Effect of Implant Number on Transverse Bending Moments During Simulated Unilateral Loading of Mandibular Fixed-Detachable Prostheses

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KEY WORDS

Implantology
Biomechanics
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High bending moments acting on osseointegrated implants due to transverse forces are believed to be potential contributors to mechanical implant failure. Theoretically, the rigidity of a system comprised of five implants would seem to counter these moments more effectively than one with only three implants. To study this, we built an experimental model comprised of five Brånemark implants embedded in an acrylic mandibular edentulous arch and connected by a metal framework. This lower prosthesis was mounted with an opposing maxillary complete denture in nonbalanced lingualized occlusion on a semiadjustable articulator. Eccentric static bites were simulated by fixing the dentures at 1.5 mm left and right working side (WS) and balancing side (BS) positions, respectively, and loading the upper member of the articulator with 50 N. The distal right implant abutment was transformed into a loadcell by bonding four strain gauges at 90° intervals across its surface. Three 10-second static load ramps were carried out for each of 4 experiments: (1) WS loadcell with five implants, (2) BS loadcell with five implants, (3) WS loadcell with three implants, and (4) BS loadcell with three implants. Transverse bending moments were found to be significantly higher on the WS for the three-implant prosthesis as compared to the five-implant design (1.469 Ncm for five implants vs 2.151 Ncm for three implants; $p = 0.001$, Student's t-test). This difference was insignificant on the BS (0.532 Ncm for five implants vs 0.521 Ncm for three implants; $p = 0.34$). These results suggest that a higher number of mandibular implants may decrease the bending moments affecting mandibular fixed-detachable prostheses during unilateral biting tasks.

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Introduction

It is generally believed that mechanical overloading is an important contributing factor to the failure of dental implants.[1–3] Although the majority of implants have a high survival rate, two of the most frequently reported clinical complications are screw loosening and, less so, implant fracture.[4] The occurrence of implant fractures varies among several studies, which generally indicate a decreasing tendency in more current reports.[5–8] However, when implants fail, they often have to be retrieved surgically with an accompanying high risk of significant surrounding bone loss. Thus, a fundamental understanding of the mechanical factors affecting the long-term success is necessary to maintain and improve the survival rate of implants.

Various theoretical and experimental models have been used to predict the load distribution among dental implants supporting a prosthesis.[1,9,10] In general, these models indicate that the load affecting dental implants depends on a number of factors, which include the number, arrangement, and angulation of implants in the jaws; the nature of the prosthesis (*ie,* full, partial, or single); the mechanical stiffness of the implants in the bone; and the magnitudes, directions, locations, and modes of action of the functional and parafunctional forces on the restored dental implant.[11] Although the majority of these analyses conclude that transverse moments on implants should be minimized, it is still uncertain how these moments affect distal implants when prosthetic superstructures with differing number of implants are used. Of particular interest is the assessment of implant bending moments in a bucco-lingual plane. This is important since several *in vivo* and numerical studies have demonstrated that the mandibular corpus can be twisted around its long axis during lateral function.[12,13] This twisting action can impart moments to dental implants if these are restrained at their occlusal level, and they may be increased in the presence of attached prostheses. Moments such as these may be deleterious if the abutment-to-implant ratio is less than ideal. This study deals with the methodological setup and the experimental measurement of distal implant bending moments in the bucco-lingual plane for differing implant number during simulated lateral static biting tasks.

MATERIALS AND METHODS

A model of an edentulous mandible was made from self-cured acrylic (Orthodontic Resin, Caulk, Dentsply, York, Pa) in which five 3.75 × 10-mm titanium implant fixtures (Nobelpharma AB, Gothenburg, Sweden) were embedded at positions 3.3, 3.2, 3.1, 4.2, and 4.3 (Federation Dentaire Internationale nomenclature). A completely edentulous maxilla model was then mounted to the mandibular model on a semiadjustable articulator (Denar Mark II, Teledyne Water Pik, Fort Collins, Colo) at an arbitrarily chosen symmetrical centric position. Implant abutments (7-mm height; Nobelpharma AB) were attached to the fixtures and a bilaterally cantilevered fixed-detachable prosthesis (85% palladium, 2% gold alloy; Legacy, JF, Jelenko Co, Mo) was fitted passively on the implants. The superstructure had 17-mm-long distal cantilevers measured from the distal aspects of the most terminal abutments. Denture teeth (20° Bioblend IPN, Trubyte, Dentsply, York, Pa) were arranged in a nonbalanced lingualized occlusion, and the dentures were heat processed with high impact acrylic (Lucitone 199, Trubyte, Dentsply). After processing, both prosthetic devices were occlusally adjusted to compensate for any inherent processing errors.

One implant abutment was transformed into a loadcell by bonding four strain gauges (FLG-02-11-1L, Tokyo Sokki Kenkyujo Co, Tokyo, Japan) at 90° intervals across its surface. In the present study, signals from only two opposing strain gauges were used. All gauges were positioned parallel to each other and also to the long axis of the abutment, with the lower gauge margins located approximately 3 mm from the lower margin. The strain gauge lead wires were connected to a data acquisition unit (HP-E1300 Main Frame, Hewlett Packard, Fort Collins, Colo), which had an analogue/digital high-speed scanner attached to it (HP-E1313A, Hewlett Packard). Strain signals were calibrated and controlled

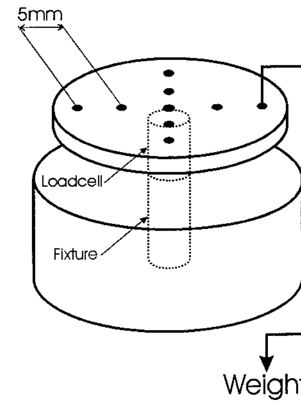

FIGURE 1. Illustration of calibration setup. A circular aluminum plate fixed with gold screw to implant abutment (*eg,* loadcell) and fixture. The fixture was rigidly embedded in an acrylic block.

through specialized computer software (HP VEE, Hewlett Packard).

A series of calibration experiments was carried out on the abutment loadcell by mounting it on a standard titanium fixture (Nobelpharma AB). A circular aluminum plate was rigidly fixed to the abutment with a standard gold screw. Various dead weights were attached to a custom-machined aluminum framework (Fig 1). A total of nine positions were selected for calibration. Loads were applied through the long axis of the implant (center position) and radially away from the abutment at 5-mm and 10-mm distances (eight radial positions). Free-hanging brass weights were attached to the framework, and bending moments in two orthogonal planes were calibrated for loads ranging from 0.98 N to 9.8 N. The analysis of the calibrations was based on the following equation derived from the geometry of the strain-gauged abutment[14]:

$$M_{BL} = K_{BL} \cdot (V_B - V_L)/2,$$

where M_{BL} represents the moment in the bucco-lingual plane and K_{BL} is a calibration constant defined by inserting the known values of the applied moments with the corresponding voltage readings (buccal, V_B, and lingual, V_L) from the calibration process.

A lateral static bite was simulated by fixing the dentures on the articulator at

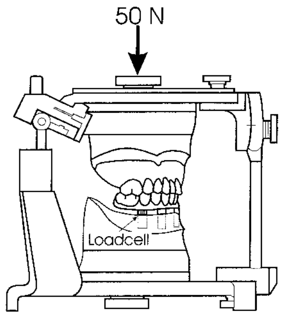

FIGURE 2. Experimental model comprised of five Brånemark implants embedded in an acrylic mandibular edentulous arch and connected by a metal framework. This lower prosthesis was mounted with an opposing maxillary complete denture in nonbalanced lingualized occlusion on a semiadjustable articulator. An eccentric static bite was simulated by fixing the dentures at a 1.5-mm left lateral position and loading the upper member of the articulator with 50 N. The most distal implant abutment was transformed into a loadcell by bonding four strain gauges at 90° intervals across its surface.

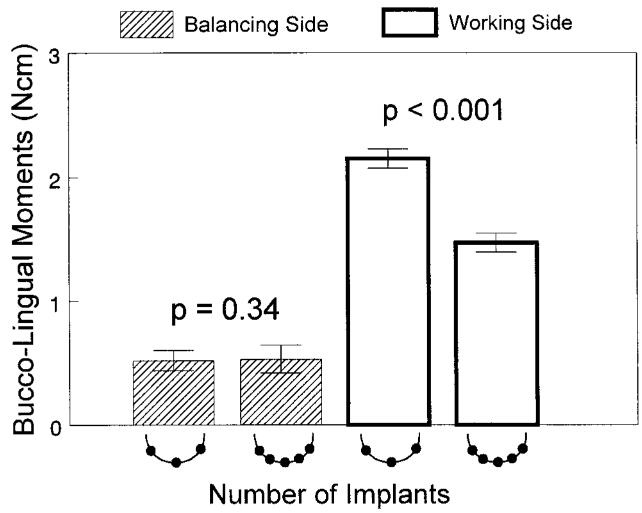

FIGURE 4. Bar graph illustrating the comparisons in distal implant abutment bending moments between a superstructure supported by five implants vs one with three implants.

a 1.5-mm right or left lateral position (measured at the second premolars) and loading the upper member of the articulator with 50 N (Fig 2), which was thought to be within the lower range of reported *in vivo* force data.[15,16] Three 10-second static load ramps were carried out for each of four experiments: (1) working side loadcell with the superstructure supported by five implants, (2) balancing side loadcell with the superstructure supported by five implants, (3) working side loadcell with the superstructure supported by three implants, and (4) balancing side loadcell with the superstructure supported by three implants. In the case of the superstructure supported only by three implants, the removed abutments were from the 3.2 and 4.2 positions (FDI nomenclature), still giving tripodal support to the lower prosthetic structure.

Bending moments in the bucco-lingual plane were quantified by measuring the strain signals on a right distal implant according to the number of implants. A Student's *t*-test was used to compare the computed bending moments between sides (working vs balancing side) by implant number (three vs five) at the 5% level of significance.

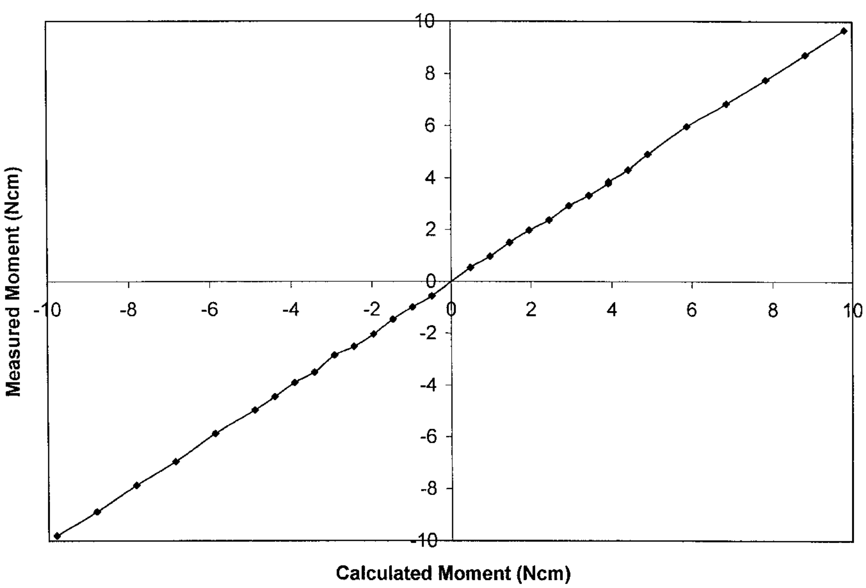

FIGURE 3. Calibration results of the loadcell. Selective weights were applied to the calibration framework at precise locations along one plane (bucco-lingual). A strong linear correlation between measured and calculated moments was achieved.

RESULTS

The calibrations performed on the abutment loadcell along one plane revealed a strong linear correlation (r = 0.99) over the range of moments applied to the implant by means of the custom-made fixture (Fig 3). Bending moments in the bucco-lingual plane were found to be significantly higher on the working side for the three-implant prosthesis as compared to the five-implant design (1.469 Ncm for five implants vs 2.151 Ncm for three implants; $p < 0.001$) (Fig 4). This difference was insignificant on the balancing side (0.532 Ncm for five implants vs 0.521 Ncm for three implants; $p = 0.34$).

DISCUSSION

Our implant loading simulations suggest that a higher number of mandibular implants may help decrease the bending moments affecting mandibular fixed-detachable prostheses during unilateral biting tasks. These results indirectly corroborate experimental analyses on stress distributions in prosthetic superstructures that predict significantly higher stress magnitudes for fewer implants.[17] In a recent study,[18] the selective loosening of gold screws between the implant abutments and the superstructure led to an increase in bucco-lingual bending moments for a point load on the ipsilateral distal cantilever. It appears that not only gold screw loosening but also a significant decrease in implant number may cause a similar effect on the most distal implant abutment. This seems to be the case even with differing locations of loading. This indicates that cantilever loads as well as unilateral surface loads on prosthetic superstructures may both result in an increase in ipsilateral implant bending moments in a plane perpendicular to the long axis of the superstructure. This effect may be increased if the axial occlusal loading is already shifted away from the long axis of the implant during lateral excursive bites. Since our study was experimental in nature, we hypothesize that this effect may be potentiated in the clinical setting due to the presence of selective masticatory muscle action and consequent complex bending of the human jaw.[13] If one side of the jaw is subjected to a twisting action due to strong action of the masseter and temporal muscles, then the lower mandibular border will be displaced laterally outwards, therefore imparting moments mainly in the bucco-lingual direction to teeth or implants during occlusal biting tasks. In these cases, an application of our methodology to a clinical scenario where strong biting tasks are performed under well-controlled settings should yield a similar trend as the one found in the present experiment. Ideally, such clinical study should incorporate the precise spatial orientation of the implant abutments to allow for comparisons to be made between other studies and to express the physical data in relation to more physiologically meaningful coordinate systems.[10]

REFERENCES

1. Rangert B, Jemt T, Jorneus L. Forces and moments on Brånemark implants. *Int J Oral Maxillofac Implants.* 1989;4:241–247.
2. Quirynen M, Naert I, van Steenberghe D. Fixture design and overload influence on marginal bone loss and fixture success in Brånemark system. *Clin Oral Implant Res.* 1992;3:104–111.
3. Rangert B, Krogh PHJ, Langer B, Van Roekal N. Bending overload and implant fracture: a retrospective clinical analysis. *Int J Oral Maxillofac Implants.* 1995;10:326–334.
4. Jendresen MD, Allen EP, Bayne SC, *et al.* Annual review of selected dental literature: report of the Committee on Scientific Investigation of the American Academy of Restorative Dentistry [review]. *J Prosthet Dent.* 1995;74(1):60–99.
5. Adell R, Eriksson B, Lekholm U, Brånemark PI, Jemt T. A long-term follow-up study of osseointegrated implants in the treatment of edentulous jaws. *Int J Oral Maxillofac Implants.* 1990;4:347–359.
6. Zarb GA, Schmitt A. The longitudinal clinical effectiveness of osseointegrated dental implants. Part III: problems and complications encountered. *J Prosthet Dent.* 1990;64:185–194.
7. Lekholm U, van Steenberghe D, Herrmann I, *et al.* Osseointegrated implants in the treatment of partially edentulous jaws. A prospective 5-year multicenter study. *Int J Oral Maxillofac Implants.* 1994;9:627–635.
8. Spiekermann H, Jansen VK, Richter EJ. A 10-year follow-up study of IMZ and TPS implants in the edentulous mandible using bar-retained overdentures. *Int J Oral Maxillofac Implants.* 1995;10:231–243.
9. Skalak R. Biomechanical considerations in osseointegration prostheses. *J Prosthet Dent.* 1983;49:843–848.
10. Morgan MJ, James DF. Force and moment distributions among osseointegrated dental implants. *J Biomech.* 1995;38:1103–1109.
11. Hoshaw SJ, Brunski JB, Cochran GVB. Mechanical loading of Brånemark implants affects interfacial bone modeling and remodeling. *Int J Oral Maxillofac Implants.* 1994;9:345–360.
12. Hobkirk JA, Schwab J. Mandibular deformation in subjects with osseointegrated implants. *Int J Oral Maxillofac Implants.* 1991;6:319–328.
13. Korioth TWP, Hannam AG. Deformation of the human mandible during simulated tooth clenching. *J Dent Res.* 1994;73:56–66.
14. Glantz P-O, Rangert B, Svensson A, *et al.* On clinical loading of osseointegrated implants. A methodological and clinical study. *Clin Oral Implant Res.* 1993;4:99–105.
15. Gunne J, Rangert B, Glantz P-O, Svensson A. Functional loads on freestanding and connected implants in three-unit mandibular prostheses opposing complete dentures: an *in vivo* study. *Int J Oral Maxillofac Implants.* 1997;12:335–341.
16. Richter E-J. *In vivo* vertical forces on implants. *Int J Oral Maxillofac Implants.* 1995;10:99–108.
17. Davis DM, Zarb GA, Chao YL. Studies on frameworks for osseointegrated prosthesis: the effect of varying the number of supporting abutments. *Int J Oral Maxillofac Implants.* 1988;3:197–201.
18. Patterson EA, Burguete RL, Thoi MH, Johns RB. Distribution of load in an oral prosthesis system: an *in vitro* study. *Int J Oral Maxillofac Implants.* 1995;10:552–560.