Effects of Prosthesis Materials and Prosthesis Splinting on Peri-implant Bone Stress Around Implants in Poor-Quality Bone: A Numeric Analysis

Tong-Mei Wang, DDS, MS[1]/Liang-Jenq Leu, BS, MS, PhD[2]/Juo-Song Wang, DDS, MS[3]/Li-Deh Lin, DDS, PhD[4]

Purpose: *A 3-dimensional finite element model consisting of a bone block and 2 simulated premolar crowns supported by 2 adjacent cylindric implants without immediately surrounding cortical bone was generated and used to investigate the effects of prosthesis materials and prosthesis splinting on the peri-implant bone stress under static loads.* ***Materials and Methods:*** *The peri-implant maximum equivalent bone stress (von Mises [VM] stress) was evaluated when a vertical or a horizontal load of 1 N was applied to the center of a single resin, gold alloy, or porcelain crown, nonsplinted or splinted to the adjacent crown.* ***Results:*** *The numeric results indicated that: (1) in a single crown, no significant difference could be found in the maximum VM stress between different materials for both vertical and horizontal loading; (2) splinting the crowns reduced the maximum VM stress induced by the horizontal load, and the maximum VM stress increased about 14% for the horizontal loading when the restorative material was changed from gold alloy or porcelain to resin.* ***Discussion:*** *Under the condition of this study's analysis, prosthesis materials of a single crown have insignificant effects on the peri-implant bone stress. Splinting the crowns reduced the peri-implant bone stress under horizontal load, and gold alloy and porcelain each demonstrated less peri-implant bone stress than resin in the splinted crown situation under static horizontal load.* ***Conclusion:*** *Splinting the crowns of adjacent implants with relatively stiff restorative materials is recommended for implants surrounded by poor-quality bone.* (Int J Oral Maxillofac Implants 2002;17:231–237)

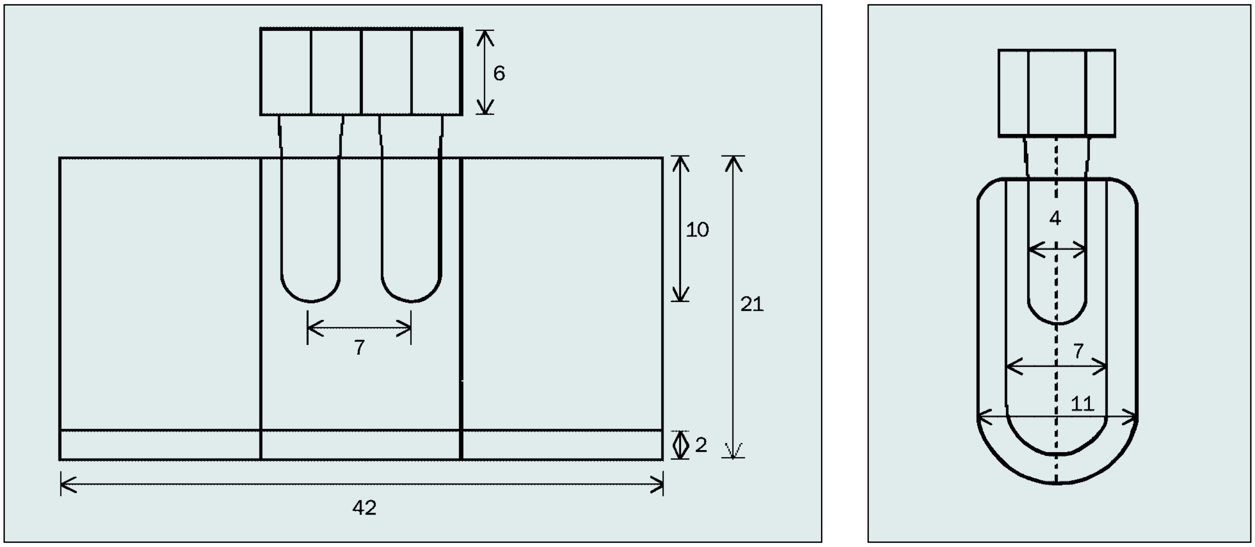
Key words: *dental implants, finite element analysis, prosthesis material*

[1]Teaching Assistant, School of Dentistry, National Taiwan University, Taipei, Taiwan, Republic of China.
[2]Associate Professor, Department of Civil Engineering, National Taiwan University, Taipei, Taiwan, Republic of China.
[3]Associate Professor, School of Dentistry, National Taiwan University, Taipei, Taiwan, Republic of China.
[4]Associate Professor, Graduate Institute of Dentistry, National Taiwan University, Taipei, Taiwan, Republic of China; Attending Staff, National Taiwan University Hospital, Taipei, Taiwan, Republic of China.

Reprint requests: Li-Deh Lin, Graduate Institute of Dentistry, College of Medicine, National Taiwan University, 1 Chang-Te Street, Taipei, Taiwan 100, Republic of China. Fax: +88-62-23831346. E-mail: lidehlin@ha.mc.ntu.edu.tw

Abstract presented at the 14th Annual Meeting of IADR/SEA Division, Singapore, 1999.

Since high success rates have been reported in clinical studies,[1,2] implant-supported fixed partial prostheses have been gradually established as a treatment option for partially edentulous patients. However, variable failure rates have been reported and "unfavorable loading conditions" was thought to be one of the reasons for implant failures.[3] Furthermore, early implant failures after surgical survival were as great as 35% in cases with bone of poor quality.[4–6] The connection between osseointegrated implants and the surrounding bone is direct and relatively stiff; therefore, it may be assumed that an impact load applied to the implants will be transferred to the bone directly, causing bone microdamage and then marginal bone loss.[3] Thus, resilient



Figs 1a and 1b *(Left)* Lateral view and *(right)* mesial view of the 3-dimensional finite element model. All measurements are in millimeters.

occlusal materials such as acrylic resin[7,8] or intramobile elements as used in the IMZ implant system[9] (Interpore International, Irvine, CA) have been recommended, especially in patients with inadequate marginal cortical bone, to reduce the impact effects arising from masticatory forces.

Misch[10] has also suggested a "progressive loading" protocol whenever implants are placed into bone of poor quality. In this protocol, initial provisional resin restorations are used to splint the implants together, thereby reducing stress from the biomechanical standpoint.[10] However, the effects of these resilient materials are still controversial[7,9–13] and many complications have been reported clinically, eg, resin wear, resin fracture, and screw loosening or fracture. In addition, when fixed partial dentures were used, it was suggested that stiff prosthesis materials might distribute the stress more evenly to the abutments and implants.[14] Using the technique of 3-dimensional finite element analysis (FEA), the purpose of this study was to investigate the effects of different prosthesis materials for a single crown or splinted crowns on the peri-implant bone stress around implants in poor-quality bone under static loading.

MATERIALS AND METHODS

Model Design

A 3-dimensional model simulating a mandibular segment with 2 premolar crowns supported by 2 adjacent cylindric implants was generated using I-DEAS MS 6.0 finite element analysis software (Structural Dynamics Research, Milford, OH). The bone model, 42 mm long, 11 mm wide, and 21 mm high, consisted of a cancellous core surrounded by a 2-mm cortical layer except the upper surface (ie, no cortical bone around the neck of implants). This model was used to simulate a condition of poor-quality bone, which could benefit from the use of resilient restorative materials according to the literature.[7,10] The mesial and distal section planes were not covered by cortical bone (Figs 1a and 1b).

The 2 titanium implants were modeled as 2 solid cylinders, 10 mm long and 4 mm in diameter, corresponding to the dimensions of the Spline implant (Sulzer Calcitek, Carlsbad, CA). They were placed in the bone block 7 mm apart (Fig 1a). Two titanium abutments attached to the implants were 3 mm high, and their diameter widened from 4 mm at the implant-abutment junction to 6 mm at the abutment-superstructure junction. To simulate the 2 premolar crowns roughly, simplified superstructures were modeled as 2 hexagonal columns 6 mm high and 4 mm wide. The abutment screws and retaining gold screws were ignored. Six FEA models were generated according to the 2 parameters: *(1)* crowns splinted or not, *(2)* different restorative materials: resin, gold alloy, or porcelain.

Material Properties

All materials used in the models were considered as homogeneous, isotropic, and linearly elastic. Their elastic properties obtained from literature sources are listed in Table 1. All interfaces in the models were assumed to be fully bonded. Thus, complete osseointegration between the implants and the bone structure was simulated, and the friction of each interface in the implant prosthesis was ignored.

Table 1 Properties of Materials Utilized in the Finite Element Models

	Modulus of elasticity (MPa)	Poisson's ratio
Titanium[13,26]	110,000	0.35
Cortical bone[13]	15,000	0.30
Cancellous bone[13,26]	1,500	0.30
Gold alloy[27]	96,600	0.35
Resin[20]	2,700	0.35
Porcelain[20]	68,900	0.28

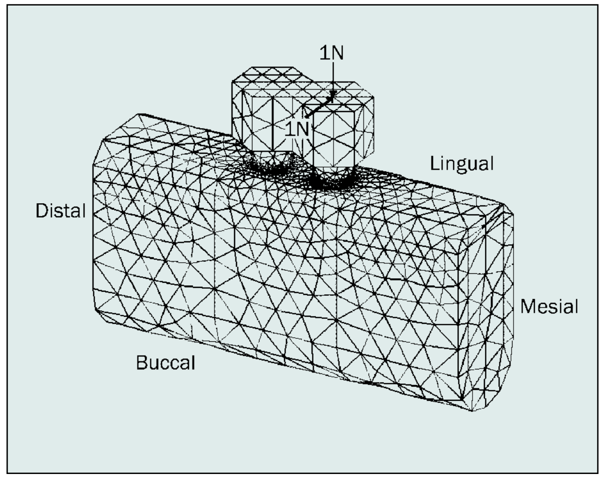


Fig 2 The final mesh of the model after the convergence test. A vertical or horizontal load of 1 N was applied to the center of the mesial crown.

Elements and Nodes

All models were meshed with 4-node tetrahedral solid elements, and finer meshes were generated at the cervical area of implants to enhance the accuracy (Fig 2). After testing for convergence with mesh refinement, the nonsplinted model had 26,078 elements and 5,126 nodes, while the splinted model had 20,916 elements and 4,224 nodes.

Boundary and Loading Conditions

All of the models were restrained in all directions on the mesial and distal border surfaces of the bone block to simulate the clinical situation.[15] Clinically, there were many variations in the direction and the magnitude of occluding force, which could influence the results. However, most forces on the posterior teeth could be resolved into 2 components along axial and buccolingual directions. And since all materials were considered to be linearly elastic, the stress in the model would increase proportionally with the applied load. With the maximum von Mises (VM) stress induced by unit loads known, the stress generated by loads in the range of the occlusal forces could be deduced. Thus, as suggested in a previous study,[13] no attempt was made to use a particular occlusal load. Stress may be overestimated when loads are applied to 1 crown instead of both crowns; however, the worst condition of loading transfer was of concern. Static loads of 1 N were applied vertically or horizontally (in the buccolingual direction) to the center of the occlusal surface on the mesial crown of each model (Fig 2).

Solution

Analysis of each loading condition on each model was performed by the I-DEAS software program. The maximum principal stress, minimum principal stress, and VM stress distribution within the bone were recorded.

RESULTS

The maximum VM stress, the highest maximum principal stress, and the lowest minimum principal stress in the bone of each model under both loading cases are listed in Table 2. Since the tendency and the percentage of changes were similar for VM stress and principle stresses, only VM stress is reported. For better understanding, the VM stress distribution in the bone of each model was shown in the mesiodistal section surface of the lingual half of the bone block, and only the middle portion surrounding the 2 implants is displayed (Figs 3 and 4). The highest VM stress in the bone appeared near the cervical area of the loaded implant in each model, regardless of whether it was splinted or not, type of prosthesis materials, or load direction.

In the nonsplinted models, (ie, load on a single crown), no significant difference could be found in the maximum VM stress of the bone around the implants when different prosthesis materials were used. Stress distribution area in the vertically loaded models was extended to the apex of the implant (Fig 3a), while it was more restricted to the cervical area

Table 2 Peri-implant Bone Stress (MPa)*

	Nonsplinted model		Splinted model	
	Vertical	**Horizontal**	**Vertical**	**Horizontal**
Maximum VM stress				
Gold alloy	2.39E-02	2.13E-01	3.04E-02	1.20E-01
Porcelain	2.39E-02	2.13E-01	3.03E-02	1.21E-01
Resin	2.39E-02	2.13E-01	2.98E-02	1.37E-01
Maximum principal stress				
Gold alloy	6.71E-03	2.55E-01	5.87E-03	1.52E-01
Porcelain	6.71E-03	2.55E-01	5.88E-03	1.53E-01
Resin	6.71E-03	2.55E-01	6.06E-03	1.72E-01
Minimum principal stress				
Gold alloy	−3.16E-02	−2.90E-01	−4.24E-02	−1.67E-01
Porcelain	−3.16E-02	−2.90E-01	−4.24E-02	−1.68E-01
Resin	−3.16E-02	−2.90E-01	−4.17E-02	−1.91E-01

* Static loads of 1 N applied in each case.

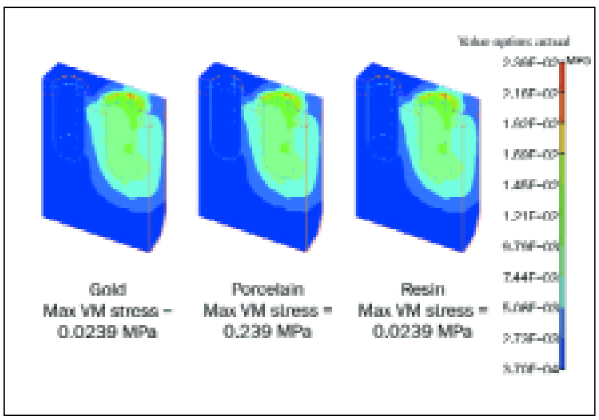


Fig 3a VM stress distribution in the peri-implant bone of the nonsplinted crown models under 1 N vertical load.

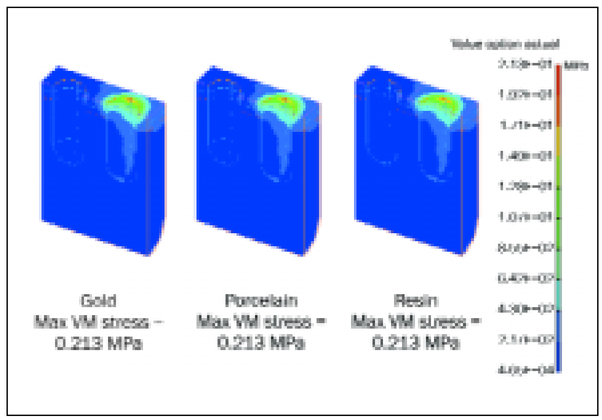


Fig 3b VM stress distribution in the peri-implant bone of the nonsplinted crown models under 1 N horizontal load.

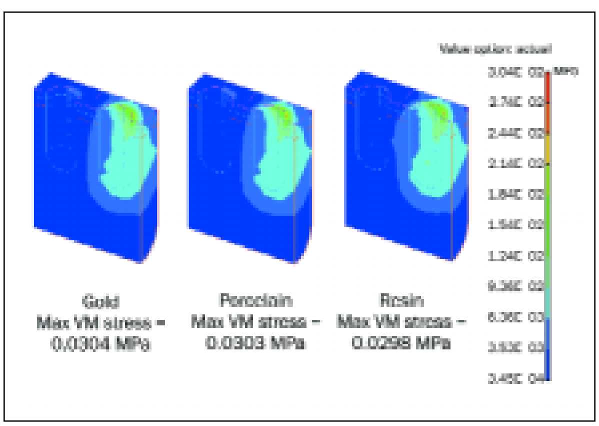


Fig 4a VM stress distribution in the peri-implant bone of the splinted crown models under 1 N vertical load.

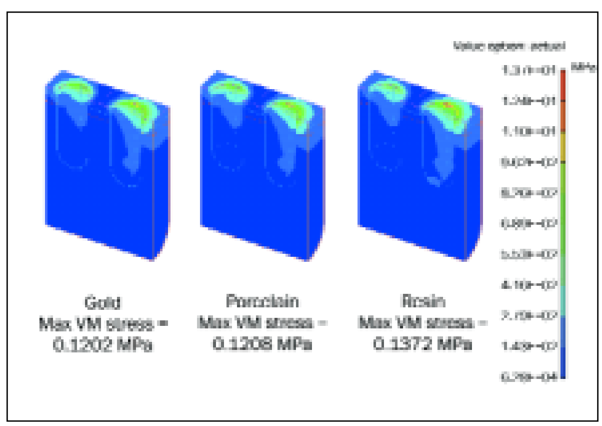


Fig 4b VM stress distribution in the peri-implant bone of the splinted crown models under 1 N horizontal load.

of the implant in the horizontally loaded models (Fig 3b). The maximum VM stress in the bone induced by 1 N horizontal load was about 8.91 times as much as that induced by 1 N vertical load.

However, in the splinted models, the results were slightly different. The area of stress distribution was extended from the loaded implant to the unloaded implant under each loading condition (Figs 4a and 4b). Under both horizontal and vertical loads, the greatest difference in the maximum VM stress occurred between the models using resin and gold alloy as the prosthesis material (Table 2). While the maximum VM stresses were intermediate in the models using porcelain as the prosthesis material, the values were closer to those of the gold alloy models under both loading situations (Table 2). Under 1 N vertical load, the maximum VM stress of bone was decreased by about 2% when the material of the splinted crowns was changed from gold alloy to resin. However, under 1 N horizontal load, the value was increased about 14% in resin versus gold alloy. Compared with the results of nonsplinted models, the maximum VM stress was increased about 24% to 27% under 1 N vertical load, but decreased about 36% to 44% under 1 N horizontal load in the splinted models (Table 2).

DISCUSSION

It has been theorized that the actual bone strain around implants may initiate a chain of bone-remodeling events. For example, Frost[16] established a mechanical adaptation chart relating trivial loading, physiologic loading, overloading, and pathologic overloading zones to ranges of microstrain. The present study employed the 3-dimensional FEA technique to investigate the effects of different occlusal materials on the peri-implant maximum VM stress in a mandibular posterior segment bone block. While computer modeling offers many advantages over other methods in considering the complexities that characterize real clinical situations, a computer simulation such as FEA operates with several simplifications related to material properties, geometry, load, and interface conditions. Since the FEA results are sensitive to these model parameters, when considering the clinical situation a qualitative comparison between different models would seem to be recommended rather than emphasizing the quantitative data from FEA.

Regarding the condition of applied loads, there are 2 types of FEA: static analyses and dynamic analyses. A static analysis was adopted in this study since it is considered suited to simulation of the slow mandibular movements as seen with clenching and grinding,[13] and these activities have been reported to be one of the main factors that can potentially damage bone and implants.[17,18] If higher mandibular velocities are involved, a dynamic analysis may be required.[3,13] However, it has been questioned whether mandibular velocities are fast enough to have any impact effects.[14]

In this study, a model of a mandibular segment containing 2 implant-abutment units and prostheses was used. In the literature, similar bone models have been utilized and restrained in all 3 directions at the nodes of the mesial and distal surfaces[19,20] or the nodes of the bottom of bone blocks.[13] The former seemed to correspond to the mandibular situation better; therefore, it was adopted for this study. In a preliminary study, the results of this model have been compared with the whole human mandibular model, with restraints at the locations of major jaw muscle insertions.[21] The differences in VM stress between the 2 models were less than 1%. This observation corresponds to the results from the study done by Teixeira and coworkers,[19] which suggested no significant difference in stress values and stress distribution between models of different bone lengths if the length was sufficient. To conserve calculation time and computer memory, this model, which has fewer elements and nodes, was used. The distribution pattern of VM stress also showed that the length of this model was reasonable because little stress was transmitted to the mesial and distal ends of the model (Figs 3 and 4).

The effect of different prosthesis materials on the peri-implant maximum VM stress has been studied in "normal"-quality bone in previous FEA studies.[11,13] Very few studies have compared the effect of different prosthesis materials on bone stress when the implants were placed into bone without cortical bone around the neck.[22] During implant surgery, the surgeon may remove the thin alveolar ridge to create a wider platform for implant placement or countersink in the cortical bone around the implants, which may result in no cortical bone around the implants after initial healing. This is probably one of the worst implant beds for loading and, in fact, one of the clinical situations in which resilient prosthesis materials instead of rigid ones have been recommended to reduce peri-implant bone stress.[10,23] However, it was not possible to demonstrate the benefit of using resin, in comparison to gold alloy or porcelain, as a prosthesis material for reducing the maximum peri-implant VM stress in this "poor" bone condition.

The obtained results were consistent with the previous FEA studies, which could not demonstrate a protective role of resin for the implant-bone interface.[13,20,24] For a single implant-supported crown (the nonsplinted model), changing the prosthesis material from gold alloy or porcelain to resin did not result in significant change in the maximum peri-implant VM stress under either horizontal or vertical load. This may be the result of the fact that the total energy transferred through the abutment-implant interface and then to the implant-bone interface is similar, although crowns of different materials might show different amounts of displacement under a load. However, for the splinted crowns, slight differences in the maximum VM stress were observed when different prosthesis materials were used.

In the splinted models compared to the nonsplinted models, a significant decrease in stress under horizontal load for the 3 prosthesis materials was seen. This may be because the nonloaded adjacent implant shared a part of the stress from the loaded implant. The amount of stress reduction would depend on the rigidity of splinting. With less rigidity, the splinted resin crowns likely transferred less stress to another implant and thus a greater VM stress was observed at the loaded implant. Under vertical load situations, although the phenomenon of stress-sharing of the nonloaded implant was noted, splinting slightly increased the maximum peri-implant VM stress. This may be the result of the fact that the vertical load applied at the center of the mesial crown no longer induced evenly distributed bone stress around the implant, but caused a concentration of bone stress at the implant-bone interface away from the splinting joint. However, this situation is the worst-case condition because loads are applied only rarely on a single crown during mastication.

Based on the above discussion, splinting is still recommended when implants are placed in bone of poor quality, since bone stress is reduced significantly when the implant is under the more detrimental horizontal loads.[25] From the present study, although the use of a resilient occlusal material for reduction of bone stress under static vertical or horizontal loads is not supported, it is not possible to exclude the possibility that a resilient occlusal material such as resin may absorb the impact load transferred to the implant-bone interface when a higher speed of mandibular movement during mastication is involved. In fact, resins have been shown to reduce impact loads transferred to prostheses under impact conditions.[11,12] Further studies are necessary to clarify whether mandibular speed in the physiologic range will cause any impact effects on bone stress.

CONCLUSION

The effects of different prosthesis materials and prosthesis splinting on peri-implant bone stress were investigated using the 3-dimensional FEA technique. The results indicated that the difference in peri-implant bone stress was very minor when different materials were used for a single (nonsplinted) implant prosthesis under static loads. In the case of a splinted prosthesis, the maximum peri-implant bone stress increased slightly when the prosthesis material was changed from gold alloy or porcelain to resin under a static horizontal load. Thus, under the conditions of this analysis for implants surrounded by cancellous bone, no obvious benefit of resin single crowns on the peri-implant bone stress could be found, while splinting the crowns of adjacent implants with relatively stiff restorative materials could be recommended.

ACKNOWLEDGMENTS

This work was supported by National Science Council, Republic of China, NSC-89-2314-B-002-166.

REFERENCES

1. Naert I, Quirynen M, van Steenberghe D, Darius P. A six-year prosthodontic study of 509 consecutively inserted implants for the treatment of partial edentulism. J Prosthet Dent 1992;67:236–245.
2. Lekholm U, van Steenberghe D, Hermann 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.
3. Brunski JB. Biomaterials and biomechanics in dental implant design. Int J Oral Maxillofac Implants 1988;3:85–97.
4. Jemt T, Linden B, Lekholm U. Failures and complications in 127 consecutively placed fixed partial prostheses supported by Brånemark implants: From prosthetic treatment to first annual checkup. Int J Oral Maxillofac Implants 1992;7:40–44.
5. Friberg B, Jemt T, Lekholm U. Early failures in 4,641 consecutively placed Brånemark dental implants: A study from stage 1 surgery to the connection of completed prostheses. Int J Oral Maxillofac Implants 1991;6:142–146.
6. Jaffin RA, Berman CL. The excessive loss of Brånemark fixtures in type IV bone: A 5-year analysis. J Periodontol 1991;62:2–4.
7. Skalak R. Biomechanical considerations in osseointegrated prostheses. J Prosthet Dent 1983;49:843–848.
8. Brånemark P-I. Osseointegration and its experimental background. J Prosthet Dent 1983;50:399–410.
9. Babbush CA, Kirsch A, Mentag PJ, Hill B. Intramobile cylinder (IMZ) two-stage osteointegrated implant system with the intramobile element (IME): Part I. Its rationale and procedure for use. Int J Oral Maxillofac Implants 1987;2:203–216.

10. Misch CE. Progressive bone loading. In: Misch CE (ed). Contemporary Implant Dentistry, ed 2. St Louis: Mosby, 1999:595–608.
11. Davis DM, Rimrott R, Zarb GA. Studies on frameworks for osseointegrated prostheses: Part 2. The effect of adding acrylic resin or porcelain to form the occlusal superstructure. Int J Oral Maxillofac Implants 1988;3:275–280.
12. Gracis SE, Nicholls JI, Chalupnik JD, Yuodelis RA. Shock-absorbing behavior of five restorative materials used on implants. Int J Prosthodont 1991;4:282–291.
13. Stegaroiu R, Kusakari H, Nishiyama S, Miyakawa O. Influence of prosthesis material on stress distribution in bone and implants: A 3-dimensional finite element analysis. Int J Oral Maxillofac Implants 1998;13:781–790.
14. Lundgren D, Laurell L. Biomechanical aspects of fixed bridgework supported by natural teeth and endosseous implants. Periodontology 2000 1994;4:23–40.
15. Meijer HJ, Kuiper JH, Starmans FJ, Bosman F. Stress distribution around dental implants: Influence of superstructure, length of implants, and height of mandible. J Prosthet Dent 1992;68:96–102.
16. Frost HM. Bone "mass" and the "mechanostat": A proposal. Anat Rec 1987;219:1–9.
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;3:104–111.
18. Rangert B, Krogh PH, Langer B, Van Roekel N. Bending overload and implant fracture: A retrospective clinical analysis. Int J Oral Maxillofac Implants 1995;10:326–334.
19. Teixeira ER, Sato Y, Akagawa Y, Shindoi N. A comparative evaluation of mandibular finite element models with different lengths and elements for implant biomechanics. J Oral Rehabil 1998;25:299–303.
20. Sertgoz A. Finite element analysis study of the effect of superstructure material on stress distribution in an implant-supported fixed prosthesis. Int J Prosthodont 1997;10:19–27.
21. Wang TM. 3-dimensional finite element analysis of peri-implant bone stress with implant prostheses under dynamic and static loadings [thesis]. Taipei, Taiwan: National Taiwan University, 2000.
22. Papavasiliou G, Kamposiora P, Bayne SC, Felton DA. 3-dimensional finite element analysis of stress-distribution around single tooth implants as a function of bony support, prosthesis type, and loading during function. J Prosthet Dent 1996;76:633–640.
23. Lewis S, Parel S, Faulkner R. Provisional implant-supported fixed restorations. Int J Oral Maxillofac Implants 1995;10:319–325.
24. Ismail JY, Kukunas S, Pipko D, Ibiary W. Comparative study of various occlusal materials for implant prosthodontics [abstract]. J Dent Res 1989;68:962.
25. Isidor F. Loss of osseointegration caused by occlusal load of oral implants. A clinical and radiographic study in monkeys. Clin Oral Implants Res 1996;7:143–152.
26. Benzing UR, Gall H, Weber H. Biomechanical aspects of two different implant-prosthetic concepts for edentulous maxillae. Int J Oral Maxillofac Implants 1995;10:188–198.
27. Holmes D, Haganman CR, Aquilino SA. Deflection of superstructure and stress concentrations in the IMZ implant system. Int J Prosthodont 1994;7:239–246.