3-D FEA of three different single tooth abutments : Cement-retained Vs Screw-retained

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Ⅰ. Introduction

The osseointegrated implant has been used as a safe and useful tool in prosthetic dentistry[1].

When osseointegration concept was first introduced to dentistry, the object for treatment was limited only to restoring the masticatory function of endentulous patients[2]. Now, With the high success rate of osseointegration[3], implants are being widely used to restore the partial edentulism[4-7] and single tooth missing[8-10].

As esthetics is very important in single tooth replacement[11], numerous system have been developed[12] and manufactured for that purpose. CeraOne™ (NobelBiocare. Sweden) is a basic abutment of Branemark system[13], CerAdapt™ (NobelBiocare. Sweden) is a newly developed all-ceramic abutment[14] and the UCLA system abutment is a castable abutment[15,16]. All of these systems have been used widely with high success rate.

CeraOne™ abutment is the first one to be produced on a commercial scale by Nobelpharma.[1] It is composed of titanium abutment, gold screw and gold cylinder[17]. In this system, the weakest part is the abutment screw and success rate was reported as 97.3% for 3 - 4 years[18]. Its advantages are precisely-fitting prefabricated components and adequate esthe-tics. In spite of these advantages, screw loosening is a serious complication[18].

CerAdapt™, a newly developed all-ceramic abutment, is made of densely sintered aluminum oxide[19]. In this system, the abutment screw, like the CeraOne system, is made of gold. Compared with gold or titanium, CerAdapt has adequate strength for use as an abutment[20]. In addition, it was reported that, as this system has no metal component, excellent esthetics can be expec-ted[21].

The UCLA abutment is the system by which conventional abutment can be skipped and the superstructure is connected directly to the implant hex. This system is composed of castable plastic pattern and abutment screw[15]. UCLA system has a subgingival margin allo-wing this abutment to be used in cases with mi-nimal interocclusal clearance with proper esthe-tics[22]. With this advantage, many systems were developed following this concept. A high success rate was reported (4 years: 95.8%)[16]. In this system, two kinds of materials are used for the abutment screw, gold alloy and titanium alloy. When titanium alloy is used, because its material property is stronger than the titanium fixture, the fixture can be damaged before the abutment screw. Thus, gold abutment screws have come into favor because of their failsafe characteristics[16].

Some dentists prefer the screw-retained prosthesis to the cement-retained prosthesis in view of its "retrievability"[23]. Clinicians who prefer the screw-retained prosthesis claim that once the screw is loosened, the prosthesis is already disconnected from the implant. This can protect the implant from being overloaded with stress[23]. Clinicians who prefer the cement-retained prosthesis insist that this system has many advantages over the screw-retained. These include passivity, broad occlusal surface which allows for a favorable stress distribution, preserving the intact occlusal surface and esthetics[23,25].

Superstructures(abutment and prosthesis) on the implant must be designed to avoid the undesirable responses, such as, the resorption of bone. Also, superstructures must be able to preserve osseointegration between implant and bone and tolerate occlusal stress[26].

The choice between the screw-retained prosthesis and the cement-retained prosthesis has heretofore been made merely on the grounds of the clinicians, therefore an objective analysis of the occlusal stress of these systems is required.

There are many methods for analyzing stress. Among these, finite element analysis is appropriate for the stress analysis when external force is loaded on complex internal structures. With this method, it is possible to analyze the stress distribution of implants with the different abutment and prosthesis and of the surroundings[27,28]. It is possible to reproduce complex structures accurately and change the model and design with ease. Also, it is possible to analyze the distribution of stress on components of internal structures in one-dimension, two-dimension and three-dimension[29,30].

In this study, the distributions of stress in abutments which are widely used for single tooth replacement, CeraOne™, CerAdapt™, UCLA type abutment, were analyzed by the use of FEA. Each system was fitted with a screw-retained prosthesis and a cement-retained prosthesis to analyze the stress distribution on these two types of prostheses. Stress induced by vertical, oblique, horizontal occlusal forces loaded on the superstructures was analayzed.

Ⅱ. Materials and Methods

(1) Geometry

The I-DEAS(SASI. U.S.A) was the finite element model designing software used for constructing the model. During the designing of the models, all these softwares were mounted on Iris Indigo workstations. To evaluate the internal stress of implants and bone, each component was designed separately. Each model was designed to represent the following components. A threaded fixture with 3.75mm in diameter and 10mm in length was used in all models. In the screw-retained prosthesis, the screw-hole was covered with feldspathic porcelain for convenience.

Model 1: A fixture was connected to a CeraOne abutment with 1mm collar using a CeraOne gold screw and then a PFG crown which was made as a single unit ~~with~~ a CeraOne gold cylinder was cemented on the CeraOne abutment by use of zinc phosphate cement(photo 1).

Model 2: A fixture was connected to a CeraOne abutment with 1mm collar. A PFG crown which was made as a single unit with a CeraOne gold cylinder was the connected using a CeraOne gold screw(photo 11).

Model 3: A fixture was connected to a CerAdapt abutment which had been prepared with a 6 degree taper using a CeraOne gold screw. A PFG crown was cemented on the CerAdapt abutment using of zinc phosphate cement(photo 21).

Model 4: A fixture was connected to a CerAdapt abutment on which feldspathic porcelain had been built-up using a CeraOne gold screw(photo 31).

Model 5: A fixture was connected to an internal coping made of type III gold and with a 6 degree taper using an abutment screw. Then a PFG crown was cemented on the internal coping using zinc phosphate cement(photo 41).

Model 6: A fixture was connected to a PFG crown which was composed of Au-Pd coping and feldspathic porcelain the same as conventional PFG crown using an abutment screw(photo 51).

Each model was designed with CeraOne™, CerAdapt™ and UCLA abutment system on the Branemark fixture. The size in the catalog from the manufacturer and the standard data which were obtained from 10 measurements using vernier's caliper were the references for the geometry. Diameter of the bone was 12mm and the shape of the bone was cylindrical. The thickness of the cortical bone at the level of the implant neck was assumed to be 2mm and the same thickness at the bottom of the bone block. Full osseointegration surrounding the implant was assumed. All these models were designed to reconstruct the mandibular first premolar. In models 3 and 5, the taper of prepared abutments was 6 degrees and cement space was assumed to be 40㎛. Zinc phosphate cement was the cement used in models 1, 3 and 5[23]. The threaded portions were assumed to have the symmetry of long axis[32]. Every effort was made to simulate the real size and the shape of fixture and its components. Contact surfaces between components were assumed to be initially unloaded and then in intimate contact[32]. Implants were designed to be in the center of the bone block. The number of nodes and elements of each model are presented at Table 1.

Table 1. The number of nodes and elements

Model	# of nodes	# of elements
1	10648	12840
2	10865	13608
3	10355	11928
4	10355	11928
5	10209	12288
6	9896	11760

(2) Material properties

All the components and cortical, cancellous bone were assumed to be isotropic, homogeneous and linearly elastic[33]. Table 2 shows Young's modulous and Poisson's ratio of the components, implant and bone[27-29,33].

(3) Restraints

Inferior border of the bone block was fixed in order not to occur any possible movements[33,34].

(4) Load.

The loading forces were static[28,35]. In this study, three directions were chosen[28] and the amount of the forces was standardized at 20kgf. The three directions were horizontal bite force (0°), oblique bite force (30°) and vertical bite force (90°)[33](Fig. 1).

(5) Solution

In this study, ANSYS (SASI. U.S.A) was the

Table 2. Young's modulous and Poisson's ratio

Materials	Young's modulus(GPa)	Poisson's ratio(υ)
Titanium	10.50	0.30
Type IV gold (gold screw cylinder)	98.00	0.45
Type III gold	66.00	0.33
Cancellous bone	0.49	0.30
Cortical bone	14.70	0.30
CerAdapt	107.00	0.23
Au-Pd	134.00	0.33
ZPC	13.70	0.35
Feldspathic porcelain	70.00	0.19

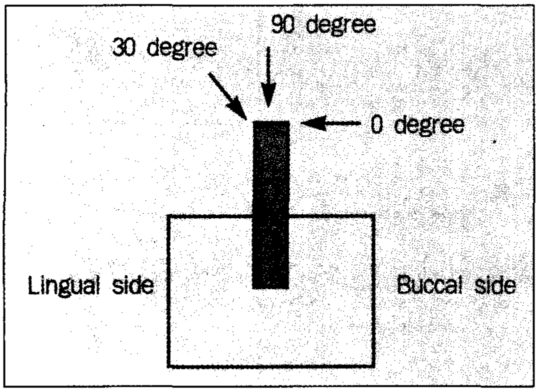

Fig. 1. Buccolingual section and applied forces(20kgf)of 3 directions

solving program used. The principal stress of each of the components were compared and analyzed. Stress distribution was presented as color differences. Using this color presenting system it was easy to evaluate the stress concentration of the models. ANSYS was the postprocessing program used in this study.

Ⅲ. Results.

The patterns of stress distribution were similar in all models. Both cement-retained (Model 1, 3, 5) and screw-retained prostheses (Model 2, 4, 6) showed stress concentration at the occlusal surface of the prosthesis. Comparing cement- retained prostheses (Model 1, 3, 5) and screw-retained prostheses (model 2, 4, 6), the former showed more fovarable stress distribution than the latter. Maximum stress was observed during horizontal bite force and minimal stress was observed during vertical bite force. Table 3 shows the maximum principal stress of implants during vertical, oblique and horizontal forces.

Table 3. The principal stress of the fixtures (Pa)

Model \ Force	Vertical	Oblique	Horizontal
1	0.32778E+08	0.10406E+09	0.24127E+09
2	0.33494E+08	0.11425E+09	0.25845E+09
3	0.32804E+08	0.11208E+09	0.25843E+09
4	0.33295E+08	0.11971E+09	0.27251E+09
5	0.34325E+08	0.10374E+09	0.23743E+09
6	0.34939E+08	0.10890E+09	0.24592E+09

1. Model 1.

Table 4 and photo 2 - 10 show the principal stress and color presentation of stress distribution when three types of loads were applied. The design of model 1 was a fixture connected to a CeraOne abutment with 1mm collar using a CeraOne gold screw. Then a PFG crown which was made as a single unit with a CeraOne gold cylinder was cemented on the CeraOne abutment using zinc phosphate cement. In this model, stress distribution was relatively even. When vertical bite force was loaded, the principal stress occurred at the occlusal surface of the prosthesis and at the neck of the fixture. The bone in contact with the neck of the implant showed maximum stress concentration. Table 4 shows principal stresses decreasing in the order of horizontal, oblique and vertical loads. Thses results are similar to those reported in previous articles[33].

2. Model 2.

Table 5 and photo 12 - 20 show the principal stress and color presentation of stress distribution when three types of loads were applied. The design of model 2 was a fixture connected to a CeraOne abutment with 1mm collar and a PFG crown which was made as a single unit with a CeraOne gold cylinder using a CeraOne gold screw. Model 2 shows that stress distribution pattern similar to model 1, but the amount of the principal stresses seen in the implant and the surrounding bone is greater. It is interesting to note that the principal stresses in the screw, gold cylinder and prosthesis of model 2 shown in

Table 4. The principal stress of components in model 1 (Pa)

Components \ Force	Horizontal	Oblique	Vertical
Fixture	0.24127E+09	0.10406E+09	0.32778E+08
Bone	0.12308E+09	0.45920E+08	0.98690E+07
CeraOne abutment	0.22987E+09	0.97069E+08	0.24132E+07
Screw	0.14325E+09	0.58374E+08	0.60428E+07
Cement	0.13728E+09	0.60247E+08	0.11676E+07
Gold cylinder	0.19759E+09	0.88213E+08	0.67832E+07
Prosthetic structure	0.12161E+09	0.49531E+08	0.71529E+07

Table 5. The principal stress of components in model 2 (Pa)

Components \ Force	Horizontal	Oblique	Vertical
Fixture	0.25845E+09	0.11425E+09	0.33494E+08
Bone	0.12337E+09	0.46006E+08	0.10048E+08
CeraOne abutment	0.22413E+09	0.99393E+08	0.91925E+06
Screw	0.11257E+09	0.42794E+08	0.21340E+07
Gold cylinder	0.17327E+09	0.78894E+08	0.88667E+06
Prosthetic structure	0.10275E+09	0.43868E+08	0.17205E+07

Table 4 and 5 are lower than in model 1. It means that model 2 received lesser stress on the superstructure but greater stress on the implant and the surrounding bone compared with model 1. In short, screw-retained CeraOne prosthesis is biomechnically less favorable than cement-retained CeraOne prosthesis[26].

3. Model 3.

Table 6 and photo 22 - 30 show the principal stress and color presentation of stress distribution when three types of loads were applied. The design of model 3 was a fixture connected to a CerAdapt abutment which had been prepared with a 6 degree taper using a CeraOne gold screw. Then a PFG crown was cemented on the CerAdapt abutment using zinc phosphate cement. Model 3 shows that stress distribution pattern similar to those of model 1 and model 2. When vertical bite force was loaded, the principal stress occurred at the occlusal surface of the prosthesis and the neck of the fixture. The area of bone contacting the neck of the implant showed the greatest concentration of stress. But the amount of stress was higher in model 3 than in model 1, 2.

4. Model 4.

Table 7 and photo 32 - 40 show the principal stress and color presentation of stress distribution when three types of the load were applied. The design of model 4 was a fixture connected to a erAdapt abutment on which feldspathic porcelain had been built-up using a CeraOne gold screw. The color presentations showed that the stress value on the whole model was higher than in models 1, 2 and 3. Similar to the relationship between model 1 and model 2, model 4 has higher stress concentration on implant and bone compared with the model 3. On the occlusal surface, area where high stress value was induced was broader than

Table 6. The principal stress of components in model 3 (Pa)

Force / Components	Horizontal	Oblique	Vertical
Fixture	0.25843E+09	0.11208E+09	0.32804E+08
Bone	0.12371E+09	0.46231E+08	0.98848E+07
CerAdapt abutment	0.24478E+09	0.10631E+09	0.88459E+07
Screw	0.92555E+08	0.36435E+08	0.49150E+07
Cement	0.17981E+09	0.80316E+08	0.16863E+07
Prosthetic structure	0.13954E+09	0.57055E+08	0.75991E+07

Table 7. The principal stress of components in model 4 (Pa)

Force / Components	Horizontal	Oblique	Vertical
Fixture	0.27251E+09	0.11971E+09	0.33295E+08
Bone	0.12402E+09	0.46352E+08	0.10030E+08
CerAdapt abutment	0.20217E+09	0.82157E+08	0.62938E+07
Screw	0.95731E+08	0.35570E+08	0.52869E+07
Porcelain	0.12267E+09	0.71688E+08	0.37858E+08

in model 3, but the value of the principal stress was lower than in model 3.

5. Model 5.

Table 8 and photo 42 - 50 show the principal stress and color presentation of stress distribution when three types of the load were applied. The design of Model 5 was a fixture connected to an internal coping made of type III gold with a 6 degree taper using an abutment screw. A PFG crown was cemented on the internal coping using zinc phosphate cement. The stress distribution of the whole model is similar to that of model 1. The stress value on the superstructure is higher than in model 1. In considering stress distribution, model 5 is more disadvantageous than model 1, but is more advantageous than model 3.

6. Model 6.

Table 9 and photo 52 - 60 show the principal stress and color presentation of stress distribution when three types of the load were applied. The design of Model 6 was a fixture connected to a PFG crown composed of Au-Pd coping and feldspathic porcelain the same as conventional PFG crowns using an abutment screw. Model 6 shows the highest stress values among all the models. The principal stress value on the implant and bone is the highest among all the models. In the bone, stress is concentrated in a broader area contacting the neck of implant compared to other models.

Ⅳ. Discussion.

The osseointegrated implant developed by Brånemark is considered a safe and useful tool in restorative dentistry[3-7]. When this concept was first introduced, the main object of treatment was restoring masticatory function. As times went on, clinicians have gone on to focus on esthe-tics.

Thanks to the high success rate of osseointe-

Table 8. The principal stress of components in model 5 (Pa)

Components \ Force	Horizontal	Oblique	Vertical
Fixture	0.23743E+09	0.10374E+09	0.34325E+08
Bone	0.12353E+09	0.46108E+08	0.10036E+08
UCLA abutment	0.23114E+09	0.10000E+09	0.25415E+07
Screw	0.22301E+09	0.82734E+08	0.47368E+07
Cement	0.23009E+09	0.99862E+08	0.15388E+07
Prosthetic structure	0.13422E+09	0.56484E+08	0.14624E+08

Table 9. The principal stress of components in model 6 (Pa)

Components \ Force	Horizontal	Oblique	Vertical
Fixture	0.24592E+09	0.10890E+09	0.34939E+08
Bone	0.12365E+09	0.46134E+08	0.10214E+08
UCLA abutment	0.23017E+09	0.10012E+09	0.13825E+07
Screw	0.23155E+09	0.83236E+08	0.56158E+07
Prosthetic structure	0.12884E+09	0.55878E+08	0.17053E+08

gration, this concept of treatment has expanded to include treatment of partial edentulism[4-7] and cases with single tooth missing[8-10]. Using osseointegrated implants, clinicians have been able to meet patients' expectations, such as esthetics.

It has been reported that the etiology of cases with single tooth missing is external trauma, root fracture and congenital missing, in that order. This means that the mean age of patients treated using implants has been lowered[18]. During single tooth replacement, one of the most serious complications reported appear to be related to the loosening of abutment screws[37,38].

A number of companies have developed a variety of systems that can be used for single tooth replacement[12]. Among these systems, CeraOne™, CerAdapt™ UCLA system are the ones most frequently used.

A new prosthodontic concept for single tooth implants, CeraOne™, was developed in 1991[25] in response to increasing demands from patients and dentists regarding abutment screw stability and esthetics. CeraOne prosthodontic concept is simple to use because of prefabricated components, and favorable esthetic and clinical short-term results were achieved[18]. For single tooth restorations, there are two different ways to connect a crown to an implant ; either by a tightened screw[36] or by cementation[13]. A low failure rate for implants has been reported for single tooth replacement. Cementation caused problems related to excess or shortage of cement that could be difficult to diagnose or to remove[13]. No clinical signs of loosening have been reported since the adjunct of a torque controller that provides a tightening force of 32 N/cm to the abutment gold fixation screw. Advantages of having the titanium abutment include the fact that there is now a titanium-titanium interface at the level of the implant fixture, preventing galvanism and corrosion[41].

The development of high alumina ceramic

materials[14] has allowed the fabrication of the more esthetic, all-ceramic single tooth abutment. The strength and mode of failure of all-ceramic implant abutments were compared to conventional metal-ceramic implant abutments[20]. All-ceramic-core restorations can solve many of the esthetic problems associated with implant-supported prosthesis[40].

Prefabricated patterns machined to fit precisely or the top of implant fixtures (and fixture analogues, Calif. Patent Pending were developed). These plastic cylinders, called "UCLA" abutments[15] which precludes the use of transmucosal abutment and gold-palladium cylinders, has initially proven to be successful. This technique is valuable in overcoming problems of limited interocclusal clearance, interproximal distance, implant angulation, and soft tissue response. Another major advantage of the UCLA abutment is that of improved esthetics. The 4-year success rates is 95.8%[16].

Screw-retained restorations are "retrievable" implying that cemented prostheses are not. But clinicians claim that cemented fixed prosthesis can be removed when a soft cement has been used for fixation. Crown and bridge cement materials do not adhere to titanium, and natural undercuts do not exist. As a result, a harder cement may be used on implants than on teeth, and the prosthesis can still be readily removed. To date, it has been reported that clinicians have never encountered a root-form implant abutment fracture or an implant loosening while removing a cemented prosthesis. Loosening of the screw was once believed to protect the implant under the loose crown, but to the contrary, it has been shown to increase the incidence of significant complications, including cantilever effects[24]. It is impossible to fabricate a truly passive screw retained dental restoration. When attempting to fabricate a prosthesis with zero tolerance for error, too may variables are out of the dentist's control[23]. Fatigue failure of the screw components is a complication that occurs with long-term restorations[24]. Cemented prostheses have no small diameter components and no metal-to-metal wearing. Therefore, similar complications are rarely observed.

In a cement-retained implant-supported prosthesis, the occlusal surface is intact, and the implant body may be loaded in an axial direction, which decreases the load on crestal bone. The occlusal load on a screw-retained restoration is inevitably in the region of the screw. Occlusal adjustments on the head of screw may destroy the screw notch required to retrieve the prosthesis[23].

Stress distribution patterns depended on material and design. CeraOne abutment is made of titanium, CerAdapt is made of aluminum oxide and UCLA abutment is made of Type III, or Au-Pd alloy. Each abutment comes in screw-retained type and cement-retained type. It was thus necessary to analyze the stress distribution of these systems. There was a stress concentration on the neck of the implant and bone under horizontal loads[32]. In this study, stress distribution patterns of 6 models were analyzed using the finite element method.

In this study, stress was concentrated on the occlusal surface of the superstructure and the neck of the implant under vertical bite force. The occlusal surface is the area where the force was loaded directly and the neck of implant is the area of the smallest diameter in the implant body[33]. It was observed that cement-retained prostheses (Model 1, 3, 5) have lower stress values than screw-retained prostheses (Model 2, 4, 6). Existence of cement in the former models allowed favorable passivity that can be advantageous for load distribution compared with the latter models tightened using screws[23]. Similar to reported articles[33], in the fixtures, maximal principal stress was observed at the neck of implant. The stress value in the area where the abutment contacted with the top of implant is lower than that seen in the surrounding area. The patterns of stress distribution in the bone were similar. The area in contact with the neck of the implant showed the greatest principal stress. Among the three directional forces, the stress value induced by horizontal force was the greatest and stress was concentrated around the neck of implant, opposite to the direction of the force. Horizontal force induced the highest stress values and vertical force induced the lowest stress values.

Comparing model 1 with 3, the stress value on the occlusal surface of the latter is higher than in the former. In model 3, the area where the stress was concentrated is larger than in model 1. Also, in the bone, the position of maximal principal stress is the area in contact with the neck of implant, and the stress value was higher and the area of stress concentration was broader in model 3 than in model 1. The reason for this is the CerAdapt abutment with a 6 degree taper which is shorter than CeraOne abutment and has lesser surface area. Thus,. model 3 has less favorable stress distribution characteristics compared to model 1.

Comparing model 4 with 3, the difference between cement-retained prosthesis and screw-retained prosthesis is more clear than in model 1 and 2. Model 4 has higher stress values along the entire model than model 3, and the stress is concentrated broadly on entire occlusal surface. Model 4 also shows high stress values at the neck of the implant. Because there is nothing to aid in the distribution of stress in model 4.

Comparing model 5 with 1, there is a similar pattern of stress distribution. But in model 5, the higher stress values are observed on the occlusal surface compared to model 1. But the pattern of stress distribution of model 5 is more favorable than that of model 3.

Comparing model 6 with 5, the difference between cement-retained prosthesis and screw-retained prosthesis becomes clear It was observed that model 6 has the highest stress value along the entire occlusal surface and the stress values at the neck of the implant and in the surrounding bone is very high.

Finite element analysis used in this study demand precision of material properties and size, every effort was made to achieve accurate reproduction, but the adhesiveness of the cement was impossible to reproduce. CerAdapt™ (Model 3, 4) is a recently developed system requiring long-term clinical trials, histological studies and stress analyses using different methods.

V. Conclusions.

1. In CeraOne, CerAdapt and UCLA type abutment, stress concentration was greater in the screw-retained type compared to the cement-retained type.
2. Stress distribution was the most favorable in model 1, the cement-retained CeraOne and the least favorable in model 6, the screw-retained UCLA type.
3. In all models the greatest concentration of stress occurred at the neck of the fixture. This concentration was most notable in the UCLA type.
4. In the superstructure, stress was concentrated on the occlusal surface.
5. In the bone, the greatest concentration of stress occurred in the upper cortical bone where it came into contact with the neck of the fixture. When horizontal and oblique loads were applied, stress was concentrated at the neck of the fixture, away from the direction of the load.
6. In the bone, fixture and the model as a whole, lesser stress values were observed when vertical loads were applied as compared to horizontal and oblique loads.

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