In Vitro Study of a Mandibular Implant Overdenture Retained with Ball, Magnet, or Bar Attachments: Comparison of Load Transfer and Denture Stability

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Purpose: When implants are used to support a removable overdenture, the optimal stress distribution to minimize both forces on the implants and denture movement is desirable. This study compared the stress patterns generated around implants and denture movement among three retention systems. **Materials and Methods:** Two root-form implants were anchored in a mandibular model made of resin, and a removable overdenture on which all experiments were performed was fabricated. The surface of the model was covered with a layer of impression material to simulate oral mucosa. Ball/O-ring, bar/clip, and magnetic attachments were used. A vertical force was applied to the left first molar and gradually increased from 0 to 50 N in 5-N steps. The resultant stress distribution and denture movement were evaluated. **Results:** The ball/O-ring attachment transferred the least stress to both implants and produced less bending moment than the bar/clip attachment. Vertical force applied to the bar/clip attachment created immediate stress patterns of greater magnitude and concentration on both implants. **Conclusion:** This in vitro study suggested that the use of the ball/O-ring attachment could be advantageous for implant-supported overdentures with regard to optimizing stress and minimizing denture movement. *Int J Prosthodont 2003;16:128–134.*

Implant-supported overdentures are a useful treatment modality for compromised completely edentulous patients. They are an especially attractive treatment option because of their relative simplicity, minimal invasiveness, and affordability. Fewer implants and a removable prosthesis offer a less expensive option for an edentulous patient.[1] Masticatory load transmission in mandibular implant-supported overdentures differs substantially from that in implant-supported fixed restorations. In general, an implant appears to be loaded through axial forces. However, depending on the location and number of implants in the dental arch, as well as on chewing function, horizontal forces and even moments can arise. As denture saddles tend to function like a fulcrum, implants may, depending on the attachments, receive considerable bending moment transferred from the implant into the bone.

An in vivo study interpreted a reduction in the compression/tension forces transmitted through the implant to the periimplant bone in implant-supported overdentures compared to implant-supported fixed restorations to be a consequence of the mucosal resilience in the distal edentulous ridges.[2] Although the masticatory loads in mandibular implant-supported overdentures are smaller than those in either the natural dentition or implant-supported fixed restorations,[3–5] studies have demonstrated that implants retaining overdentures are subject to both axial and transverse forces,[4] the latter being smaller, but potentially more harmful.[6]

Mandibular implant-supported overdentures are generally retained by at least two implants, placed in or slightly medial to the canine area,[7] and commonly

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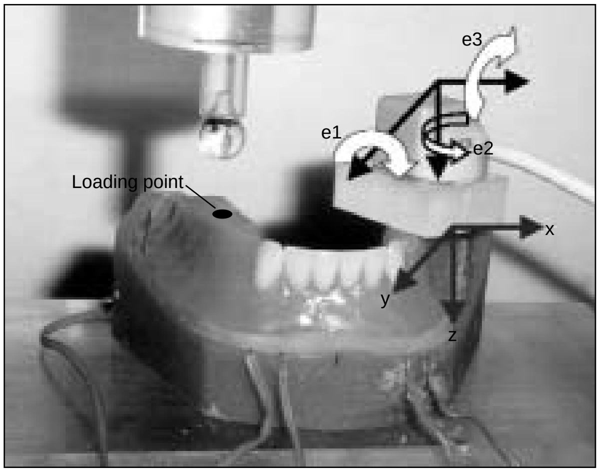


Fig 1 Experimental model. *x* = medial and distal directions; *y* = forward and backward directions; *z* = upward and downward directions; *e1* = frontal plane; *e2* = horizontal plane; *e3* = sagittal plane.

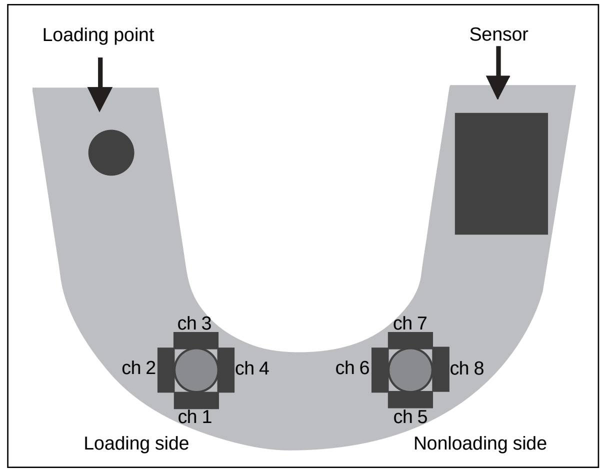


Fig 2 Measuring devices: Four strain gauges are attached around each implant. A movement sensor is attached to the molar region opposite the loading point. *Channels 1 to 4* = loading-side implant; *channels 5 to 8* = nonloading-side implant.

used forms of anchorage include ball attachments,[8] clips on a bar connecting the implants,[9] and magnetic attachments.[10] Despite the different designs of attachments for overdentures, neither experimental nor clinical data are available on the effects of different attachments on denture movement under occlusal loading. Using a cross-over experimental design, patients preferred attachments with superior stability.[11] Therefore, overdenture stability can be seen as important for patient satisfaction.

The question to be answered is whether implants need to be splinted together to better withstand the loads associated with supporting an overdenture, or whether freestanding implants alone can withstand the loads. The decision of how to stabilize and retain an implant overdenture is based on the personal preference of the clinician, without meaningful scientific support for the treatment rationale. The authors hypothesized that the use of a certain type of attachment for implant-supported overdentures can minimize not only stress on implants, but denture movement as well. This in vitro study compared the load transfer characteristics to the implant and the movement of implant-supported overdentures among three types of attachments.

Materials and Methods

Experimental Mandibular Model

An edentulous mandibular acrylic resin model (Palapress, Heraeus Kulzer) was fabricated (Fig 1). ITI implants (4.1 mm in diameter, 12.0 mm long; Straumann) were placed bilaterally in the canine region vertical to the residual ridge. They were set 22 mm apart, similar to the distance between two natural canines. The implants were retained using a resin cement (Superbond CB, Sun Medical) to simulate osseointegration. A 2-mm-thick layer was removed from the denture-supporting surface of the resin model and then replaced with polyvinyl siloxane impression material (Exafine injection type, GC) to simulate resilient edentulous ridge mucosa. An experimental acrylic resin denture was fabricated on the model in the usual manner. One denture was made and used for all experiments.

Measuring Devices

Stress on the implant surface was measured using a strain gauge technique, and it was assumed that stress measured directly on the implant surface could be representative of stress that is introduced to the bone. Four strain gauges (KFR-05-120-C-11, Kyowa Electronic Instruments) were attached to the mesiodistal and buccolingual sides of each implant body to measure the strain on the implant (Fig 2). The electric signals from the eight strain gauges were amplified and transmitted, and recorded by a personal computer (Aptiva 2168-S65, IBM) following A/D conversion (PCD-200A, Kyowa Electronic Instruments).

A movement sensor (3SPACE, Polhemus) that uses electromagnetic fields to determine the position and

Fig 3a Ball attachment.

Fig 3b Magnetic attachment.

Fig 3c Bar attachment.

orientation of a remote object was put on the left first molar region to measure the displacement and rotation of the denture. The 3SPACE system measures a single point that is a receiver's three-dimensional position coordinates value (x, y, z) and the flexibility of the Euler angle (pitch, yaw, roll) in real time by application of magnetic conversion technology. This device consists of a system electronics unit, one receiver, a single transmitter, and a power supply. The output of the movement sensor was input to a computer (OptiPlex GX1, Dell), and a mathematic algorithm computed the receiver's position and orientation relative to the transmitter and recorded the result.

Attachments

Prefabricated ball, bar, and magnetic attachments were used to attach the denture to the implants. The ball attachment consisted of an anchor head (048.439, Straumann) and a plastic female component (048.407, Straumann) (Fig 3a). The magnetic attachment consisted of a keeper as the magnet head (Platon) and a magnet (Hicolex slim G780, Hitachi) that was embedded in the denture. The keeper was prefabricated and had threads identical to those of an abutment screw (Fig 3b). The bar attachment consisted of an Octa abutment (048.404, Straumann), an Octa gold cap (048.203, Straumann), an occlusal screw (048.305, Straumann), a new CM bar, and a 10-mm female component (Cendres & Métaux). The denture was attached at the female component, and no spacer was used (Fig 3c).

Experiment

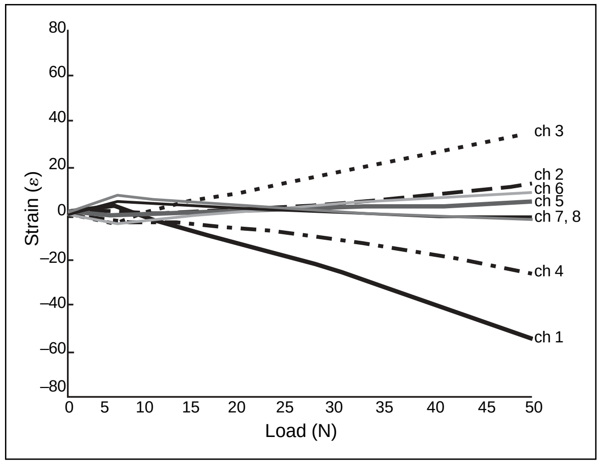
An autograph (AGS-10kng, Shimadzu) applied loads to the occlusal surface of the right first molar region. This study used the one-point concentration load of the molar part, considered where a denture will move most, since it is almost impossible to reproduce chewing pattern by in vitro experiments. A moderate level of biting force on an implant-retained overdenture was simulated. Loads from 0 to 50 N were applied gradually and increased in 5-N steps. Three sessions, one for each attachment, were performed at suitable intervals. Five measurements at each load were made under the same conditions, allowing at least 5 minutes for recovery.

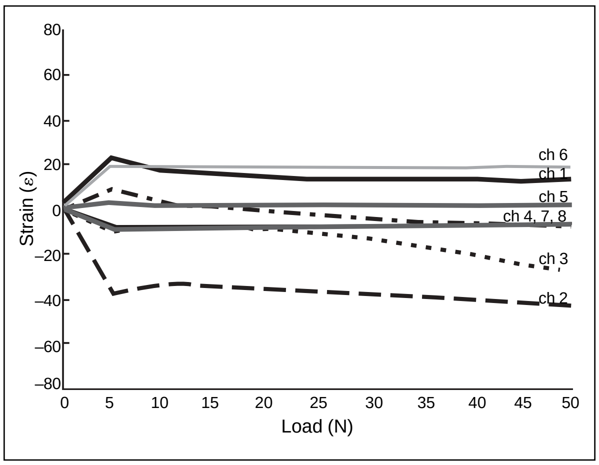
Each sequence of strain data was used to calculate the axial force and bending moment transmitted to the implant, using original software. A $^{1}/_{4}$ Wheatstone bridge configuration was used to measure axial strains on the implant abutments. Pairs of opposing gauges were wired in a $^{1}/_{2}$ Wheatstone bridge configuration to double the sensitivity to bending in the buccolingual and mesiodistal planes. Each experiment was repeated five times. The means and standard deviations were calculated, and statistical comparison was made using a one-way analysis of variance (ANOVA) and Fisher's calculation for post hoc comparisons ($P < .05$).

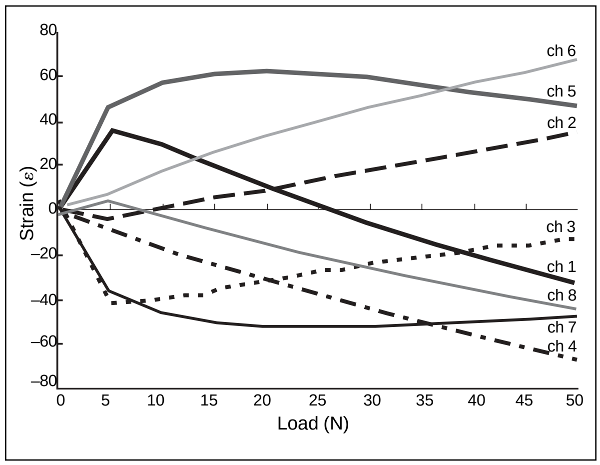
Fig 4 *(right)* Strains in the implants during load application for the ball attachment.

Fig 5 *(below)* Strains in the implants during load application for the magnetic attachment.

Fig 6 *(below right)* Strains in the implants during load application for the bar attachment.







Results

Strain Around Implants

The ball attachment transmitted a small strain in each channel at the beginning of the load (Fig 4). As the load was increased, the strain increased linearly. In addition, the strain at the loading-side implant was greater than at the nonloading-side implant. The maximum compressive strain occurred in channel 1, the buccal site of the loading-side implant. The maximum tensile strain was observed in channel 3, the lingual site of the loading-side implant.

With the magnetic attachment, the strains in the eight channels differed at the initial load, unlike with the ball attachment (Fig 5), but beyond 5 N, the strain in each channel was constant. The maximum compressive strain was found in channel 2, the distal site of the loading-side implant. The maximum tensile strain was found in channel 6, the mesial site of the nonloading-side implant.

With the bar attachment, the strains in the eight channels differed at the beginning of the load, and no clear trend in strain change with load increase was found. Some of the channels changed from compressive strain to tensile strain, and some changed from tensile strain to compressive strain (Fig 6). The maximum compressive strain was found in channel 4, the distal site of the loading-side implant. The maximum tensile strain was detected in channel 6, the mesial site of the nonloading-side implant.

The axial force was calculated from the strain data at 50 N. In all attachments, the axial force was greater in the loading-side implant than in the nonloading-side implant. In the loading-side implant, the ball attachment resulted in a low axial force and there was no difference between the magnetic and bar attachments. About 3%, 6%, and 7% of the load was transmitted to the implant through the ball, magnet, and bar attachments, respectively. The bar attachments resulted in a significantly greater axial force on both the loading- and nonloading-side implants than the ball or magnetic attachments ($P < .05$). The bending moment was calculated from the strain at 50 N. At the loading-side implant, the magnetic attachments produced the smallest bending moment and there was no difference between

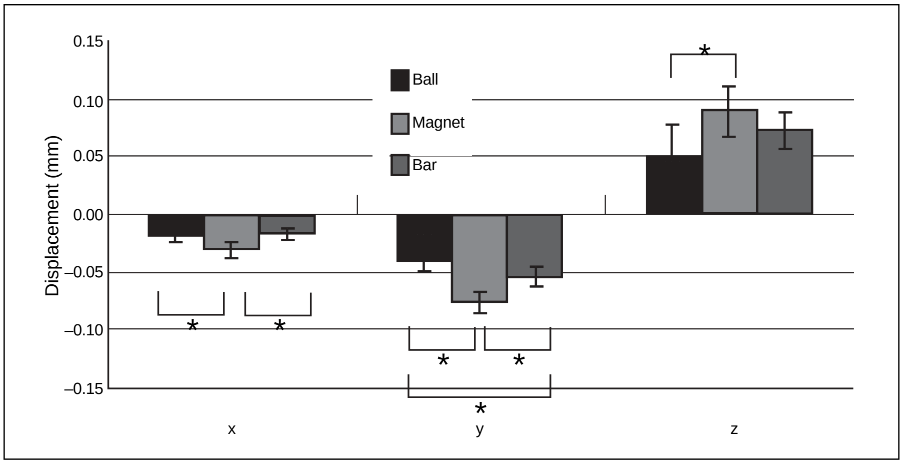


Fig 7 Denture displacement. *x* = mediolateral direction; *y* = backward-forward direction; *z* = upward-downward direction; *$P < .05$.

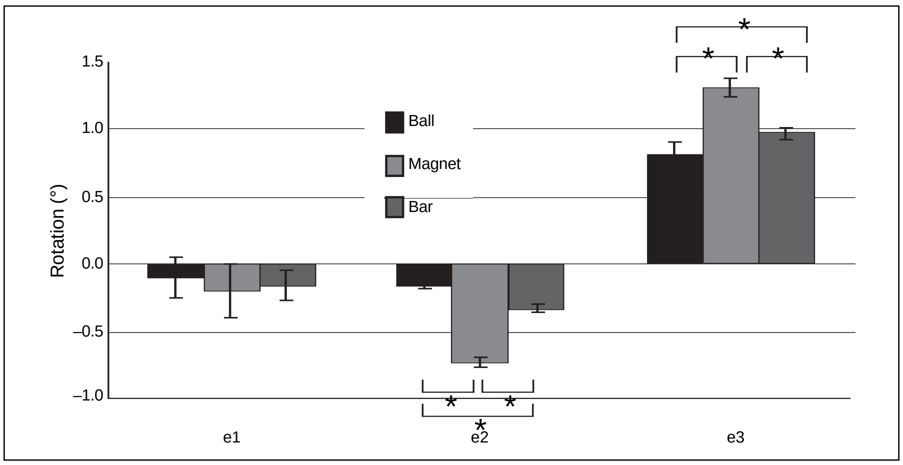


Fig 8 Denture rotation. *e1* = frontal plane; *e2* = horizontal plane; *e3* = sagittal plane;*$P < .05$.

the ball and bar attachments. At the nonloading-side implant, the bar attachment produced greater (2.5 N) bending moment than the other two types (< 0.5 Ncm).

Denture Movement

In the mediolateral direction (x), the denture displacement with the magnetic attachment was most significant ($P < .05$), and the difference between the ball and bar attachments was not significant (Fig 7). In the backward-forward direction (y), the ball attachment had significantly less displacement than the other attachments ($P < .05$). In the upward-downward direction (z), the difference between the ball and bar attachments was not significant. The magnetic attachment had a significantly greater displacement than the ball attachment ($P < .05$).

For rotation in the frontal plane (e1), there was no signficant difference among the three attachments (Fig 8). For rotation in the horizontal (e2) and sagittal (e3) planes, there were significant differences among the three attachments ($P < .05$). Furthermore, the amount of rotation in the sagittal plane was the greatest of all three planes for every attachment. The bar attachment resulted in significantly greater rotation in the horizontal and sagittal planes than the ball attachment ($P < .05$).

Discussion

When a photoelastic model was subjected to a posterior vertical load, ball/O-ring attachments transferred less stress to the implant than bar/clip attachments.[12] When ball and bar attachments were compared using 3-D finite element analysis methods, the periimplant bone stress was greater with the bar/clip attachments.[13] These studies focused only on minimizing the stress on the implant and periimplant tissue. The minimum stress can be obtained if there is no retentive mechanism or support from the implant. However, implants are necessary to stabilize the denture. Therefore, in an implant-supported overdenture, two conditions are necessary: One is to minimize the stress on the implants, and the other is to minimize the movement of the denture.

We found that with ball and magnetic attachments, the strain was concentrated on the loading-side implant.

The stress on the loading-side implant was small when the load was slight because of the secondary splinting that occurs with ball attachments. The bar attachment produced higher stress on the nonloading-side implant compared with the ball and magnet attachments because of the primary splinting effect, even at low pressure. Our result is consistent with a previous report.[14] The axial force on the loading-side implant was minimal with the ball attachment. This may be a result of the stress-absorbing effect of the plastic female component. Under our experimental conditions, when a ball attachment was used, the force was not transmitted to the implant body. The force may be absorbed at the plastic female component and anchor head connection and also by denture deformation. Therefore, in the long term, prosthodontic complications such as screw loosening or the need to replace O-ring matrices may occur.[15] When magnetic attachments were used, the axial force exceeded the bending moment because of the low point of action, although the total force to the implant was small. As for the bending moment, at the loading-side implant, the difference between the ball and bar attachments was not significant, but at the nonloading-side implant, the bar attachment produced a significantly greater bending moment.

In in vivo force measurements with single ball anchors, maximum forces measured in centric occlusion and on the ipsilateral implant when using a bite plate were slightly increased in the vertical and backward-forward dimensions (z- and y-axes) compared to the lateromedial direction (x-axis). On the contralateral implant, equally low values were found in all three dimensions.[16] On the contrary, we found that a connection between two implants burdened the nonloading-side implant from the viewpoint of bending moment. Of the three attachments, the ball attachment resulted in the least denture displacement and rotation; this is thought to be a result of the plastic female component and deformation of the denture. Our experimental conditions, such as the position and direction of the applied force, and the movement sensor position, may have contributed to this result.

It was reported that there is a high correlation between patient satisfaction and denture stability.[11] From this perspective, we conclude that a mandibular implant-supported overdenture with magnetic attachments would not significantly improve patient satisfaction. Stress distribution is a function of implant length, geometry, and diameter, so different stress patterns might be found if implants of different length, width, and shape are used, even with the same model.

It is obvious that implants cannot be stress free in cases like this experimental model. Since implant failure can result from excessive load on the implant, the practical goal for clinicians is to avoid excessive stress on implants. In other words, our goal can be expressed as minimizing stress on the implants, although we do not know how much stress could be harmful. Until scientific studies provide insight into the biologic effects of interfacial stress transfer, one goal of the clinician should be to provide the most favorable delivery of forces to the implant through prosthesis design. Thus, ball/O-ring attachments might provide an adequate attachment system with respect to reducing the stress on the implant bodies and promoting denture stability.

Conclusions

This simulation study measured and compared the load transfer characteristics on implants and the movement of implant-supported overdentures among three types of attachments.

1. The bar attachment induced the greatest axial force and bending moment on both the loading- and nonloading-side implants, but the denture was relatively stable.
2. The magnetic attachment induced the least bending moment, but resulted in the greatest denture movement.
3. The ball attachment induced a concentrated axial force and bending moment onto the loading-side implant, but the magnitude was the smallest and the movement of the denture was similar to that with the bar attachment.
4. Ball/O-ring attachments may provide an adequate attachment system with respect to reducing the stress on the implant bodies and promoting denture stability.

References

1. Johns RB, Jemt T, Heath MR, et al. A multicenter study of overdentures supported by Brånemark implants. Int J Oral Maxillofac Implants 1992;7:513–522.
2. Jemt T, Carlsson L, Boss A, Jörnéus L. In vivo load measurements on osseointegrated implants supporting fixed or removable prostheses: A comparative pilot study. Int J Oral Maxillofac Implants 1991;6:413–417.
3. Naert I, De Clercq M, Theuniers G, Schepers E. Overdentures supported by osseointegrated fixtures for the edentulous mandibule: A 2.5-year report. Int J Oral Maxillofac Implants 1988;3:191–196.
4. Mericske-Stern R, Geering AH, Burgin WB, Graf H. Three-dimensional force measurements on mandibular implant-supporting overdentures. Int J Oral Maxillofac lmplants 1992;7:185–194.
5. 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.
6. Rangert B, Jemt T, Jörnéus L. Force and moments on Brånemark implants. Int J Oral Maxillofac Implants 1989;4:241–247.
7. 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.

8. Donatsky O. Osseointegrated dental implants with ball attachments supporting overdentures in patients with mandibular alveolar ridge atrophy. Int J Oral Maxillofac Implants 1993;8:l62–l66.
9. Jennings KJ, Lilly P. Bar-retained overdentures for implants: Technical aspects. J Prosthet Dent 1992;68:380–384.
10. Fujimoto T, Niimi A, Murakami l, Ueda M. Use of new magnetic attachments for implant-supported overdentures. J Oral Implantol 1998;24:147–151.
11. Burns DR, Unger JW, Elswick RK Jr, Giglio JA. Prospective clinical evaluation of mandibular implant overdentures: Part II—Patient satisfaction and preference. J Prosthet Dent 1995;73:364–369.
12. Kenny R, Richards MW. Photoelastic stress patterns produced by implant-retained overdentures. J Prosthet Dent 1998;80:559–564.
13. Menicucci G, Lorenzetti M, Pera P, Preti G. Mandibular implant-retained overdentures: Finite element analysis of two anchorage systems. Int J Oral Maxillofac Implants 1998;13:369–376.
14. Meijer HJ, Starmans FJ, Steen WN, 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.
15. Payne AG, Solomons YF. The prosthodontic maintenance requirements of mandibular mucosa- and implant-supported overdentures: A review of the literature. Int J Prosthodont 2000;13:238–243.
16. Mericske-Stern R. Three-dimensional force measurements with mandibular overdentures connected to implants by ball-shaped retentive anchors. A clinical study. Int J Oral Maxillofac Implants 1998;13:36–43.

Literature Abstract

Dietary intake in edentulous subjects with good and poor quality complete dentures.

This interesting study investigated the relationship between masticatory performance, perceived ability to chew, diet quality, and complete denture quality. Fifty-four complete denture wearers were recruited. Data were obtained from clinical examinations involving masticatory function measurements using various types of food. Dietary data were obtained by trained interviewers who collected two separate 24-hour dietary recalls from each individual. These data were converted into a Healthy Eating Index (HEI). The denture quality of the subjects was divided into good, medium, and poor based on a rating scale. Outcome variables included HEI, masticatory performance, and reported chewing ability. Data were analyzed with Kruskal-Wallis tests, Mann-Whitney *U* tests, and Fisher's exact tests, with significance at the .01 level. Masticatory performance and perceived chewing ability were unrelated to dietary quality. The medium- and poor-quality denture groups had significantly lower masticatory performance than the good-quality denture group. However, there were no significant differences among the three groups in median HEI scores or dietary intake. Denture quality, food chewing function, and perceived chewing ability were not related to diet quality. It is interesting to note that most of the subjects had poor diets in spite of the quality of their dentures. Based on the result of this study, technically perfect dentures are not of prime significance to diet quality. It is tempting to conclude that the pursuit of technically perfect dentures is unimportant. However, the choice of dietary intake could be a socioeconomic rather than prosthodontic issue.

Shinkai RSA, Hatch JP, Rugh JD, Sakai S, Mobley CC, Saunders MJ. *J Prosthet Den*t 2002;87:490–498. **References:** 42. **Reprints:** Dr Rosemary Shinkai, Department of Orthodontics, University of Texas Health Science Center, 7703 Floyd Curl Drive, San Antonio, Texas 78229-3900. Fax: + (210)567-3513. e-mail: rosemary_shinkai@yahoo.com—*Ansgar C. Cheng, Toronto*