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2009년 8월
박사학위논문

수직적 골흡수가 나타난 골유착 임플란트 경부에 대한 평가: 삼차원 유한요소 분석

조선대학교 대학원

치의공학과

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수직적 골흡수가 나타난 골유착 임플란트 경부에 대한 평가: 삼차원 유한요소 분석

Evaluation of biomechanical weak point
on osseointegrated implant with vertical bone resorption:
a three-dimensional finite-element study

2009년 8월 25일

조선대학교 대학원

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지도교수 김 수 관

이 논문을 치의학 박사학위신청 논문으로 제출함.

2009년 4월

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국문 초록

수직적 골흡수가 나타난 골유착 임플란트 경부에 대한 평가: 삼차원 유한요소 분석

윤 경 호
지도교수 : 김 수 관
조선대학교 대학원 치의공학과

연구목적 : 본 연구의 목적은 유한요소분석을 이용하여 주변골 흡수에 대한 internal submerged type implant의 응력분포의 영향을 평가하는데 있다.

실험방법 : 본 연구에서는 직경 4.0mm, 길이 11.5mm의 HS Ⅱ 임플란트를 thread의 노출 정도(노출 안함, 1mm, 2mm, 3mm 노출)를 다르게 하여 4개의 cylindrical alveolar bone model에 식립하였다. Gold alloy crown을 solid abutment 위에 식립하였다. 각 임플란트에 가해진 부하는 von Mises stress(유효응력)와 principal stress(장축 방향과 30도의 측방압)이었다. 임플란트 주변골과 임플란트 결합부위 사이에서 부하의 차이는 ANSYS 분석법을 이용하여 비교 분석하였다.

결 과 : 수직압 하에서 나타나는 stress values의 비교에서 측방압이 적용되었을 때 보다 임플란트 주위 골의 응력이 더 크게 관찰 되었다. 측방압의 적용 하에서, 임플란트 경부에서의 골 소실은 더 분명하였다. 더 많은 thread가 노출되었을 때 bone level은 감소되었고 fixture에 적용되는 최대 부하는 증가되었다. 이 관찰은 임플란트 파절의 증가된 가능성을 보여준다. 임플란트 파절의 위험성은 파절하기 쉬운 경부의 두께를 강화한 1-stage implant를 이용

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함으로써 감소되었다.

결 론 : 본 연구에서는 높은 수준의 bone level은 응력분산에 대한 생역학적 이점이 있었다.

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1. INTRODUCTION

In the last three decades, advances in dental implants and surgical procedures have assured predictable results, improved function and enhanced esthetics, such as the development of HS II implants (HIOSSEN, Philadelphia, USA), a one-stage implant system designed to simplify the surgical and restorative aspects of implant therapy.[1] In the investigation of dental implants, finite element method has become one of the many tools used by scientists to understand and advance the science of dental implantology. It is a numerical method used to help solve problems in engineering and mathematical physics and analyzes a structure by dividing it into smaller elements with similar physical properties.[1-8] Additionally, for successful maintenance and management of implants, biodynamics must also be considered, since the physical properties of the body and implant are the most important factors determining the long-term effectiveness of implants.[9] The occlusal forces are known to affect an oral implant and the surrounding bone. According to bone physiology theories, bones carrying mechanical loads adapt their strength to the load applied by modeling or remodeling. This modeling or remodeling also applies to bone surrounding an oral implant. An increased mechanical stress below a certain threshold is known to strengthen the bone by increasing the bone density or bone apposition, whereas strain in the bone beyond this range will at some point result in fatigue fracture and bone resorption.[10]

It is also known that stresses and changes in the implant surroundings or bone-implant interface involves various factors, including cantilever length and the number or width of the implants.[9] Bone resorption close to the first thread of osseointegrated implants is frequently

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observed during initial loading.[11] Clinical observations have indicated that less bone resorption with bone preservation is possible when the narrower diameter of abutment is connected to the implant, so called platform switching.[12] As such, using finite element modeling, the effect of stress distribution around the internal non-submerged type implants on marginal bone resorption was investigated in this study.

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2. MATERIALS AND METHODS

2.1. Finite element model

For this study, a single implant fixture (Ø 4.0mm × L 11.5mm, HS II implant, HIOSSEN, Philadelphia, USA) was embedded in a cylindrical alveolar bone model (Ø 28mm × L 30mm). The implantation model included a 1-piece type solid abutment and simplified crown. A total of four bone models with a implant were constructed, and these four models included a non-resorption model (0 mm) and three variations with different resorption depths combined with pure vertical resorption (Fig. 1). The following conditions were considered during finite element modeling:

a. *Material properties* : All materials used in the models were considered to be isotropic, homogeneous, and linearly elastic. For bone, this is a rough approximation that enabled the construction of complex models. Firm osseointegration was also assumed to be the state of connectivity between bone and implant elements. The elastic properties were taken from the literature, as shown in Table 1.

Table 1. Specification and properties of finite element model

Component	Size	Materials	E	ν
HSII implant	D 4.0, L 11.5mm	TiGr4	105	0.34
Solid abutment	D 4.08, H 5.5mm	Ti-6Al-4V	113	0.342
Crown	Wheeler's model	Gold alloy	170	0.3
Alveolar bone	D 28, L 30mm	-	13.7	0.3

D : diameter, L : length

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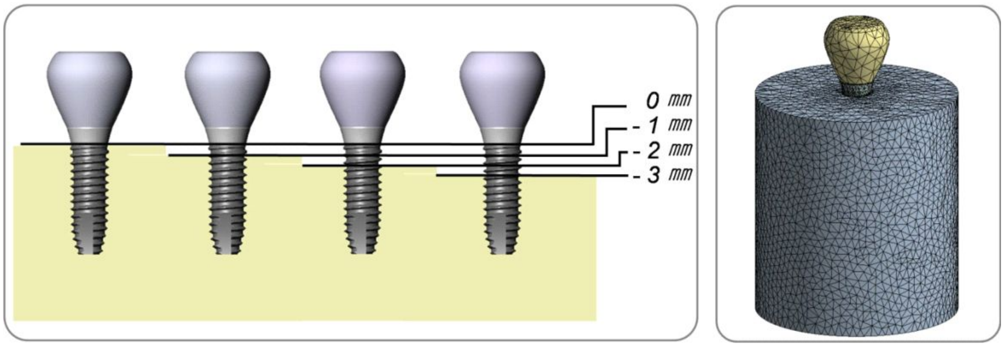

(a) (b)

Fig. 1. Finite element modeling. (a) FE-model where bone resorption are applied. (b) meshed FE model.

a. *Interface conditions* : The implant was rigidly anchored in the bone model along its entire interface. The same type of contact was provided at the prosthesis-abutment interface.

b. *Elements and nodes* : Because of the mesiodistal symmetry, only half of the model was meshed with 10-node tetrahedral element of ANSYS' s solid187 (Fig. 2). A finer mesh was generated around the implant. Models were composed of 81,637-91,534 elements and 138,097~152,753 nodes (Table 2).

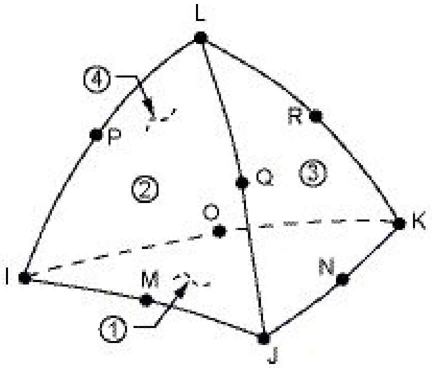

Fig 2. ANSYS's solid 187.

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Table 2. Amount of mesh

Model	Mesh	Cortical bone	Cancellous bone	implant	abutment	crown	Total
0mm Model	Nodes	7,080	61,846	75,830	4,147	3,850	152,753
	Elements	3,456	39,693	44,078	2,078	2,229	91,534
-1mm Model	Nodes	7,887	54,292	75,830	4,147	3,850	146,006
	Elements	3,933	34,529	44,078	2,078	2,229	86,847
-2mm Model	Nodes	7,120	52,219	75,830	4,147	3,850	143,166
	Elements	3,513	33,252	44,078	2,078	2,229	85,150
-3mm Model	Nodes	7,316	46,954	75,830	4,147	3,850	138,097
	Elements	3,594	29,658	44,078	2,078	2,229	81,637

2.2. Contact and loading conditions

The following contact and loading conditions were used in the study (Fig. 3):

a. *Contact condition*:

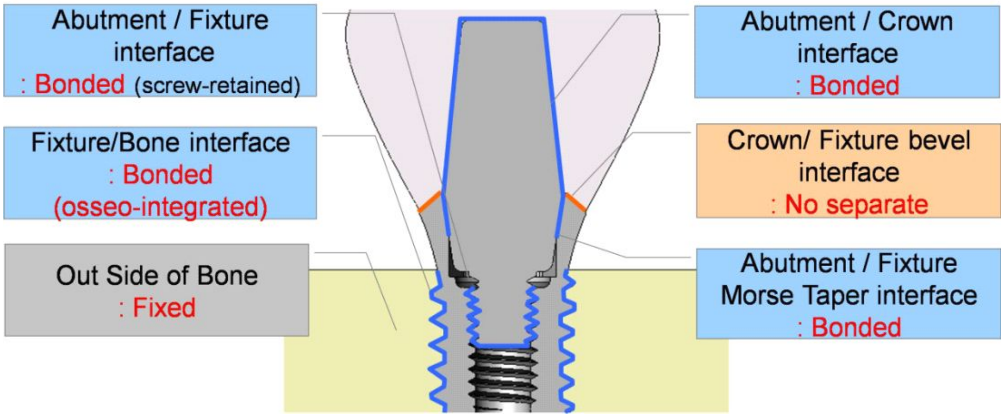

Fig. 3. Contact and constraint of FE-model.

b. *Loading condition* : Forces of 250N were applied axially (AX) and buccolingually (BL), respectively, to the center of the superstructure. It gave an identical loading condition from the FE-model, 250N oblique load (average bite force from the posterior region) of 30° on the central fit of the superstructure (Fig. 4).

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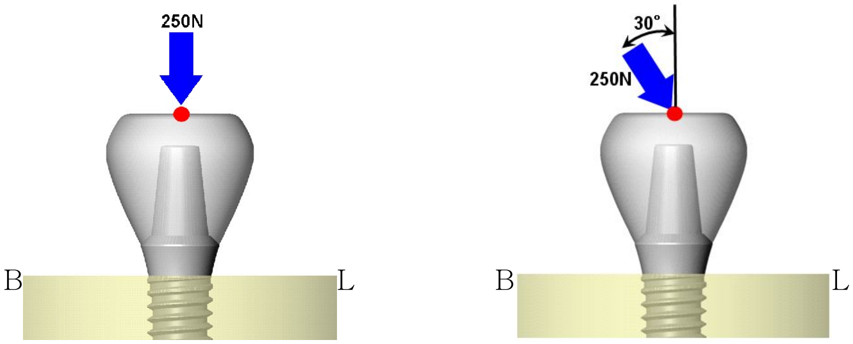

(a) (b)

Fig.4. Loading condition. (a) axial load, (b) oblique load.

2.3. Analysis

Each load was analyzed using the ANSYS software program (ANSYS Workbench™ 11.0 sp.1, ANSYS Inc., Canonsburg, USA). The von Mises stress (equivalent stress, abbreviated EQV stress) and principal stress were used to display the stress in the bone and implant-abutment unit in all four models.

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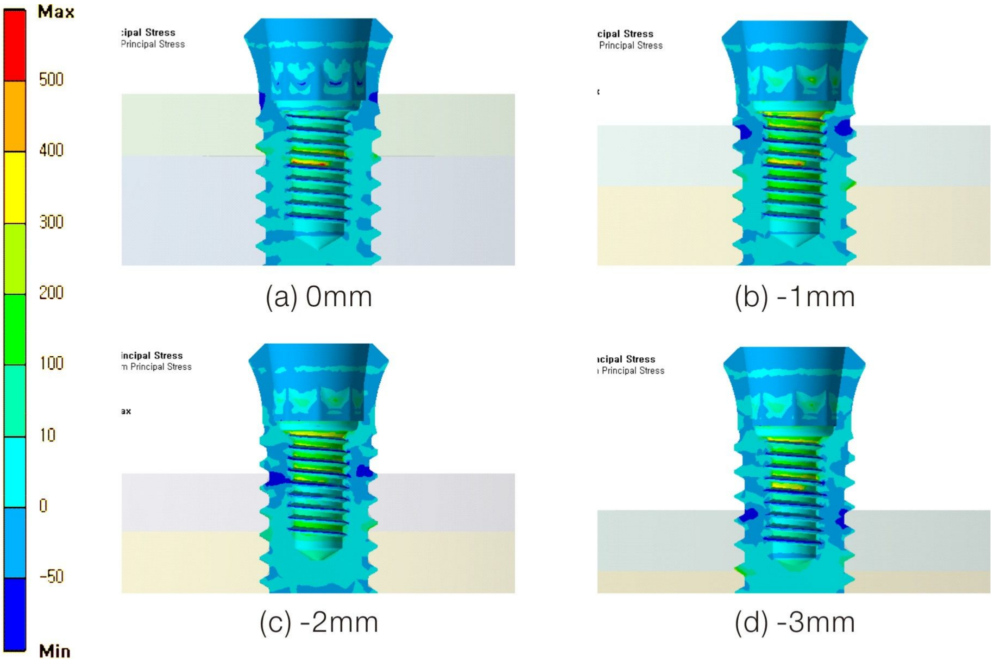
3. RESULTS

3.1. Maximum principal stress in implant

EQV stress patterns are shown as contour lines with different colors connecting equivalent stress points between certain ranges (Fig.5−7)



(a) 0mm (b) -1mm

(c) -2mm (d) -3mm

Fig. 5. Maximum principal stress and its distribution in implant under axial load and bone resorption.

Table 3. Maximum principal stress for each load in implant. (a) Axial load of implant, (b) Oblique load of implant

[unit : ㎫]

Model	Axial load		Oblique load	
	Max.	Min.	Max.	Min.
0㎜	68.62	−45.18	419.28	−182.26
−1㎜	75.52	−30.48	538.57	−172.62
−2㎜	89.04	−34.40	584.43	−195.45
−3㎜	86.64	−44.19	706.47	−236.83

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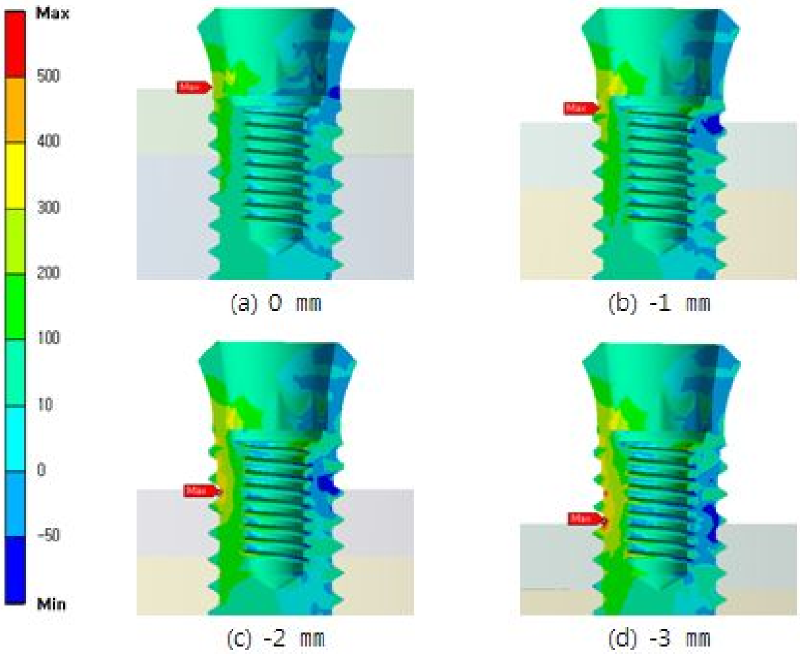
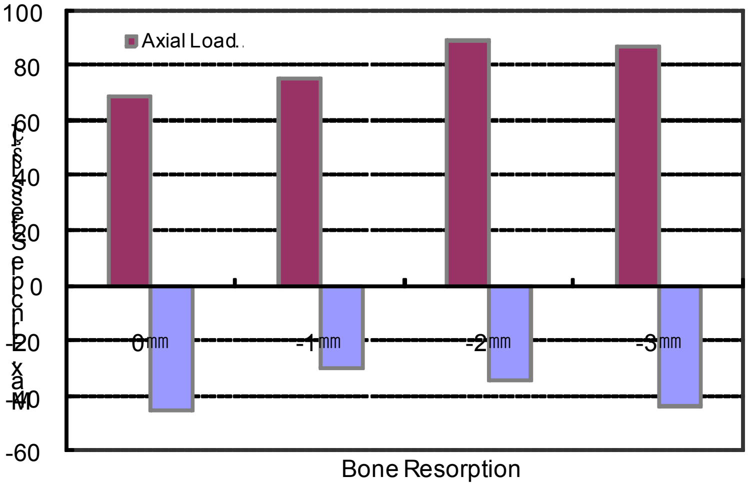


(a) 0 mm (b) -1 mm

(c) -2 mm (d) -3 mm

Fig. 6. Maximum principal stress and its distribution in implant under oblique load and bone resorption.



(a) axial load of implant (b) oblique load of implant

Fig. 7. Maximum principal stress of implant under each load and bone resorption.

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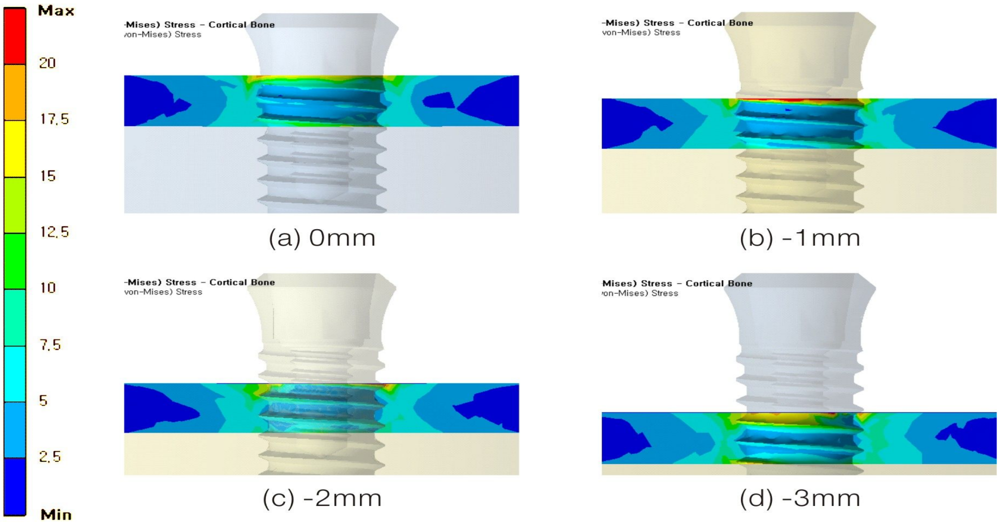
3.2. Equivalent stress

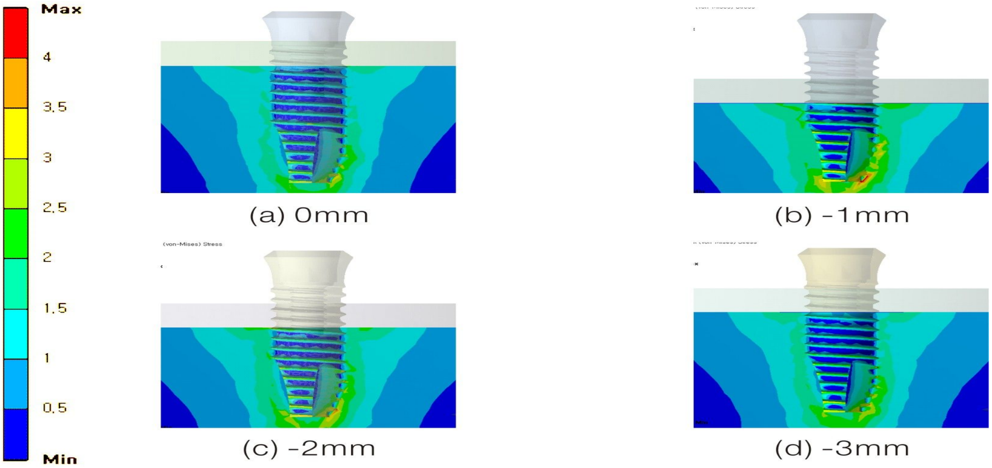
EQV stress patterns are shown as contour lines with different colors connecting equivalent stress points between certain ranges. Under axial load, the maximum EQV stress was increased with the depth of resorption (Figs. 8, 9).



(a) 0mm (b) -1mm

(c) -2mm (d) -3mm

Fig. 8. EQV stress and its distribution in cortical bone under axial load and bone resorption.



(a) 0mm (b) -1mm

(c) -2mm (d) -3mm

Fig. 9. EQV stress and its distribution in cancellous bone under axial load and bone resorption.

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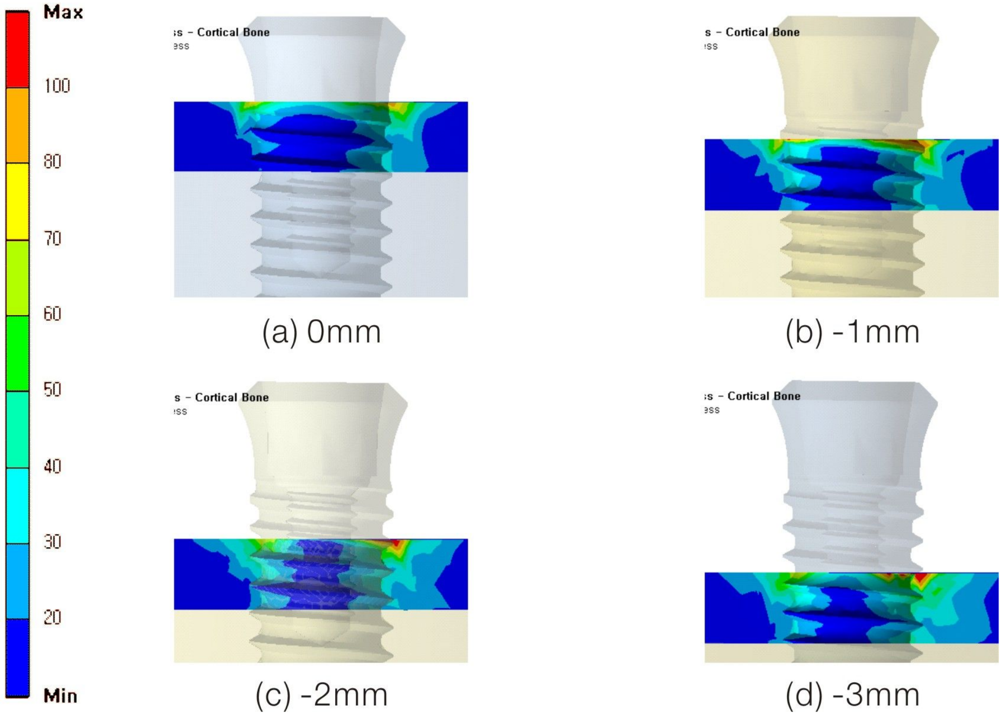
Under oblique load, the changes of maximum EQV stress showed the same tendency as under axial load (Figs. 10, 11).



(a) 0mm (b) -1mm

(c) -2mm (d) -3mm

Fig. 10. EQV stress and its distribution in cortical bone under oblique load and bone resorption.

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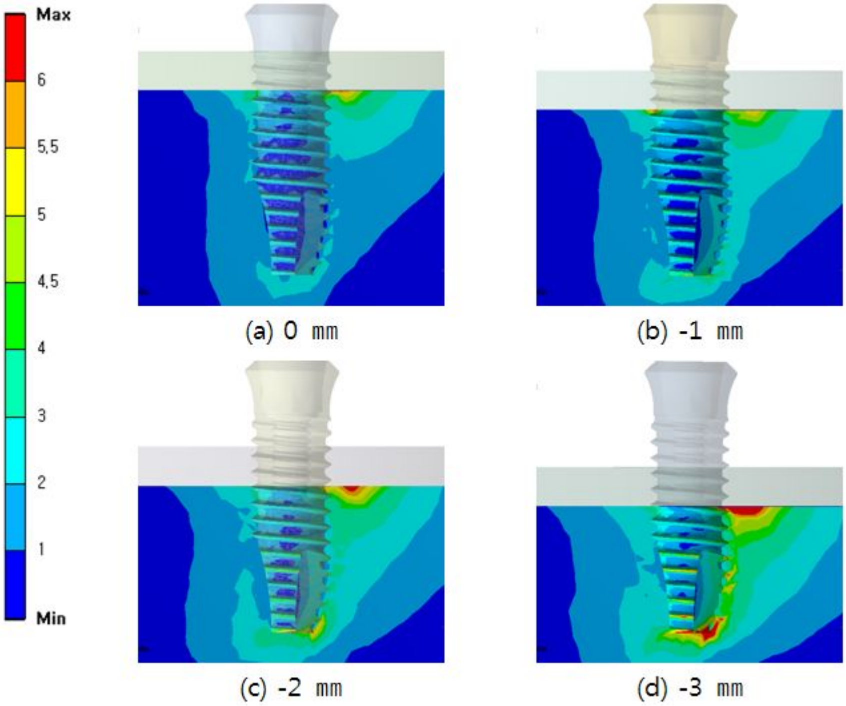

(a) 0 mm (b) -1 mm

(c) -2 mm (d) -3 mm

Fig. 11. EQV stress and its distribution in cancellous bone under oblique load and bone resorption.

Table 4. EQV Stress for each load in alveolar bone

[unit : ㎫]

Model	Axial load				Oblique load			
	Cortical bone		Cancellous bone		Cortical bone		Cancellous bone	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
0㎜	27.73	0.17	4.39	0	109.60	0.04	6.62	0
−1㎜	31.80	0.18	4.84	0	128.37	0.09	7.23	0
−2㎜	30.55	0.11	5.33	0	153.93	0.10	9.15	0
−3㎜	26.35	0.16	5.27	0	166.70	0.10	11.33	0

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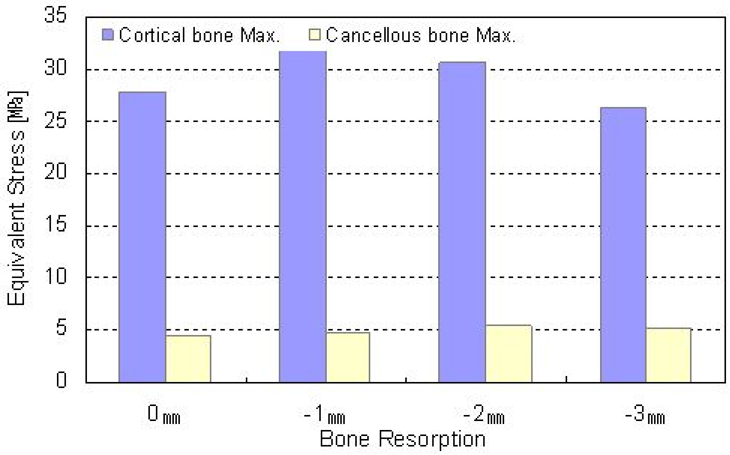
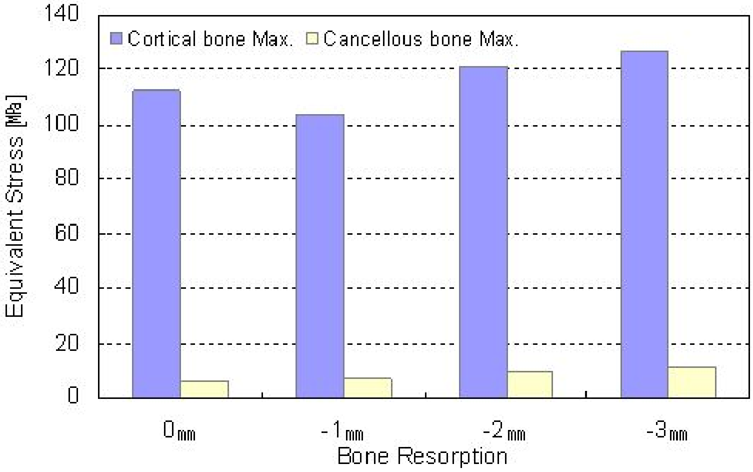


(a) Axial load of implant



(b) Oblique load of implant

Fig. 12. EQV stress of alveolar bone under each load and bone resorption.

Table 5. Results of maximum principal stress in implant

Bone resorption	0 ㎜	− 1 ㎜	− 2 ㎜	− 3 ㎜
Maximum principal stress	419.28 ㎫	538.57 ㎫	584.43 ㎫	706.47 ㎫
Increased rate	Ref.	28%	39%	68%

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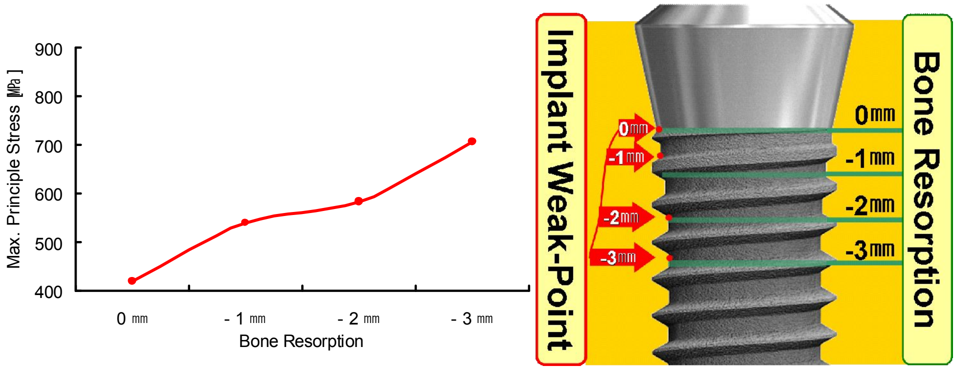

Fig. 13. Maximum principal stress for fixture and weak-point position

There was no difference in stress when bone level decreased by 1mm. In contrast, stress increased when bone level decreased by 2mm or more (above 25%). In terms of stress concentrated position, a decrease in bone level caused be moved the position on bone level circumferences with the exposed fixture thread.

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4. DISCUSSION

Bone tissue reacts to strain or deformation. Depending on the properties of the tissue, a given force may affect different bones or bone tissues differently. However, mechanically loaded bones adapt to the load. If the strain in the bone surrounding an oral implant is in the ‘mild overload’ range (1500–3000 microstrain), apposition of bone appeared to be the biological response.[10]

Additionally, occlusal forces may exceed the mechanical or biological load-bearing capacity of the osseointegrated oral implants or the prosthesis. If this occurs, the result will either be a mechanical failure of the implant or an uncontrolled vertical bone loss leading to the ultimate loss of bone-implant osseointegration.[3,10] Histological findings reported for failed Branemark implants inserted in humans indicated that occlusal overload was the etiologic factor for the failure of 8 of 10 examined implants.[13]

Among the different loadings, non-axial loads are considered to create more stress in the peri-implant bone than axial loads.[2,14] Bone loss was observed around the necks of implants exposed to high cyclic axial tension but not around unloaded controls in a study with screw-type implants inserted in dog tibiae.[15] In addition, crater-like bone defects were also observed in the marginal bone area around the cyclic loaded implants. Therefore, it is biodynamically sound to apply a load along the long axis of an implant because of the adverse development of high stress with an oblique load.[9] Higher remodeling activity under non-axial versus axial loads were also reported in an animal model study,[16] which was correlated with higher equivalent stresses in a finite element analysis study.[17]

The implant fracture risk is also assumed to increase in the presence

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of deep bone defects and/or a pure vertical bone loss around an implant in regions with high lateral occlusal loads. As such, careful occlusal adjustments, fabrication of protective splints, and, whenever possible, placement of additional implants may be considered in these situations in an attempt to prevent biomechanical failure of the implant.[3] During the investigation of stress distribution in bone and implant in the presence of a bone defect of various shapes and dimensions, Kitamura et al.[3] suggested that a certain amount of conical resorption may be the result of biomechanical adaptation of bone to stress. However, as bone resorption progresses, the increasing stresses in the cancellous bone and implant under lateral load may result in implant failure. Using 3-D finite element method to evaluate the effect of stress and strain distributions on different graft materials, Kwon and Kim[9] reported a change in stress distribution over time, with no change in stress observed after 50 days. The investigators also reported a relatively large stress occurred immediately after graft implantation, and that the highest stress was seen with an oblique load when DFDB Bio-Oss was used for grafting.

When the marginal bone resorption was observed clinically, additional verification was needed to determine the influence of marginal bone resorption on a change of implant strength. The region at the implant-abutment connection is expected to be the weakest for internal non-submerged type implant. As the bone level decreases, maximum stress increases and the position moves on bone level circumferences with the exposed fixture thread. Additionally, as bone resorption progresses, the increasing stresses of the bone and implant, especially under lateral load, may raise the risk of failure. Thus, special clinical precaution should be taken when bone level decreases, as the possibility of fracture increases due to the increased maximum stress. As the one-stage implant supplements the strength of the neck area by anchoring

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to its thickness, the possibility of a fixture fracture is expected to be reduced. Further studies should be conducted utilizing modified 3-D finite element models and animal experiments, as well as longitudinal clinical observations to support these findings. Within the limitations of this study, it was concluded that higher bone level has a biomechanical advantage with respect to stress concentration.

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ABSTRACT

Evaluation of biomechanical weak point on osseointegrated implant with vertical bone resorption: a three-dimensional finite-element study

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Using finite element modeling, the effect of stress distribution around the internal non–submerged type implants on marginal bone resorption was investigated in this study.

Study Design. An HS II implant with a diameter of 4.0 mm and a length of 11.5mm was placed in each of the four cylindrical alveolar bone models with differing degrees of thread exposures (not exposed, 1mm, 2mm, and 3mm exposure). A gold alloy crown was then placed over the solid abutment. The load applied to each implant was von Mises stress (equivalent stress) and principal stress, 250N in axial direction and 30 degree lateral pressure (bucco–lingually). The difference in the load between the bone surrounding the implant and theconnective portion of the implant was obtained using ANSYS analysis.

Results. In comparing to stress values yielded under vertical pressure, the stress in bone surrounding the implant was observed to be greater when lateral pressure was applied. Under the application of lateral pressure, bone loss in the cervical area of the implant was more obvious. When more threads were exposed, bone level decreased and

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the maximum load applied on the fixture increased. This observation suggested an increasing probability of implant fracture. Additionally, the risk of implant fracture was reduced by using a 1−stage implant which reinforces the thickness of the fragile neck area.

Conclusions. Within the limitations of this study, it was concluded that higher bone level has a biomechanical advantage with respect to stress concentration.

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저작물 이용 허락서

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논문제목	한글 : 수직적 골흡수가 나타난 골유착 임플란트 경부에 대한 평가: 삼차원 유한요소 분석				
	영어 : Evaluation of biomechanical weak point on osseointegrated implant with vertical bone resorption: a three-dimensional finite-element study				

본인이 저작한 위의 저작물에 대하여 다음과 같은 조건아래 조선대학교가 저작물을 이용할 수 있도록 허락하고 동의합니다.

- 다 음 -

1. 저작물의 DB구축 및 인터넷을 포함한 정보통신망에의 공개를 위한 저작물의 복제, 기억장치에의 저장, 전송 등을 허락함
2. 위의 목적을 위하여 필요한 범위 내에서의 편집・형식상의 변경을 허락함. 다만, 저작물의 내용변경은 금지함.
3. 배포・전송된 저작물의 영리적 목적을 위한 복제, 저장, 전송 등은 금지함.
4. 저작물에 대한 이용기간은 5년으로 하고, 기간종료 3개월 이내에 별도의 의사 표시가 없을 경우에는 저작물의 이용기간을 계속 연장함.
5. 해당 저작물의 저작권을 타인에게 양도하거나 또는 출판을 허락을 하였을 경우에는 1개월 이내에 대학에 이를 통보함.
6. 조선대학교는 저작물의 이용허락 이후 해당 저작물로 인하여 발생하는 타인에 의한 권리 침해에 대하여 일체의 법적 책임을 지지 않음
7. 소속대학의 협정기관에 저작물의 제공 및 인터넷 등 정보통신망을 이용한 저작물의 전송・출력을 허락함.

동의여부 : 동의(○) 반대( )

2009 년 8 월 일

저작자: 윤 경 호 (서명 또는 인)

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