Cantilever and Implant Biomechanics: A Review of the Literature, Part 2

Arthur M. Rodriguez, DMD, MS, Steven A. Aquilino, DDS, MS,† and Peter S. Lund, DDS, MS‡*

In Part 2 of this literature review, a summary of the literature regarding the determination of acceptable cantilever lengths for fixed implant prostheses is presented. Studies examining the possible effects of biomechanical stress on both the implant prosthesis and the supporting bone are also discussed.

J Prosthod 1994;3:114-118. Copyright © 1994 by the American College of Prosthodontists.

INDEX WORDS: implant prosthesis design, implant cantilever length

PROSTHODONTIC complications reported by the Brånemark research group primarily involved fracture of the framework, gold screw, or abutment screw.[1-6] The biomechanical forces generated during cantilever loading of the fixed implant prosthesis most likely contributed to these complications. Published discussions of acceptable cantilever length have been few. Implant cantilever recommendations have been based primarily on empiricism.[7-9] Discussion of the effects of biomechanical stress on the fixed implant prosthesis and supporting bone are central to the development of implant prosthesis design. This article summarizes current literature regarding the above topics.

Implant Cantilever Recommendations

Although cantilevers have been used to varying extents in dentistry for years, their use has been discouraged because of the potentially destructive torque and rotational forces that they may impart to the abutment teeth.[10,11] However, implant prostheses routinely rely on cantilever designs. The classic Brånemark design involved four to six implants placed between the mandibular mental foramina or maxillary sinuses with cantilevered segments distally to replace the posterior occlusion.[12] Specific cantilever lengths were not stated, although Brånemark recommended a length of two to three premolars.[12] Zarb and Schmitt[13] worked within the 20-mm limitation of cantilever extension. Taylor and Bergman[14] stated that cantilever extension should not exceed 20 mm if five or six abutments were used and should not exceed 15 mm if four abutments were used. Rangert et al[8] recommended 15 to 20 mm in the mandible, while the softer, more porous bone in the maxilla should not support cantilevers exceeding 10 mm.

Rangert et al[8] as well as English[7] have theorized that the anterior-posterior span of fixtures may be more important than the actual number of fixtures in determining cantilever length. English defined the "A-P spread" as the distance between two parallel lines: one connecting the most distal fixtures and the second, parallel to the first, through the most anterior fixture. Rangert et al[8] recommended an A-P spread of at least 10 mm. English recommended limiting cantilever extension to one and one-half times the A-P spread when five fixtures were present. However, English recommended shorter cantilevers (6 to 8 mm) for the maxilla because of poorer bone quality.

Skalak[9] theorized that during cantilever loading, the best force distribution could be achieved by spreading out the maximum number of abutments as much as possible. According to his theoretical construct, he believed that this would decrease the load per implant as much as possible.

English[7] also emphasized that the occlusal plane–to-implant height ratio, or the distance between the top of the implant fixture and the occlusal plane,

**Staff Prosthodontist, Veteran's Administration Medical Center, Highland Drive, Pittsburgh, PA; Assistant Professor, Department of Prosthodontics, University of Pittsburgh School of Dental Medicine, Pittsburgh, PA.*

†*Professor and Graduate Program Director, Department of Prosthodontics, University of Iowa College of Dentistry, Iowa City, IA.*

‡*Associate Professor, Department of Restorative Dentistry, University of Illinois at Chicago, Chicago, IL.*

Correspondence to: Arthur M. Rodriguez, DMD, MS, Veteran's Administration Medical Center, Highland Drive, Pittsburgh, PA 15206.

1059-941X/94/0302-0012$5.00/0

should play a role in determining cantilever length. For example, heights of 20 to 28 mm from implant to prosthesis would produce crown-to-root ratios of 2:1 to 3:1 with 8 to 10 mm fixtures. These vertical levers, coupled with long cantilever lengths, could lead to mechanical or osseous failure.[7] Therefore, English recommended shorter cantilever lengths for situations with poor crown-to-root ratios.

Framework and prosthetic modifications aimed at decreasing stress specifically caused by cantilever loading have been suggested by many authors.[8-16] Worthington et al[16] and Sones[17] recommended an adequate bulk of metal distal to the posterior abutment as well as around each cylinder for support. Taylor and Bergman[14] recommended a minimum occlusogingival thickness of 5.4 mm and faciolingual thickness of 4.2 mm for the area of the framework immediately distal to the last fixture. Jemt[18] recommended an occlusogingival thickness of 4 to 6 mm. Rasmussen[19] proposed making the cantilever framework pattern into an I-beam design with a metal framework modulus roughly equal to but slightly less than titanium.

Davis et al,[20] using strain gauges, studied the effects of varying the number of abutments from five to two in a cantilevered framework in vitro. One strain gauge was placed 7 mm distal to the terminal abutment on the upper surface of the cantilever arm. A 20-kg load was applied 14 mm distal to the last abutment. Also, finite element analysis (FEA) was performed to predict framework stress and deflection for variations of five, four, three, or two gold screw fastening sites during a vertical load application of 20 kg, 10 mm distal to the last screw. Only the framework and gold screw were modeled in the FEA, not the abutments or implant fixtures. Strain gauge measurements showed a decrease in framework strain as the number of abutments was decreased from five (approximately 1,000 strain units after 20 seconds) to two (approximately 350 strain units after 20 seconds) with increasing cantilever beam deflection. The largest decrease in strain occurred when the abutment number was decreased from three to two. The finite element analysis also predicted that the largest change in cantilever deflection occurred while decreasing from three to two screws. This effect was most dramatic for the opposite end of the framework during cantilever loading. When the number of screws was reduced from three to two, significant deflection occurred not only on the loaded end, but also on the opposite end. This was not observed during any of the other combinations.

Jemt et al[21] incorporated strain gauges into the distal abutments of a single patient who had received six Brånemark mandibular implants. They then constructed both a conventional fixed prosthesis as well as an overdenture utilizing all implants to compare differences in the cantilever forces between the two designs. Higher forces were observed with the fixed prosthesis (50 to 90 N versus 5 to 65 N), however, the bending moment was the same or larger with the overdenture. The investigators concluded that this was probably attributable to the smaller dimension and decreased stiffness of the overdenture framework. Both the overdenture and the fixed prosthesis incorporated 7-mm cantilever extensions distal to the terminal implants bilaterally. When loading on the side opposite the recording strain gauge, forces measured were very low (0 to 10 N).

A similar study by Schwartzman et al[22] incorporated Brånemark implant fixtures in photoelastic resin models of a human mandible. For models incorporating four or five implant fixtures, an overdenture and conventional fixed bridge were fabricated. The frameworks were loaded, and the resulting stresses were analyzed. Vertical loading of the distal cantilever caused the highest stresses to develop at the closest implant fixture. Little cross-arch stress was recorded during loading for fixed prostheses incorporating four and five implant fixtures. In general, the highest stresses were generated by the fixed bridges, whereas the overdenture bar prosthesis showed the best distribution of occlusal loads.

Effects of Biomechanical Stress on Implant Prostheses

Many authors have emphasized the importance of achieving a passive fit between the gold cylinders of the prosthesis framework and the abutments.[8,16,23] An inaccurate fit may cause increased tension on the gold screw. In addition, microscopic flexure may occur, resulting in work hardening and eventual fracture of the gold screw.[16] Rangert et al[8] also pointed out that an inaccurate fit may permit some of the anchorage units to take proportionately excessive amounts of load, while others would be virtually unloaded.

Outlining the specifications for framework design, Klineberg and Murray[23] stated that the most technically difficult phase in prosthetic reconstruction of osseointegrated implants was the achievement of an accurate, passive fit of the framework.

They recommended that castings with discrepancies exceeding 30 μm extending more than 10% of the circumference be deemed unacceptable.

Visual and tactile verification of a passive fit may be misleading. While evaluating different impression techniques, Iturregui[24] found widely varying amounts of microstrain between numerous pairs of analog abutments on a test framework. However, visually, the framework appeared to passively fit all analog pairs.

Jemt et al[21] compared abutment strain for a two-abutment overdenture prosthesis to a fixed prosthesis supported by six implant fixtures. They reported a significant increase in force on the abutments when the prostheses were secured to the abutments, even though the fit was visually passive before screw tightening. They concluded that it was probably not possible to construct a multi-implant prosthesis with a completely passive fit. Additional prosthesis loading would be added to the baseline strain created by a nonpassive prosthesis. Therefore, loading a clinically poor-fitting prosthesis could quickly lead to an overstressed situation within the implant prosthesis and at the bone interface.[21]

Rangert et al[8] theoretically recommended maximum gold screw tightness to prevent opening of the cylinder/abutment joint as mentioned previously. However, McGlumphy et al[25] were unable to show in vitro differences in the ability of Brånemark components to resist a bending force with varying degrees of gold screw tightening.

Hobkirk et al[26] showed that physiological variables such as mandibular flexure may influence the stress transmission to prosthetic components. Five subjects were tested using intraoral devices attached to the fixtures and incorporating a miniature transformer and foil strain gauges. They showed that mandibular flexure could result in relative displacements of up to 420 μm between implants, with force transmission of up to 16 N between linked implants. These effects were most dramatic for subjects with decreased symphysis height.

Methods of reducing stress to the prosthetic components and implant fixture/bone complex have been discussed with respect to the type of occluding surface[9,27] and the incorporation of resilient elements within the abutment/fixture complex.[28,29]

Because plastics are considerably more resilient than implant components, their use as occluding surfaces for implant prostheses has been recommended for shock-absorbing advantages.[9,27] Theoretically, under impact loading the peak magnitude of force will be reduced while being distributed over an increased length of time. Davis et al[27] proposed that a porcelain superstructure had a stiffening effect on the prostheses and more evenly distributed force to the framework. They concluded that this could be an advantage during clenching or sustained static loading.

Richter,[28] using a theoretical mathematical explanation, recommended the incorporation of a soft cushioning element within the implant/abutment complex to enable the implant to simulate the mobility of the natural tooth. He believed this was especially important when connecting an implant to a natural tooth.

The intramobile element (IME), introduced in 1974 as part of the Interpore IMZ implant system (Interpore International, Irvine, CA), is an attempt to integrate shock-absorbing elements into the implant fixture/framework complex. The acrylic used is polyoxymethylene. McGlumphy et al[30] questioned the effectiveness of the IME by demonstrating equal deflections of an 18-mm cantilevered two-unit model with either polyoxymethylene or titanium internal elements. They hypothesized that the abutment screw was being flexed against the rigid titanium internal element, with possible fatigue and eventual failure of the abutment screw as the end result. Holmes,[31] using finite-element analysis, supported this hypothesis. McGlumphy et al[30] concluded that the abutment screw received the greatest stress regardless of whether the plastic or titanium internal element was used. With the plastic IME, the screw probably distorted the acrylic resin, resulting in frequent clinical failures of the IME.[30]

An FEA by Hata et al[32] showed that the propagation of stress to bone was reduced by the use of the IME. A 1.0-kg static compressive load was used in the simulation.

Lill et al[29] showed the IME to be effective in decreasing stress to the implant fixtures when rigid metal superstructure elements were incorporated. However, they also showed that the acrylic surface of the denture-type hybrid fixed prosthesis probably achieved the same result.

Effects of Implant Biomechanical Stress on Bone

The response of the bone-implant interface to biomechanical stress is critical for long-term success of the implant-supported prosthesis.[8] At the histological level, Gerard et al[33] and Perrott et al[34] examined the bone remodeling response surrounding loaded osseointegrated fixtures. Perrott et al placed eight Brånemark implant fixtures in maxillary and mandibular jaws of four mongrel dogs. Three months later, the implants were loaded for 15, 21, 27, and 36 months, and one animal was killed at each time period. The average bone appositional rate around the implants was 2.4 μm per day, as compared with 2.0 μm per day and 1.6 μm per day for natural tooth and edentulous areas, respectively. Gerard et al[33] found identical bone appositional rates in a similar study using Yucatan minipigs. These studies indicate that the percentage of osseointegration around an implant may increase over time and that the loaded implant may enhance bone apposition. This may be caused by stimulation via loading or simply by the presence of the implant itself.[33] Steflik et al[35] also showed that the formation of a continuously bridging, osteogenic-like remodeling tissue occurred between the calcified bone front and the implant immediately after prosthetic loading.

Roberts[36] stated that a balanced mechanical environment was critical for healing, maturation, and sustained function of bone surrounding the osseointegrated implant fixture. Both the natural tooth and the rigid implant were dependent on vascularly related bone remodeling as a response to biomechanical stress. After histologically examining these remodeling effects, Roberts concluded that rigid implants seemed to function similar to an ankylosed tooth and maintained rigidity by continually remodeling fatigued bone at the osseous interface. From the above studies, it seems that the osseointegrated interface is a dynamic biological environment.

Finite element analyses of stress locations within the bone of loaded implant fixtures were carried out by Clelland et al[37] and Cunningham et al.[38] Clelland et al modeled a 3.75 × 10-mm screw from an endosseous implant and found that in general, stress was concentrated within the implant collar immediately below the crest of bone. Maximum stresses in the bone were immediately lingual to the superior portion of the collar. Cunningham et al modeled a 3.3-mm diameter IMZ implant (with plastic IME) and a representative mandibular canine loaded with an oblique force. Again, stresses were found to be concentrated in the lingual cortical plate of bone for both the tooth and implant. Apical stresses for both tooth and implant were minor.

The bending moments described in theoretical models of implant stress distribution may be the most dangerous with respect to bone stress levels.[8] Rangert et al warn that stress gradients from remote site loading of linearly arranged fixtures or localized nonaxial implant loading may build up in the bone surrounding the implant fixtures. This may lead to higher levels of tensile stress at the bone-fixture interface. In agreement, an FEA by Watanabe et al[39] showed that stress concentrations in the cortical bone surrounding osseointegrated implants were much higher during 45° angle loading as compared with vertical axial loading. Watanabe et al modeled implant cylinders in the mandibular molar regions with angulations of 0°, 5°, and 8°.

The use of angled abutments may induce nonaxial forces to the implant fixture creating moments similar to ones described earlier by Rangert et al.[8] A photoelastic study by Clelland et al[40] showed that a vertical abutment distributed stress more evenly within the bone than angled abutments of 15° or 20°. Clelland and others used Steri-Oss (Steri-Oss, Inc, Anaheim, CA) implants embedded in a photoelastic bone simulant. A photoelastic study by Wylie et al[41] showed that for maxillary anterior implant fixtures, greater facial angulation resulted in a less favorable stress distribution at the simulated alveolar crest. Also, occlusal loads directed close to the long axis of the implant resulted in more favorable stress distribution.

Lindquist et al[42] studied bone loss around fixtures supporting fixed implant prostheses. This retrospective study observed 25 patients for 6 years. They found a greater amount of bone loss around medial fixtures than the most posterior ones. Mean bone loss, however, was minimal ($\leq$1.0 mm) at all sites. Also, seven patients with long cantilevers ($\geq$15.0 mm) had a mean loss of 0.95 mm around medial fixtures, whereas six patients with short cantilevers ($<$15.0 mm) had a mean loss of 0.61 mm around medial fixtures. The same trend was not seen for the posterior fixture sites.

Summary

Implant research has progressed from basic information pertaining to materials, placement techniques, and restorations to clinical and theoretical studies addressing characteristics such as loading, stress, flexibility and biological responses. A sustained research effort can be expected to broaden our information and skills in providing implant care.

References

1. Adell R: Clinical results of osseointegrated implant supporting fixed prosthesis in edentulous jaws. J Prosthet Dent 1983;50:251-254
2. Adell R, Eriksson B, Lekholm V, et al: A long term follow up of

osseointegrated implants in the treatment of totally edentulous jaws. Int J Oral Maxillofac Implants 1990;5:347-358
3. Adell R, Lekholm V, Rockler B, et al: A 15 year study of osseointegrated implants in the treatment of the edentulous jaw. Int J Oral Surg 1981;6:387-416
4. Albrektsson T: A multicenter report on osseointegrated oral implants. J Prosthet Dent 1988;60:75-84
5. Albrektsson T, Zarb G, Worthington P, et al: The long term efficacy of currently used dental implants: a review of proposed criteria of success. Int J Oral Maxillofac Implants 1986;1:11-25
6. Zarb GA, Schmitt A: The longitudinal clinical effectiveness of osseointegrated dental implants: the Toronto study, part II, the prosthetic results. J Prosthet Dent 1990;64:53-61
7. English C: The critical A-P spread. Implant Soc J 1990;1:2-3
8. Rangert B, Jemt T, Jorneus L: Forces and moments on Brånemark Implants. Int J Oral Maxillofac Implants 1989;4: 241-247
9. Skalak R: Biomechanical considerations in osseointegrated prostheses. J Prosthet Dent 1983;49:843-848
10. Shillingburg HT, Hobo S, Whitsett LD: Fundamentals of Fixed Prosthodontics (ed 2). Chicago, IL, Quintessence, 1981, pp 25-37
11. Tylman SD: Theory and Practice of Crown and Bridge Prosthesis (ed 2). St Louis, MO, Mosby, 1947, p 229
12. Brånemark PI, Zarb GA, Albrektsson T: Tissue Integrated Prostheses. Chicago, IL, Quintessence, 1985, pp 51-70, 117-128
13. Zarb GA, Schmitt A: The longitudinal clinical effectiveness of osseointegrated dental implants: the Toronto study, part III, problems and complications encountered. J Prosthet Dent 1990;64:185-194
14. Taylor R, Bergman G: Laboratory Techniques for the Brånemark System (ed 1). Chicago, IL, Quintessence, 1990
15. Brunski JB, Hipp JA: In vivo forces on endosteal implants: a measurement system and biomechanical considerations. J Prosthet Dent 1984;51:82-90
16. Worthington P, Bolender C, Taylor T: The Swedish system of osseointegrated implants: problems and complications encountered during a four year trial period. Int J Oral Maxillofac Implants 1987;2:77-84
17. Sones A: Complications with osseointegrated implants. J Prosthet Dent 1989;62:581-585
18. Jemt T: Failures and complications in 391 consecutively inserted fixed prostheses supported by Brånemark implants in edentulous jaws: a study of treatment from the time of prosthesis placement to the first annual checkup. Int J Oral Maxillofac Implants 1991;6:270-275
19. Rasmussen EJ: Alternative prosthodontic technique for tissue integrated prosthesis. J Prosthet Dent 1987;57:198-204
20. Davis DM, Zarb GA, Chao YL: Studies on frameworks for osseointegrated prosthesis: part I. The effect of varying the number of supporting abutments. Int J Oral Maxillofac Implants 1988;3:197-201
21. Jemt T, Carlsson L, Bass A, et al: In vivo load measurements on osseointegrated implants supporting fixed or removable prosthesis: a comparative pilot study. Int J Oral Maxillofac Implants 1991;6:413-417
22. Schwartzman B, Mito R, Caputo A, et al: Load transfer by multiple implants under various prosthetic devices. J Dent Res 1991;70:460 (abstr 1549)
23. Klineberg I, Murray G: Design of superstructures for osseointegrated fixtures. Swed Dent J 1985;28:63-69 (suppl)
24. Iturregui JA, Aquilino SA, Ryther JS, et al: Evaluation of three impression techniques for osseointegrated oral implants. J Prosthet Dent 1993;69:503-509
25. McGlumphy E, Jacks S, Mendel D, et al: The effect of torque on an implant abutment strength. J Dent Res 1991;70:399 (abstr 1069)
26. Hobkirk JA, Schwab J: Mandibular deformation in subjects with osseointegrated implants. Int J Oral Maxillofac Implants 1991;6:319-328
27. Davis DM, Rimrott R, Zarb GA: Studies on frameworks for osseointegrated prosthesis: part II. The effect of adding acrylic resin or porcelain to form the occlusal superstructure. Int J Oral Maxillofac Implants 1988;3:275-280
28. Richter E: Basic biomechanics of dental implants in prosthetic dentistry. J Prosthet Dent 1989;61:602-609
29. Lill W, Matejka M, Rambousek K, et al: The ability of currently available stress-breaking elements for osseointegrated implants to imitate natural tooth mobility. Int J Oral Maxillofac Implants 1988;3:281-286
30. McGlumphy E, Campagni WV, Peterson LJ: A comparison of the stress transfer characteristics of a dental implant with a rigid or a resilient internal element. J Prosthet Dent 1989;6: 586-593
31. Holmes DC: Comparison of Stress Transmission in the IMZ Implant System with Polyoxymethylene or Titanium Intramobile Element: A Finite Element Analysis. Iowa City, IA, University of Iowa, 1991 (Thesis)
32. Hata Y, Watanabe F, Fukura H, et al: Stress analysis of intramobile element by three dimensional finite element. J Dent Res 1990;69:117 (abstr 69)
33. Gerard D, Gotcher J, Cooper E, et al: Histomorphometric study of endosseous implants in minipigs: a pilot study. J Dent Res 1991;70:460 (abstr 1556)
34. Perrott D, Gotcher J, Gerard D, et al: Loaded endosseous implants affect bone turnover. J Dent Res 1991;70:400 (abstr 1073)
35. Steflik D, McKinney R, Parr G, et al: Comparative experimental studies of dental implants. J Dent Res 1990;69:214 (abstr 841)
36. Roberts W: Comparison of bone adaptation to loaded teeth and dental implants. J Dent Res 1991;70:430 (abstr 1312)
37. Clelland N, Ismail Y, Zaki H, et al: Three dimensional finite element analysis of the Core-Vent Implant. J Dent Res 1990;69:117 (abstr 65)
38. Cunningham W, Felton D, Bayne S, et al: Finite element analysis comparing IMZ dental implant to mandibular cuspid. J Dent Res 1990;69:116 (abstr 64)
39. Watanabe F, Hata Y, Fukuda H, et al: Stress analysis in relation to degree of inclination for implants. J Dent Res 1990;69:117 (abstr 68)
40. Clelland N, Gilat A, Goehring D: Photoelastic stress comparison of angled abutments for an implant. J Dent Res 1991;70: 459 (abstr 1548)
41. Wylie R, Caputo A, Alexandridis C, et al: Effect of maxillary fixture location and angulation on load transfer. J Dent Res 1991;70:459 (abstr 1547)
42. Lindquist L, Rockler B, Carlsson G: Bone resorption around fixtures in edentulous patients treated with mandibular fixed tissue integrated prostheses. J Prosthet Dent 1988;59:59-63