degree of freedom number."

The FE model was developed and computations were generated using Sprints software (Blue Engineering, Turin, Italy).

Results

Figures 3a and 3b, 4a and 4b, and 5a and 5b express reaction forces on the mucosa. In each figure, equal reaction forces, expressed in newtons, are shown in the same color, and the color scale is given. Figures 6, 7, 8, and 9 demonstrate stress on the bone. In each figure, areas exposed to equal Von Mises stresses are shown in the same color, and the color scale is given.

Figures 3 and 4 illustrate the reaction force on the edentulous mucosa with the two methods of anchorage. On the working-side mucosa, peaks of reaction force are about 10% higher with the clips/bar anchorage (Fig 4a) than with the ball anchorage (Fig 3a). On the nonworking-side mucosa, peaks of reaction force are much higher (+120%) with the ball anchorage (Fig 3b) than with the clips/bar anchorage (Fig 4b), where the distal edentulous mucosa shows areas of very low reaction force. Reaction forces on the nonworking side are also distributed over a wider area of the mucosa when the mandibular implant-retained overdenture is ball anchored. To verify whether this difference was influenced by the position of the clips, the distance between the clips was increased from 6 to 10 mm. The result was that the load on the nonworking-side mucosa was increased (Figs 5a and 5b).

Stress in the peri-implant bone was concentrated in the cortical layers around the neck and the bottom of the implants with both anchorage methods. The highest peaks of stress were found around the nonworking-side implant with the clips/bar anchorage (Fig 7), but around the working-side implant with the ball anchorage (Fig 6), the former was slightly higher (+6%) than the latter. Different stress values were also present in the cortical bone between the implants; with ball anchorage (Fig 8), greater peaks (+20%) were reached than with clips/bar anchorage (Fig 9). Stress distribution was also different; with clips/bar anchorage (Fig 9), stress was relatively high in the cortical bone distal to the implant on the nonworking side, while with ball anchorage, it was mainly concentrated in the central part of the mandible, between the implants.

Discussion

The distribution of reaction forces on the mucosa of both the working and nonworking sides of the ball-anchored mandibular implant-retained overdenture (Figs 3a and 3b) is the result of increased stability, which, in the FE model, depends on the position of the anchorage elements. If these elements are closer together, as in the clips/bar anchorage, lateral rocking can more easily occur under unilateral masticatory load. This is confirmed by the finding that, when the distance between the clips was increased, the distribution of masticatory load improved (Figs 5a and 5b). Since the distance between the implants is the same in both anchorage methods, the clips were always placed more medially than the balls,

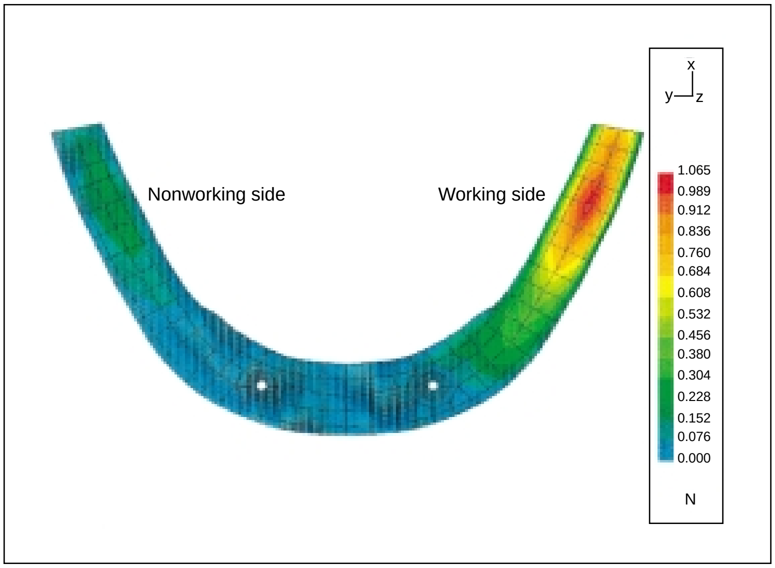


Fig 3a MIR-OVD on ball attachment: reaction forces on working- and nonworking-side edentulous mucosa.

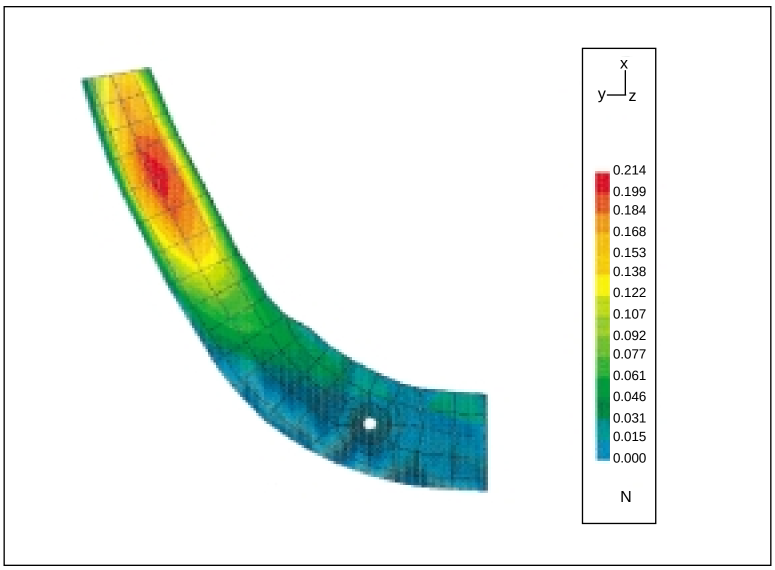


Fig 3b MIR-OVD on ball attachment: reaction forces on nonworking-side edentulous mucosa.

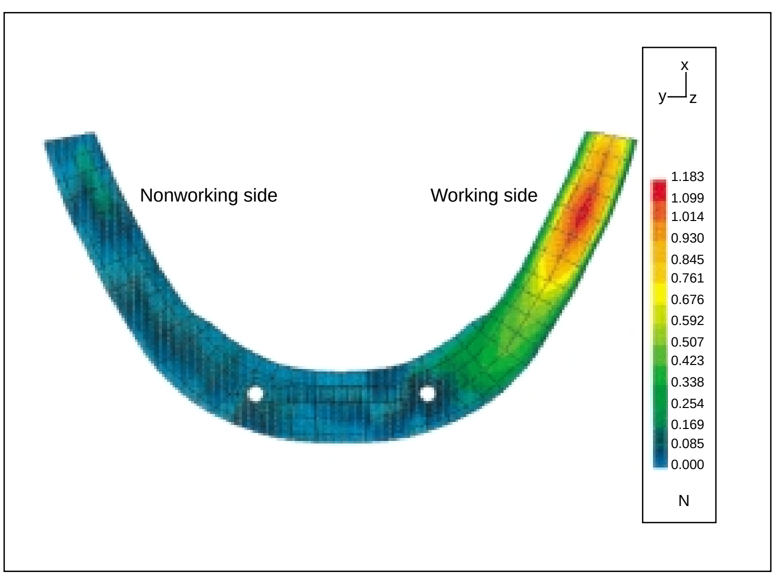


Fig 4a MIR-OVD on clips/bar attachment: reaction forces on working- and nonworking-side edentulous mucosa.

Fig 4b MIR-OVD on clips/bar attachment: reaction forces on nonworking-side edentulous mucosa.

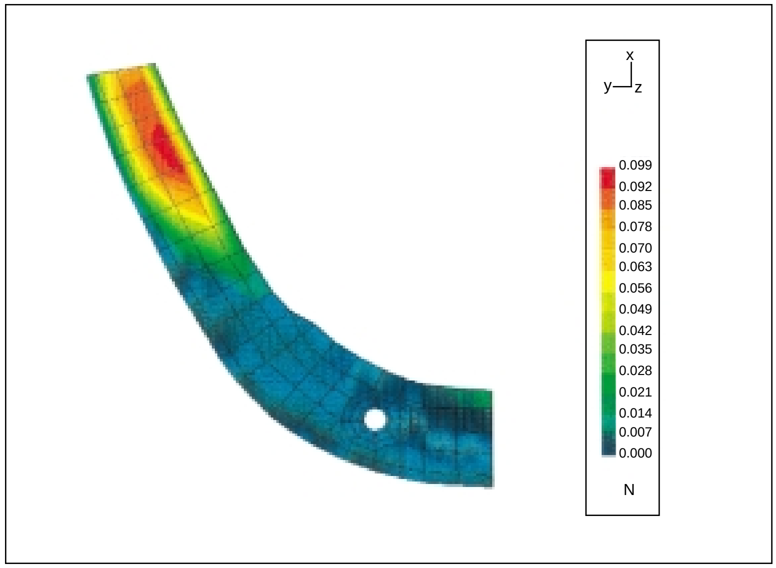


Fig 5a MIR-OVD on clips/bar attachment on which clips are 10 mm apart: reaction forces on working- and nonworking-side edentulous mucosa.

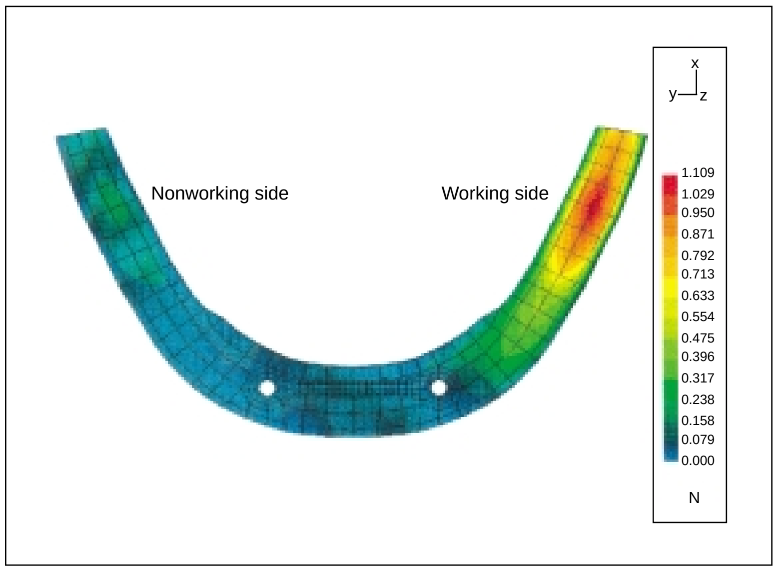
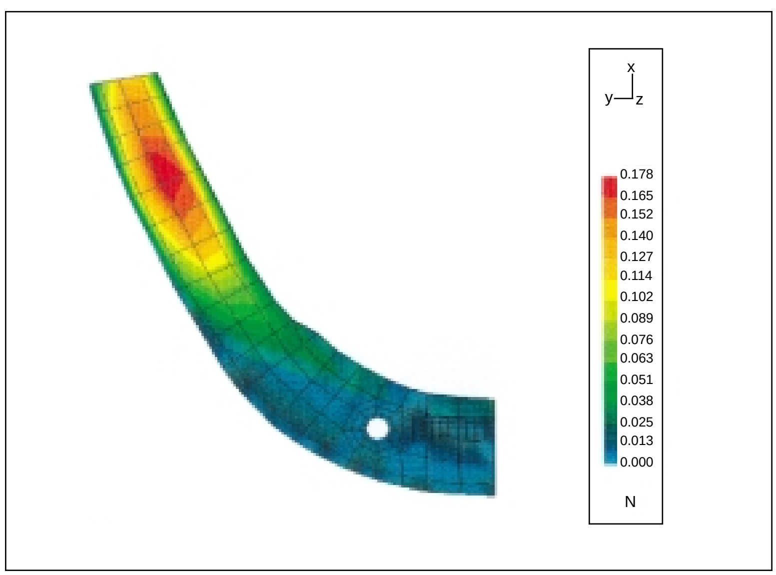


Fig 5b MIR-OVD on clips/bar attachment on which clips are 10 mm apart: reaction forces on nonworking-side edentulous mucosa.



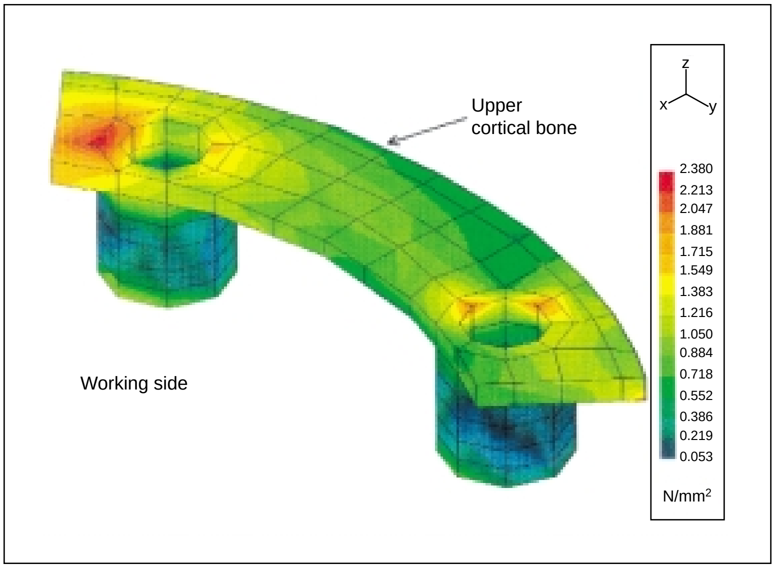


Fig 6 MIR-OVD on ball attachment: stress in the cortical peri-implant bone.

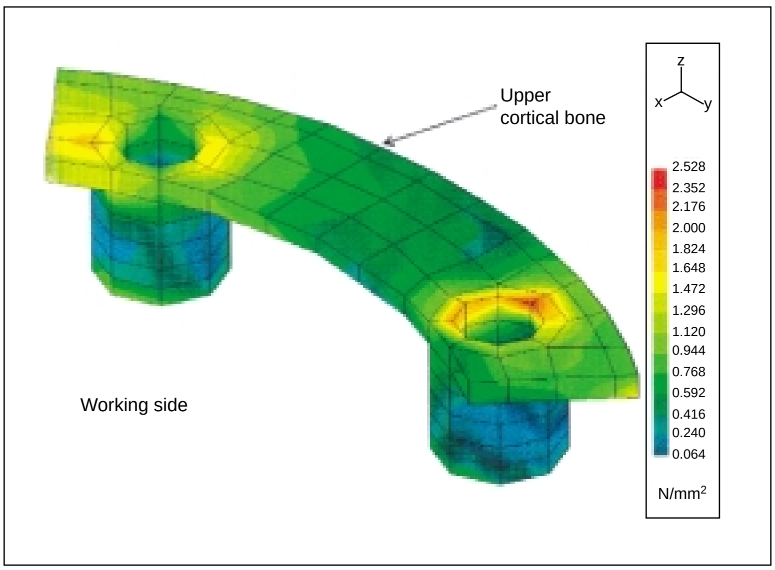


Fig 7 MIR-OVD on clips/bar attachment: stress in the cortical peri-implant bone.

unless the bar extended beyond the implants. For this reason, when using clips/bar anchorage in a clinical situation, the clips should be placed as far apart as possible.

In the FE model, bone stress concentration around the neck and at the bottom of the implants in both anchorage systems (Figs 6 and 7) is probably the result of the presence of the cortical layers, where the bone has a higher Young's modulus of elasticity. Higher peaks of stress in the peri-implant bone were found with the clips/bar anchorage; moreover, in this type of anchorage, the nonworking-side peri-implant bone showed higher peaks of stress than did that of the working side. This is probably indirectly the result of mandibular deformation during chewing[22–27]; deformation of the horizontal body on the working side is greater than that on the nonworking side, which creates torsion in the central part of the mandible. With the ball-anchored mandibular implant-retained overdentures, the two implants are independent and can thus follow the distortion of the bone without affecting it; however, with the clips/bar-anchored mandibular implant-retained overdentures, the rigid bar connecting the two implants tends to counteract this movement, so that more stress reaches the peri-implant bone. In the FE model, when the implants were connected by the bar, the stress in the medial

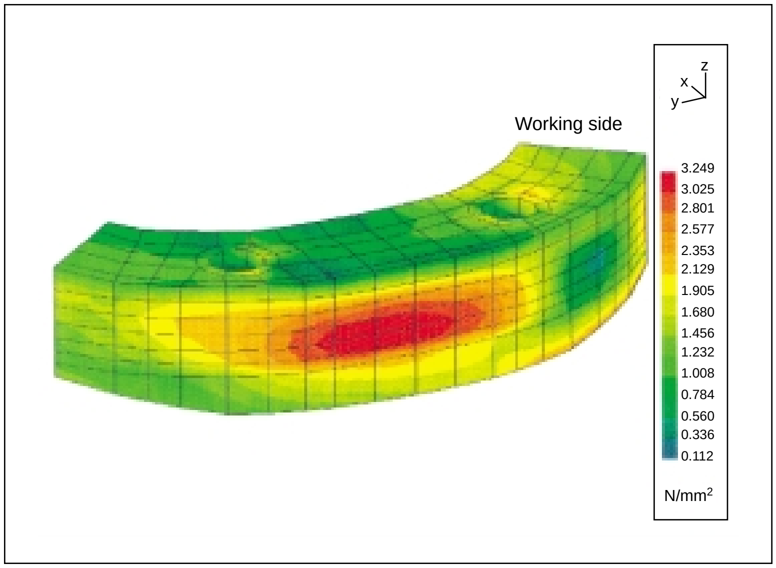


Fig 8 MIR-OVD on ball attachment: stress in the cortical bone between the implants.

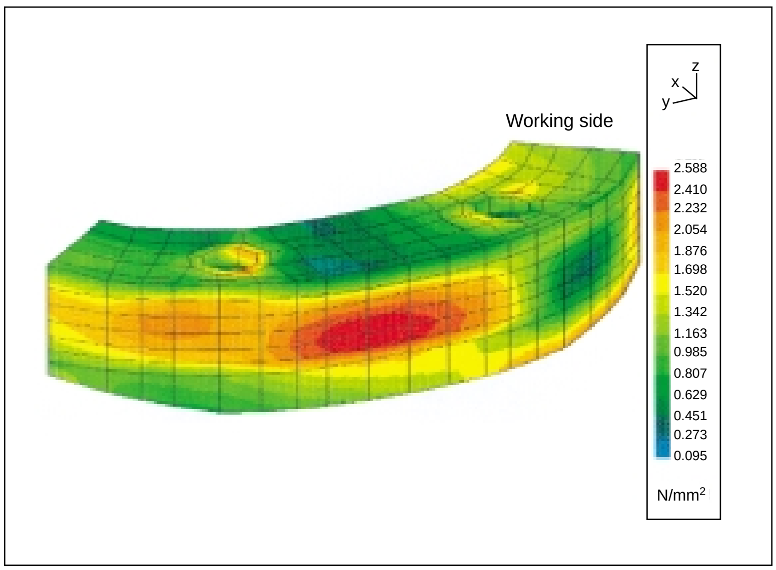


Fig 9 MIR-OVD on clips/bar attachment: stress in the cortical bone between the implants.

area of the jaw was lower, probably because, rather than remaining concentrated between the implants, the bar discharged the stress in the cortical bone beyond the distal implant (Fig 9). When the two implants were separate, as in the ball-anchored mandibular implant-retained overdentures, the stress in the medial area of the jaw is greater (Fig 8). This would appear to confirm the results obtained by Hobkirk and Schwab,[27] who conducted an in vivo study on mandibular deformation in subjects with osseointegrated implants splinted by a rigid superstructure, and by Meijer et al[6,9] in their studies using FE models.

Conclusions

From FE model analysis of the reaction force on the edentulous distal mucosa in mandibular implant-retained overdentures, ball anchorage appears to favor load distribution onto the edentulous mucosa of both the working and the nonworking side, so that the masticatory load is distributed over a wider area. In the ball-anchored overdenture, the stress on peri-implant bone seems to be lower compared to that in the clips/bar-anchored overdenture. However, these results were obtained through a mathematical model, which cannot fully represent the complexity of the biologic field.

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References

1. Jemt T, Carlsson L, Boss A, Jörnéus L. In vivo load measurements on osseointegrated implants supporting fixed or removable partial prostheses: A comparative pilot study. Int J Oral Maxillofac Implants 1991;6:413–417.
2. Naert I, De Clercq M, Theuniers G, Schepers E. Overdentures supported by osseointegrated fixtures for the edentulous mandible: A 2.5 year report. Int J Oral Maxillofac Implants 1988:3;191–196.
3. Mericske-Stern R, Geering AH, Bürgin WB, Graf H. Three-dimensional force measurements on mandibular implants supporting overdentures. Int J Oral Maxillofac Implants 1992;7:185–194.
4. Setz J, Kramer A, Benzing U, Weber H. Complete dentures fixed on dental implants: Chewing patterns and implant stress. Int J Oral Maxillofac Implants 1989;4:107–111.
5. Rangert B, Jemt T, Jörnéus L. Forces and moments on Brånemark implants. Int J Oral Maxillofac Implants 1989;4:241–247.
6. Meijer HJA, Kuiper JH, Starmans FJM, Bosman F. Stress distribution around dental implants: Influence of superstructure, length of implants and height of mandible. J Prosthet Dent 1992;68:96–102.
7. Meijer HJA, Starmans FJM, Bosman F, Steen WHA. A comparison of three finite element models of an edentulous mandible provided with implants. J Oral Rehabil 1993;20:147–157.
8. Meijer HJA, Starmans FJM, Steen WHA, Bosman F. Location of implants in the interforaminal region of the mandible and the consequences for the design of the superstructure. J Oral Rehabil 1994;21:47–56.
9. Meijer HJA, Starmans FJM, Steen WHA, Bosman F. A three dimensional finite-element analysis of bone around dental implants in an edentulous human mandible. Arch Oral Biol 1993;38:491–496.
10. Naert I, Quirynen M, Theuniers G, van Steenberghe D. Prosthetic aspects of osseointegrated fixtures supporting overdentures. A 4-year report. J Prosthet Dent 1991;65:671–680.
11. Donatsky O. Osseointegrated dental implants with ball attachment supporting overdentures in patients with mandibular alveolar ridge atrophy. Int J Oral Maxillofac Implants 1993;8:162–166.
12. Jennings KJ, Lilly P. Bar-retained overdentures for implants. Technical aspects. J Prosthet Dent 1992;68:380–384.
13. Kirsch A. Funf Jahre IMZ-Implantat-System. Grundlagen, Methodik, Erfahrungen. Symposium "Der heutige Stand der Implantologie" herausgegeben von Prof Dr Dr J Franke, 1979. Munchen, Vienna: Carl Hanser Verlag, 1980.
14. Besimo H, Kempf B. In vitro investigation of various attachments for overdenture on osseointegrated implants. J Oral Rehabil 1995;22:691–698.
15. Kidd WL, Daly CH, Wheeler JB. The thickness measurements of masticatory mucosa in vivo. Int Dent J 1971;21:430.
16. Hart RT, Hennebel VV, Thongpreda N, Van Buskirk WC, Anderson RC. Modeling the biomechanics of the mandible: A three dimensional finite element study. J Biomechanics 1992;25:261–286.
17. del Valle V, Faulkner G, Wolfaardt J. Craniofacial osseointegrated implant–induced strain distribution: A numerical study. Int J Oral Maxillofac Implants 1997;12:200–210.
18. van Zyl P, Grundling NL, Jooste CH, Terblanche E. Three-dimensional finite element model of a human mandible incorporating six osseointegrated implants for stress analysis of mandibular cantilever prostheses. Int J Oral Maxillofac Implants 1995;10:51–57.
19. Picton DC, Wills DJ. Viscoelastic properties of the periodontal ligament and mucous membrane. J Prosthet Dent 1978;40:263–272.
20. Moller E. The chewing apparatus. An electromyographic study of the action of the muscles of mastication and its connection to facial morphology. Acta Physiol Scand [Suppl] 1966;69:260.
21. Haraldson T, Jemt T, Stalblad P-A, Lekholm U. Oral function in subjects with overdentures supported by osseointegrated implants. Scand J Dent Res 1988;96:235–242.
22. McDowell JA, Regli CP. A quantitative analysis of the decrease in width of the mandibular arch during forced movements of the mandible. J Dent Res 1961;40:1183–1185.
23. Burch JG, Borchers G. Method for study of mandibular arch width change. J Dent Res 1970;49:463.
24. Goodkind RJ, Heringlake CB. Mandibular flexure in opening and closing movements. J Prosthet Dent 1973;30:134–138.
25. Fischman BM. The influence of fixed splints on mandibular flexure. J Prosthet Dent 1976;35:643–647.
26. De Marco TJ, Paine S. Mandibular dimensional change. J Prosthet Dent 1974;31:482–485.
27. Hobkirk JA, Schwab J. Mandibular deformation in subjects with osseointegrated implants. Int J Oral Maxillofac Implants 1991;6:319–328.