A STRAIN GAUGE ANALYSIS OF IMPLANT-SUPPORTED CANTILEVERED FIXED PROSTHESIS UNDER DISTAL STATIC LOAD

Byoung-Sup Sohn, D.D.S., M.S.D., Seong-Joo Heo, D.D.S., M.S.D., Ph.D., Ik-Tae Chang, D.D.S., M.S.D., Ph.D., Jai-Young Koak, D.D.S., M.S.D., Ph.D., Seong-Kyun Kim, D.D.S., M.S.D., Ph.D.
Department of Prosthodontics, Graduate School, Seoul National University

Statement of problem. Unreasonable distal cantilevered implant-supported prosthesis can mask functional problems of reconstruction temporarily, but it can cause serious strain and stress around its supported implant and surrounding alveolar bone.

Purpose. The purpose of this study was to evaluate strain of implants supporting distal cantilevered fixed prosthesis with two different cantilevered length under distal cantilevered static load.

Material and methods. A partially edentulous mandibular test model was fabricated with auto-polymerizing resin (POLYUROCK; Metalor technologies, Stuttgart, Swiss) and artificial denture teeth (Endura; Shofu inc., Kyoto, Japan). Two implants-supported 5-unit screw-retained cantilevered fixed prosthesis was made using standard methods with Type Ⅲ gold alloy (Harmony C&B55; Ivoclar-vivadent, Liechtenstein, Germany) for superstructure and reinforced hard resin (Tescera; Ivoclar-vivadent, Liechtenstein, Germany) for occlusal material.

Two strain gauges (KFG-1-120-C1-11L1M2R; KYOWA electronic instruments, Tokyo, Japan) were then attached to the mesial and the distal surface of each standard abutment with adhesive (M-bond 200; Tokuyama, Tokyo, Japan). Total four strain gauges were attached to test model and connected to dynamic signal conditioning strain amplifier (CTA1000; Curiotech inc., Paju, Korea).

The stepped 20~100 N in 25 N increments, cantilevered static load 8mm apart (Group Ⅰ) or 16mm apart (Group Ⅱ), were applied using digital push-pull gauge (Push-Pull Scale & Digital Force Gauge, Axis inc., Seoul, Korea). Each step was performed ten times and every strain signal was monitored and recorded.

Results. In case of Group Ⅰ, the strain values were surveyed by 80.7 ~ 353.8 μm / m in Ch1, 7.5 ~ 47.9 μm / m in Ch2, 45.7 ~ 278.6 μm / m in Ch3 and -212.2 ~ -718.7 μm / m in Ch4 depending on increasing cantilevered static load. On the other hand, the strain values of Group Ⅱ were surveyed by 149.9 ~ 612.8 μm / m in Ch1, 26.0 ~ 168.5 μm / m in Ch2, 114.3 ~ 632.3 μm / m in Ch3, and -323.2 ~ -894.7 μm / m in Ch4.

Conclusion. A comparative statistical analysis using paired sample t-test about Group Ⅰ Vs Group Ⅱ under distal cantilevered load shows that there are statistical significant differences for all 4 channels ($P<0.05$).

Key Words
Strain gauge analysis, Implant-supported cantilevered fixed prosthesis, Digital push-pull gauge

Over the past decades, prosthetic restoration of edentulous jaws with endosseus implants radically changed dental practice. Endosseus implants were conceived to take the place and function of natural roots. But, In the case of unfavourable local conditions of the residual edentulous ridges, two options may be considered. One is Pre-implant reconstructive and / or regenerative procedures. The other is rehabilitation of partially edentulous site with cantilever fixed prosthesis. However, the latter allows a simpler rehabilitation procedure as several studies have demonstrated.[1,2]

The cantilever length of implant-supported prosthesis has been considered an important factor in the transfer of force that results from an occlusal load through the implant to the supporting bone.[3] Brånemarkk et al.[4] stated that the "cantilevered ends of a fixed prosthesis increase loading on the screw nearest to the cantilevered end. but moderate extension may be tolerated if the fixtures are sufficiently strong."

Adell et al.[5] suggested that the cantilever length should be limited to two distal teeth for the terminal implant in the mandible and to only one tooth in the maxilla. In a study that emphasized the significance of bone quality in determining cantilever length.

Rangert et al.[6] suggested that cantilever lengths should vary with mechanical and biologic conditions, with bone status the most important factor in determining the cantilever length. The bone quality often observed in the mandibular residual arch allows an average cantilever extensions of 15 to 20 mm. In contrast, the cantilever length in the more cancellous maxilla should not exceed 10 mm.

The location, number, and dimensions of the implants (length and diameter) and the arch form are other important factors that can affect cantilever length. Other equally important factors are the opposing dentition and the anticipated forces generated by the patient during function and parafunction. Takayama et al.[7] calculated the stresses in a full mandibular prosthesis connected to a rigid foundation by implants with the formula derived by Skalak.[8]

He found maximum cantilever length to be heavily dependent on antero-posterior length and recommended that the maximum cantilever length for such a configuration that uses four to six implants should be no more than twice the antero-posterior length. He also showed that the maximum cantilever length should be reduced by half when the embedded implant length is reduced by one third.

Although many recommendations have been made regarding cantilever length, the ideal cantilever length as a function of implant length has not been determined. The ideal length is that which permits uniform distribution of the functional forces to the bone without overloading the bone / implant interface.

The purpose of this study was to evaluate strain of implants supporting cantilevered fixed prosthesis with two different cantilevered length under distal cantilevered static load.

MATERIAL AND METHODS

1. Fabrication of measurement model and cantilevered fixed prosthesis

A partially edentulous mandibular test model was fabricated with auto-polymerizing resin (POLYUROCK; Metalor technologies, Stuttgart, Swiss) and artificial denture teeth (Endura; Shofu inc., Kyoto, Japan). This auto-polymerizing resin has a flexural modulus of 3,000 MPa; similar to that of mandibular trabecular bone.[9]

An area from the mandibular canine to the second molar was specially designed to be a missing span for installation of implants and implant-supported fixed prosthesis. The interarch distance from the alveolar ridge of mandibular missing span to the cusp of opposing teeth was planned by 12 mm apart at least. Because the strain gauge and abutment complex needs a sufficient vertical space (>5mm).

After fabrication of implant surgical stent, two Brånemark system-like external type dental implants, ϕ 4.0 mm X 11.5 mm height, (US Ⅱ, Osstem inc., Seoul, Korea) were installed at the mandibular canine and the second premolar area in missing span using the standard procedure.

Two implants-supported 5-unit screw-retained cantilever fixed prosthesis was made using the standard methods of superstructure fabrication. The entire procedure, including impression making, master cast fabrication, wax-up, casting, and finishing, was carried out in accordance with recommended protocols.[10,11] The mandibular test model was fabricated using with stone and implant lab analogues, and standard abutments (ø 4.5mm X 5.5mm height) were connected to lab analogue.

A reinforced hard resin (Tescera; Ivoclar-vivadent, Liechtenstein, Germany) was selected as the material of occlusal table.

2. Attachment of strain gauges and equipments set-up

The surfaces of two standard abutments were roughened by a sandblasting media. Two strain gauges (KFG-1-120-C1-11L1M2R, KYOWA electronic instruments, Japan) were then attached to the mesial and the distal side of each standard abutment with adhesive (M-bond 200, Tokuyama, Japan). Four strain gauges were attached to the test model and connected with dynamic signal conditioning strain amplifier (CTA1000, Curiotech, Korea).

The four strain gauge channel were named as followings.

Ch1: strain gauge attached to mesial side of first implant fixture.

Ch2: strain gauge attached to distal side of first implant fixture.

Ch3: strain gauge attached to mesial side of second implant fixture.

Ch4: strain gauge attached to distal side of second implant fixture.

Two test groups were divided depending on length of cantilevered loading point from screw hole of distal implant.

Group Ⅰ : The test group with Ch1 ~ Ch4 under cantilevered static load 8mm apart.

Group Ⅱ : The test group with Ch1 ~ Ch4 under cantilevered static load 16mm apart.

The stepped 20~100 N in 20 N increment, 8 mm or 16 mm apart distal cantilevered static loads were applied using a digital push-pull gauge (Push-Pull Scale & Digital Force Gauge, Axis, Seoul, Korea) like a figure 1. Each step was per-

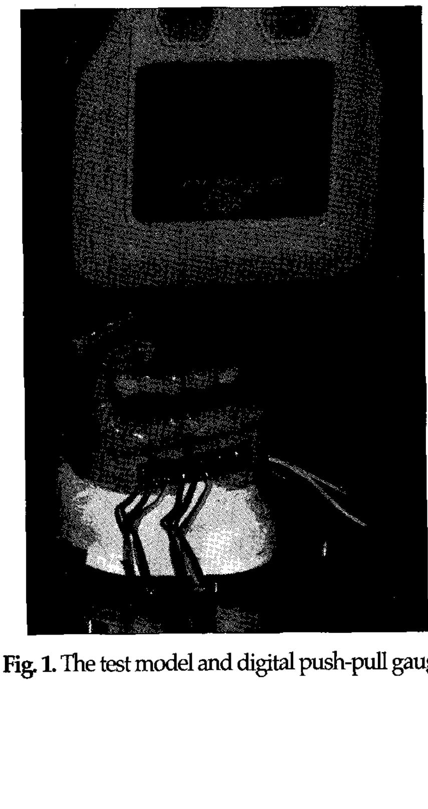

Fig. 1. The test model and digital push-pull gauge.

formed ten times and every strain signal was monitored and recorded with the computer software program (DA1700, National Instrument, TX, USA).

3. statistical analysis

The paired sample t-test about the strain values was performed to evaluate and find out the statistical significant difference between two different groups.

RESULTS

The table I and II show the mean strain values and standard deviation of Group I and Group II respectively. The strain values of Ch1, Ch2, Ch3 represent (+) values, it means tensile strain. On the other hand, the strain value of Ch4 represents (-) value, it means compressive strain.

In case of Group I, the strain values were surveyed by 80.7 ~ 353.8 μm/m in Ch1, 7.5 ~ 47.9 μm/m in Ch2, 45.7 ~ 278.6 μm/m in Ch3 and -212.2 ~ -718.7 μm/m in Ch4 depending on increasing cantilevered static load.

On the other hand, the strain valeus of Group II were surveyed by 149.9 ~ 612.8 μm/m in Ch1, 26.0 ~ 168.5 μm/m in Ch2, 114.3 ~ 632.3 μm/m in Ch3, and -323.2 ~ -894.7 μm/m in Ch4.

The strain values of Group I and II under the same cantilevered static load, the following sequence of channels were Ch4 > Ch1 > Ch3 > Ch2 in large order ($P<0.05$). Figure 2, 3 and 4 show the graphs of strain values of each channels in Group I and Group II to compare with each other easily. And they show that the strain values of each channels were increased twice in proportion to the cantilevered length. But the strain values of Ch4 were not increased in proportion to the cantilevered length (Fig. 5).

The paired sample t-test was performed to find out the statistical significant difference between two groups. In result, there were statistical significant differences ($P<0.05$) between two groups

Table I. The mean strain values ± SD of Group I (n=10, 8mm apart)

Load	Mean strain value(um/m)			
	Ch1	Ch2	Ch3	Ch4
20N	80.7±1.57	7.5±0.98	45.7±1.06	-212.2±1.95
40N	153.4±3.40	19.4±2.26	100.6±1.28	-385.0±3.35
60N	219.1±3.89	27.1±1.42	157.6±1.89	-507.4±3.96
80N	287.5±2.11	39.1±1.97	216.7±1.46	-619.2±1.51
100N	353.8±3.37	47.9±3.64	278.6±0.99	-718.7±4.63

Table II. The mean strain values ± SD of Group II (n=10, 16mm apart)

Load	Mean strain value(um/m)			
	Ch1	Ch2	Ch3	Ch4
20N	149.9±2.63	26.0±3.39	114.3±1.22	-323.2±3.18
40N	281.1±1.36	71.5±1.34	240.5±1.05	-497.3±1.21
60N	417.3±2.17	112.7±1.22	379.2±1.52	-627.7±2.66
80N	531.9±4.03	150.5±1.41	513.1±3.38	-758.7±4.39
100N	612.8±6.03	168.5±10.54	632.3±10.60	-894.7±6.49

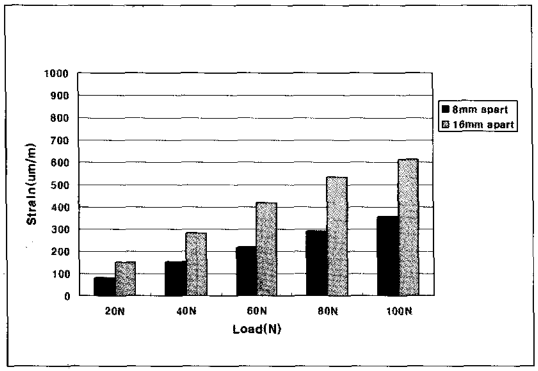

Fig. 2. The mean strain values of Ch1 under cantilevered load 8mm or 16mm apart.

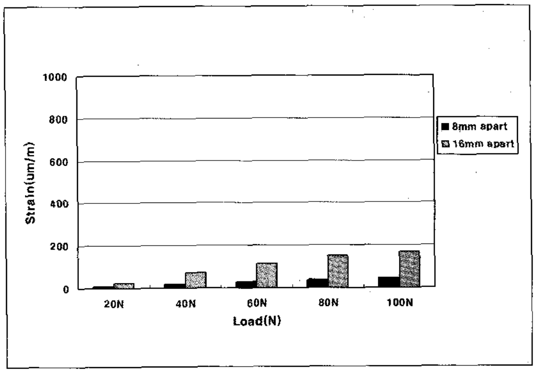

Fig. 3. The mean strain values of Ch2 under cantilevered load 8mm or 16mm apart.

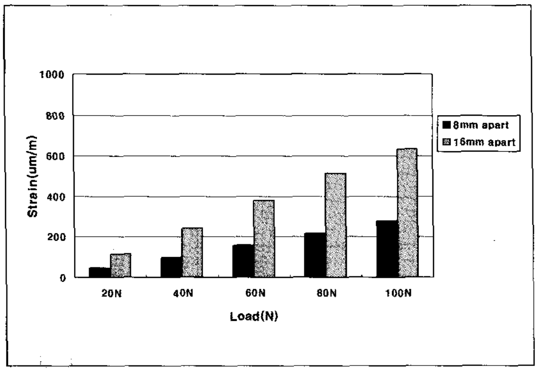

Fig. 4. The mean strain values of Ch3 under cantilevered load 8mm or 16mm apart.

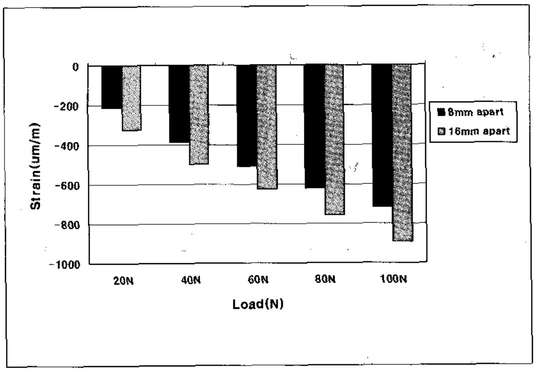

Fig. 5. The mean strain values of Ch4 under cantilevered load 8mm or 16m apart.

about all 4 channels. (P_1=0.007 in Ch1, P_2=0.015 in Ch2, P_3=0.014 in Ch3 and P_4=0.000 in Ch4)

DISCUSSION

The application of functional forces induces stress and strain within the implant-prosthesis complex and affect the bone remodelling process around implants.[12,13] Yet, the physiologic tolerance thresholds of human jawbones are not known and some reported implant failures may be related to unfavorable stress magnitudes. Studies on bone biology suggest that implant overloading may lead to implant failure. when overloaded, high deformations (above 2000 ~ 3000 microstrain) occur in bone surrounding implants.[14] When pathologic overloading occurs (over 4000 microstrain), stress and strain gradients exceed the physiologic tolerance threshold of bone and cause micro-fractures at the bone-implant interface.[15]

While overloading may be manifested by the application of repeated single loads, which causes micro-fractures within the bone tissue, continuous application of low loads may also lead to failure, namely, fatigue fracture. And excessive dynamic loading may also decrease bone density around the neck of implants and lead to crater-like defects.[16] Accordingly, overload-associated implant failures have been reported following the first year of prosthodontic treatment.[17]

Marginal bone resorption may also be related to the lack of mechanical coupling between the machined coronal region of the implant and the bone, which avoids effective transfer of occlusal forces from the implant to the cortical bone. The extremely low intraosseous strains (≥below 100 microstrain) thus cause bone resorption due to disuse atrophy.[18,19]

The fact which was found out from this study was that the strain value of abutment-prosthesis complex under cantilevered static load was proportion to the its distal cantilevered load and length. And the strain values of two strain gauges, Ch2 and Ch3, between the mesial and the distal implant have a vector sum of tensile strain to the axis of the distal implant and compressive strain to the axis of the mesial implant under distal cantilevered static load.

In other words, Ch2 attached to the distal side of the mesial implant has a little comparative tensile strain with the other channels, it means that the compressive strain of Ch2 to the axis of the mesial implant countervail against the tensile strain to the axis of the distal implant under cantilevered distal static load. Like the preceding, Ch3 attached to the mesial side of the distal implant has a half tensile strain as absolute strain value of Ch4, it means that the compressive strain of Ch3 to the axis of the mesial implant countervail against the tensile strain to the axis of the distal implant under cantilevered distal static load.

Therefore, implant-supported cantilevered prosthesis can cause various strains around its supported implants depending on the mesial or the distal side under distal cantilevered static load. And under the condition of the same distal cantilevered load and length, the sequence of channels in larger value are followings, Ch4 > Ch1 ≧ Ch3 > Ch2 ($P<0.05$), it means that the distal side of the distal implant has the largest stress concentrated around its implant and the distal side of the mesial implant has the smallest stress around its implant.

In case of Ch1 ~ Ch3, they have twice strain values as cantilevered length increased but in case of Ch4, it doesn't. It means that abutment-prosthesis complex do not have unlimited strain and elasticity of superstructures made with Type Ⅲ gold material buffer the compressive strains of Ch4.

The reason that the distal cantilevered length of 8mm or 16mm was determined is that the length of 8mm is one cantilevered tooth length and the length of 16mm is two teeth length. A comparative statistical analysis using paired sample t-test about Group Ⅰ Vs Group Ⅱ under distal cantilevered load shows that there are statistical significant differences about all 4 channels ($P<0.05$). The only increased distal cantilevered length of implant-supported prosthesis can cause more strain and stress around its supported implant, so distal cantilevered length should be determined carefully.

Unreasonable distal cantilevered length of implant-supported prosthesis can mask functional problems of reconstruction temporarily, but it can cause serious strain and stress around its supported implant and surrounding alveolar bone. This can also make complications like disosseointegration of implant or fracture of implant-supported prosthesis.

The other hand, the well-planned cantilevered implant-supported prosthesis can unburden additional expense of the additional implants or GBR.

CONCLUSION

The conclusion about this study were followings.

1. The strain values of strain gauges attached to

the implants supporting cantilevered prosthesis are proportionate to cantilevered load and its length.

2. The strain values of two strain gauges, Ch2 and Ch3, between the mesial and the distal implants have a vector sum of tensile strain to the axis of the distal implant and compressive strain to the axis of the mesial implant under distal cantilevered static load.
3. Under the condition of the same distal cantilevered load and length, the sequence of channels are followings, Ch4 > Ch1 ≧ Ch3 > Ch2 in larger order (P<0.05), it means that the distal side of the distal implant has the largest stress concentrated around its implant and the distal side of the mesial implant has the smallest stress around its implant.
4. A comparative statistical analysis using the paired sample t-test about Group I Vs Group II under distal cantilevered load shows that there are statistical significant differences about all 4 channels (P<0.05).

REFERENCES

1. Rodriguez A, Aquilino S, Lund P, Ryther J, Southard T. Evaluation of strain at the terminal abutment site of a fixed mandibular prosthesis during cantilever loading. Int J Prosthodont 1993;2:93-102.
2. Shackleton J, Carr L, Slabbert J, Becker PJ. Survival of fixed implant-supported prostheses related to cantilever lengths. Journal of Prosthetic Dentistry 1994;71:23-26.
3. Skalak R. Biomechanical considerations in osseointegrated prostheses. J Prosthet Dent 1983;49:843-8.
4. Brånemark PI, Zarb GA, Albrektsson T. Tissue-integrated prostheses osseointegration in clinical dentistry. Chicago: Quintessence Publishing Co Inc, 1985:128.
5. Adell R, Lekholm U, Rockier B, Brånemark PI. A 15-year study of osseaintegrated implants in the treatment of the edentulous jaw. Int J Oral Surg 1981;10:387-416.
6. Rangert B, Jemt T, Jorneus L. Forces and moments on Brånemark implants. Int J Oral Maxillofac Implants 1989;4:241-7.
7. Takayama H. Biomechanical considerations on osseointegrated implants. Osseointegration and occlusal rehabilitation. 2nd ed. Tokyo: Quintessence Publ Co Ltd, 1990:265-80.
8. Skalak R. Biomechanical consideration in osseointegrated prostheses. J Prosthet Dent 1983;49:843-8.
9. Keaveny TM, Guo XE, Wachtel EF, McMahon TA, Hayes WC. Trabecular bone exhibits fully linear elastic behavior and yields at low strains. J Biomech 1994;27:1127-1136.
10. Heckmann SM et al. Cement fixation and screw retention: Parameters of passive fit - An in vitro study of three-unit implant-supported fixed partial dentures. Clin Oral Implants Res 2004;15:466-473.
11. Karl M, Winter W, Taylor TD, Heckmann SM. In vitro study on passive fit in implant-supported 5-unit fixed partial dentures. Int J Oral Maxillofac Implants 2004;19:30-37.
12. Bidez MW, Misch CE. Force transfer in implant dentistry: basic concepts and principles. J Oral Implantol 1992;23:264-74.
13. Brånemark P-I, Zarb GA, Albrektsson T. Tissue-integrated prosthesis. Osseointegration in clinical dentistry. Chicago: Quintessence 1987; p. 129.
14. Stanford CM, Brand RA. Toward an understanding of implant occlusion and strain adaptive bone modelling and remodelling. J Prosthet Dent 1999;81:553-61.
15. Roberts WE. Fundamental principles of bone physiology, metabolism and loading. In: Naert I, van Steenberghe D, Worthington P, editors. Osseointegration in oral rehabilitation. An introductory textbook. London: Quintessence; 1993. p.163-4.
16. Duyck J, Naert I, Van Oosterwyck H, Ronold HJ, Naert I, Vander Sloten J, Ellingsen JE. The influence of static and dynamic loading on marginal bone reactions around osseointegrated implants: an animal experimental study. Clin Oral Implants Res 2001;12:207-18.
17. Quirynen M, Naert I, van Steenberghe D. Fixture design and overload influence marginal bone loss and fixture success in the Brånemark system. Clin Oral Implants Res 1992;3:104-11.
18. Frost HM. Wolff's law and bone's structural adaptations tomechanical usage: an overview for clinicians. Angle Orthodontist 1994;64:175-88.
19. Pilliar RM, Deporter DA, Watson PA, Valiquette N. Dental implant design-effect on bone remodelling. J Biomed Mater Res 1991;25:467-83.

Reprint request to:
Byoung Sup Sohn, d.d.s.
Department of Prosthodontics, Graduate School,
Seoul National University
28-1, Yeongun-Dong, Chongno-Gu, Seoul, 10-749, Korea
empire15@snu.ac.kr