BIOMECHANICAL EVALUATION OF SPLINTED 4- AND 6-MILLIMETERS SHORT DENTAL IMPLANTS WITH DIFFERENT CROWN-IMPLANT RATIOS, A FINITE ELEMENT ANALYSIS

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ABSTRACT

The purpose of this study was to assess the influence of the crown height, and the crown to implant ratio, of two adjacent 4- and 6-millimeters short dental implants with connected and non-connected restorations on the distribution of stress to the implant abutment and peri-implant structures, using a three-dimensional finite element method. Dental implants and abutments were scanned, and the scans were analysed using NX Nastran software to create finite element models. A total of 48 experimental states from 12 finite element models were initiated with different conditions according to diameter, length, crown height, and direction of the occlusal force. The results showed that crown height did not influence the stress concentration on implant abutment and surrounding bone under axial (90°) loading, while oblique (45°) loading strongly influenced the outcome. Increasing the crown to implant ratio from 1:1 to 2:1 resulted in increasing stress values 22.38-76.78%. The results of this study suggest that connecting two restorations does not have significance difference on stress distribution to implant. In splinted models, stress tends to concentrate on outer implant fixtures and peri-implant structures.

KEY WORDS: SHORT DENTAL IMPLANT / SPLINTED IMPLANTS/ ABUTMENT /
BONE / STRESS DISTRIBUTION / FINITE ELEMENT ANALYSIS

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LIST OF ABBREVIATIONS

CAD/CAM	Computer aided design/ computer aided manufacture
C/R ratio	Crown-root ratio
C/I ratio	Crown-implant ratio
CT	Computer Tomography
FEA	Finite Element Analysis
SLA	Sand blast, large grit, acid etching

CHAPTER I
INTRODUCTION

1.1 Background and Rationale

Dental implants are one of the most prominent dental technological advances and are widely recognized as the only best way to replace lost teeth. It is still considered permanent tooth replacement due to medical research evidence about the lifespan of dental implants that can last a lifetime of patients under good systematic treatment. A good implant has been extensively acknowledged that it is well suited for anyone who has lost a single tooth or more teeth and wants to restore the appearance or chewing ability. Nevertheless, when the teeth are lost, the alveolar ridge generally resorbs in both vertical and horizontal dimensions that result in a reduction in the height and width of the alveolar bone.

The natural tooth loss is a problem that can occur in all age groups. The position of the tooth that is found to be the most lost is the natural teeth in the jaw including the first teeth and the second teeth respectively, which are the teeth that need to be used to chew more than other teeth. The loss of such natural teeth causes a decrease in the patient's occlusion efficiency, so patients are advised to replace the lost teeth with dental implants. In the case of losing the two adjacent teeth, patients are recommended to insert two implants to adequately support the chewing force.

According to the study results, it is found that patients who have lost the jaw for a long time, especially in elderly patients, will have a large amount of bone dissolution in the vertical bone resorption that is difficult to supplement the bones.

Positioning a standard dental implant with the length of 10 mm or maybe more to the edentulous areas could have a possibility to damage the important structures, such as maxillary sinus, inferior alveolar nerve, and the vessel that may cause serious problems to the patients. In addition, if the patients have a congenital disease, the treatment will be delayed and causes anxiety about the patient's tolerance to a medium size surgery. Thus the various vertical bone augmentation techniques had been proposed. [1]

These procedures have disadvantages, for instance, the inappropriateness of surgery, high cost, and long treatment duration after a bone graft and implant installation. [2, 3] Furthermore, since the bone resorption occurs after a bone graft, an increase in the vertical height is inexact. Wallace et al. conducting the Microscopic studies suggested that it was hard to acquire bones with optimal strength from a bone graft. The Microscopic studies by Wallace et al. [4] suggested that it was difficult to obtain bones with optimal strength from a bone graft.

For this reason, a short dental Implant is invented, with a maximum length of 4 mm, but not more than 6 millimeters to meet the need of dental implant treatment for this particular group of patients because the implant surgery is not complicated, easy to do, and takes a short time for treatment. However, professionals have to make use of the splinted prostheses for better stress distribution to the system in order to guarantee the same high success rates as the normal length implants. Nonetheless, some researchers claimed that splinted prostheses involve an uncertain and empirical procedure. In addition, the particular dimension of the prosthesis might directly affect the lever and torsional forces, whether it is with or without splints, especially for a short implant.

From the case of losing two adjacent teeth as mentioned above, few clinicians have had a concern about a greater crown/implant proportion if there are variations in stress in the supporting bone with splinted or non-splinted prostheses or not, or if splinted or non-splinted prostheses could interfere with the stress developed in the supporting bone by mechanical actions from the prostheses or not. Presently, there are few studies on a short implant in long-term functioning resulted from a biomechanical issue of the excessive stress concentration around the surrounding bone generating marginal bone resorption that causes the implant failure, particularly when the restoration crown height is more than the implant length. Therefore, an increase in the crown-implant ratio is critical.

There are recommendations from the manufacturer to put the splint crowns on the implants of the two adjacent teeth to distribute the forces and support the chewing force better than separated two crowns on the implants. However, very few studies for proving such methods are found. In addition, there is no research on the proper crown-implant ratio in the event that splint crowns are connected on two fixtures of the implants. [5]

Due to a lack of supporting evidence on the above issues, it results in this study intends to study mechanical measurement of splinted and non-splinted of two crowns on two dental implants by the Finite Element Analysis. [3, 5, 6] This type of analysis supports the biomechanical understanding of structures in an individualized manner, which may be used to examine important structures for the longevity of treatment in dental implant/abutments and bone tissue. This study comprises a qualitative and quantitative assessment of the particularly developed stresses in bone edges in models that are rehabilitated with short tissue level of implants in the same context either with or without splinted prostheses by applying the three-dimensional finite element analysis (3D FEA), so a biomechanical behavior approach is analyzed in this paper.

1.2 Research Question

The occlusal force that is applied to non-splinted short dental implants creates more stress concentration to surrounding structures in both axial and oblique loads compared to the splinted restoration with the same crown-implant ratio at the same implant diameter and length.

The occlusal force that is applied to non-splinted short dental implants with the higher crown-implant ratio creates more stress concentration to the surrounding structures in both axial and oblique loads compared to the splinted restoration with the lower crown-implant ratio at the same implant diameter and length.

1.3 Objective

To demonstrates the stress concentration of short dental implants with splinted restorations to the surrounding structures in order to find the appropriate crown-implant ratio for short dental implants with splinted restorations.

1.4 Research Hypothesis

H_0 = There is no difference on stress concentration to the surrounding structures in both axial and oblique loads among separated short dental implants with the splinted restoration with the same crown-implant ratio at the same implant diameter and length.

H_1= There is a difference on stress concentration to the surrounding structures in both axial and oblique loads among separated short dental implants with the splinted restoration with the same crown-implant ratio at the same implant diameter and length.

CHAPTER II
LITERATURE REVIEW

2.1 Short Dental Implants

When the challenging situations were encountered for example: only 7 mm residual bone height over inferior alveolar canal, severe bone atrophy, maxillary sinus pneumatization in the upper arch, and the supplemental surgical procedure to increase adequate vertical bone volume for standard dental implants is not a suitable alternative for they increase the risk of possible complication such as infection, loss grafting materials, sensitivity of adjacent teeth, sinus membrane perforation. Thus, short dental implants may provide a rationale for the use.[7]

Although the definition of short implants is still controversial, in general, it is referred to an implant less than 10 mm length.[8] Short implants had become an interesting alternative since they required a shorter treatment period, easier treatment planning, reduced the chance of complication, associated with less morbidity, and, in some manufacturer, they are lower cost.[9] Due to the surface modification technology the long term results are encouraging as they lost marginal bone 0.9mm less than longer implants in augmented bone.[10] On the other hand, there were still disadvantages remained for the reduction of bone-to-implant contact area which leads to increased concentration of alveolar bone despite the surface treatment and implant shape.[7] Felice still questioned on high failure risk if the marginal bone loss progressed further in the long term. [11]

The prognosis of short implants had recently studied by Weerapong et al in 2019[12] by comparing implant survival, marginal bone level change, and implant stability quotient value between short implants and conventional length implant in term of immediate loading. The authors placed and followed up 46 implants (23 short dental implants and 23 conventional length dental implants) with provisional CAD/CAM ceramic crowns cemented to the abutments for 4 months and 1 year. The results are no significant difference between both types. Therefore, short implants are becoming a promising alternative for a simple and effective rehabilitation in limited bone availability case. Some studies have reported that short implants exhibit unfavorable biomechanical behavior compared with standard implants [13] , leading to a lower survival rate for short implants [14] . However, some authors have suggested the splinting of short implants with longer implants to reduce biomechanical risks contributing to increasing the survival rate of short implants when placed in the maxillary posterior region.[15, 16]

Straumann® had introduced 6-mm tissue-level [Fig.2] and 4-mm tissue-level [Fig.1] dental implants in 1987 and 2013, respectively. Both implants came in standard and standard plus designs, with 4.1 mm and 4.8 mm diameters, in regular- and wide-neck configurations. There was a study reported 2-year survival rate of 92.3% for 4-mm dental implant with healthy peri-implant conditions.[17]

Regarding the attention obtained from many researchers, more supporting evidence on short dental implant remains necessary to facilitate clinicians to be cautious and to be able to select their cases safely and carefully.

Figure 2.1 Straumann® Standard Plus 4mm Short Implant

Figure 2.2 Straumann® Standard Plus 6mm Short Implant

2.2 Crown-implant Ratio

Crown-to-root ratio (C/R) is an indicator to assist clinicians for planning proper treatment. The ratio comes from calculation the portion of the tooth above the alveolar bone to the part of the tooth within alveolar bone.[18] Various ratios had been established to be a desirable ratio for restoring fixed dental prostheses. Shillingburg [19] concluded that a ratio of 1:1.5 to be the most favorable for an abutment, and a C/R ratio of 1:1 as a minimum for a tooth abutment. However, Grossmann and Sadan [20] concluded that no definitive recommendations for an optimal C/R ratio could be established. As of titanium dental implants were intended to be submerged underneath alveolar bone, this rule was relatively applied to the crown-to-implant ratio (C/I).

Increasing the prosthetic crown height of implants may induce excessive stress concentrations to the fixation screw and to the surrounding bone under oblique load more than axial load. Screw loosening or fracture of abutment were generated and could lead to undesirable marginal bone loss and implant failure as the consequences.[21] Accordingly, a C/I ratio between 0.5 and 1 was recommended for a sufficient longitudinal outcome.[22, 23]

Although most clinicians preferred following the previous guideline for suitable treatment planning, some authors disagreed with the above proposal. Tawil et al. suggested that crown-to-implant ratio and marginal bone loss were not correlated. Schulte et al also supported there was no significant difference from crown-to-implant ratio to implant success rate. It is known that utilizing short dental implants would increase crown-to-implant ratio, but contemporary surface treatment could facilitate better osseointegration and may comparable to standard length implant.[12]

According to few studies were conducted to affirm the application of short dental implants, there is still a concern for the optimal conclusion for C/I ratio in short dental implant.

2.3 Splinted Restorations on Dental Implants

Several studies reported that the short implants demonstrated an adverse biomechanical behavior compared with the standard implants that led to a lower survival rate for the short implants. Nevertheless, some authors recommended the splinting of short implants to longer implants to reduce biomechanical risks. This may contribute to improving the survival rate of short implants when they are placed in the maxillary posterior area. Though, no consensus has been reached as some studies documented that the splinted prostheses did not have an impact on the stress distribution when compared with the non-splinted prostheses.[14]

Implant restoration splinting brings about a better distribution of stresses in an implant body and bone when compared with the non-splinted implant restorations, particularly when the load is applied off the center to an implant body. The stress can be reduced by angulation of implants can reduce the stress when the use of the load is in the same direction as the implant angulation.[24]

Studies by Cleidiel et al. investigated extra short implants (< 7 mm) found less stress distribution when compared splinted crowns to the non-splinted crown in implant and bone tissue.[14] Meimandi composed an experiment to compare the distribution of stress and strain around splinted and non-splinted 6-mm short implants.[25] The results from Finite Element Analysis indicated splinting short implants provided decreased stress and strain in supporting bone. In contrast, Cleland et al. showed no significant differences between splinted and non-splinted crowns.[26, 27]

The advantage of splinting restoration is sharing stress with another implant because the rigid conjunction of components facilitates stress distribution.[28]

In contrarily, non-splinted restorations are superior in enabling better oral hygiene in the proximal area.[29]

2.4 Evaluation of Stress Distribution

To measure the mechanism around loaded dental implants, there are theories used to explain the failure criteria of materials.

The distortion energy theory believed that the total strain energy can be separated into two components: the volumetric (*hydrostatic*) strain energy and the shape (*distortion or shear*) strain energy. It was proposed by Hubert in 1904 and further developed by von Mises in 1913. It was applied to many fields related to ductile materials. It was said that when the yield occurred at a different critical value for each material, the distortion was obtained at the yield point. The Von Mises stress criteria use the distortion energy theory to determine the failure of ductile materials, i.e. metals, in a value named 'Von Mises stress'. In other words, the von Mises stress is used to predict yielding of materials under complex loading from the results of uniaxial tensile tests. If the von Mises stress of material was loaded with equal or greater than the yield limit of the same material under simple tension, then the material will yield or fracture. Thus, to prevent failure, the von Mises stress of a material under load should not be equal nor greater than the yield limit of the material under uniaxial stress.[30]

Strains are a complicated thing to predict in 3D objects. In order to simplify the problem, researchers examined a material under 1D load conditions and use the experimental results to make predictions for the 3D case. The von Mises stress is used to assist in making the simulation from 1D to 3D.[31]

The Maximum Principal stress theory was established to explained failure will occur when the maximum principal stress in a system reaches the value of the maximum strength at elastic limit in simple tension by mean of Maximum principal stress. The theory explained that the growth of the crack will occur in a direction perpendicular to the maximum principal stress. Maximum principal stress theory is used for brittle materials, which fails by brittle fracture and does not undergo yielding.[32]

2.5 Finite Element Analysis in Implant Dentistry

There was Finite element analysis [FEA] is a well-known technique used to analyze stress in engineering and biomechanical fields in order to prevent the occurrence of problems associated with material failure. Originally, FEA was developed to indicate structural mechanics problems associated with aerospace and civil engineering. It was first applied to implant dentistry field in 1973 by Tesk and Widera.[33] Since then, FEA was considered to be a predictable and faster tool to optimize better product design without overwhelming physical prototypes and experiments.[34, 35]

The principal stress values for cortical and trabecular bone and the equivalent von Mises stress values for implants and frameworks were calculated to analyze the results. The unit of measurement was megapascals [MPa]. The measurements included in specific interest are principal stress values such as tensile, compressive, and shear stresses and von Mises stress values. Von Mises stress values are defined as the beginning of deformation for ductile materials and are important for interpreting stresses occurring within implants. Failure occurs when von Mises stress values exceed the yield strength of implant materials.[5, 30, 35]

In the study by Kim et al., it is assumed that implant failure and excessive loading are closely related, finite element analysis aided to clarify the dynamic relationships among the complex components.[7] Gulcan et al. used FEA to compare stress distribution of different implant materials. The author suggested that fundamental of implant design should facilitate resistant of shear and tensile stress at bone-implant interface.[35]

To simulate accurate results from the experiment, all structures were fixed with the specific value. The modulus of elasticity [Young's modulus] and the Poisson ratio of each material were taken from previous studies band are provided in Table 1.[36-38]

Table 2.1 Mechanical Properties

Structure	**Young's modulus (GPa)**	**Poisson's ratio (v)**
Trabecular bone	1.37	0.30
Cortical bone	13.7	0.30
Titanium	110.0	0.35
CoCr alloy	218.0	0.33
Feldspathic porcelain	82.8	0.35
Zirconia	210.0	0.30

This present study aims at analyzing the stress distribution on implants/abutments and bone tissues in terms of splinted crowns with different lengths of tissue level short implants in fixed implant-supported prostheses. The null hypotheses are as follows: splinted and non-splinted crowns have a similar stress distribution on implants/abutments and bone tissues, and there are no variations in the stress distribution in respect of different lengths of tissue level short implants.

CHAPTER III
MATERIALS AND METHODS

3.1 Study Design

This study is designed to be an experiment study by simulating the clinical situation for the use of a double unit restoration on short dental implant at the differences of the crown-implant ratios, implant diameters, and lengths and loading directions on stress concentration to the peri-implant surrounding structure with the three-dimensional finite element analysis.

3.2 Site of Study

The data collection will take place at the laboratory of the Faculty of Dentistry, Mahidol University, Thailand.

3.3 Materials

3.3.1 Straumann®, Standard Plus, Roxolid®, SLActive®, Diameter 4.1 mm, Length 4 mm, Regular Neck (4.8 mm)

3.2 Straumann®, Standard Plus, Roxolid®, SLActive®, Diameter 4.8 mm, Length 4 mm, Wide Neck (6.5 mm)

3.3.3 Straumann®, Standard Plus, Titanium, SLA®, Diameter 4.1 mm, Length 6 mm, Regular Neck (4.8 mm)

3.3.4 Straumann®, Standard Plus, Titanium, SLA®, Diameter 4.8 mm, Length 6 mm, Wide Neck (6.5 mm)

3.3.5 Regular Neck synOcta® Screw-retained abutment

3.3.6 Wide Neck synOcta® Screw-retained abutment

3.4 Instruments

3.4.1 Micro-CT Scanner (Skyscanner 1173, Bruker Company, Belgium)

3.4.2 Three-dimensional Finite Element Analysis Software (NX Nastran® software, Siemens PLM Software®, version 11.0)

3.5 Ethics Approval

Since this laboratory study aims to conduct without violating any human rights, ethics approval is not involved.

3.6 Methods

3.6.1 Three-dimensional Object Scan

All implants and abutments will be scanned using the Micro-CT object scanner (Skyscanner 1173, Bruker Company, Belgium) [Figure.3.1] at the Faculty of Dentistry, Mahidol University to generate dimensional data under 130 kV. Example of the three-dimensional data of the implant and abutment obtained from the Micro CT is shown in Figure 3.2.

Figure 3.1 Micro-CT object scanner (Skyscanner 1173, Bruker Company, Belgium)

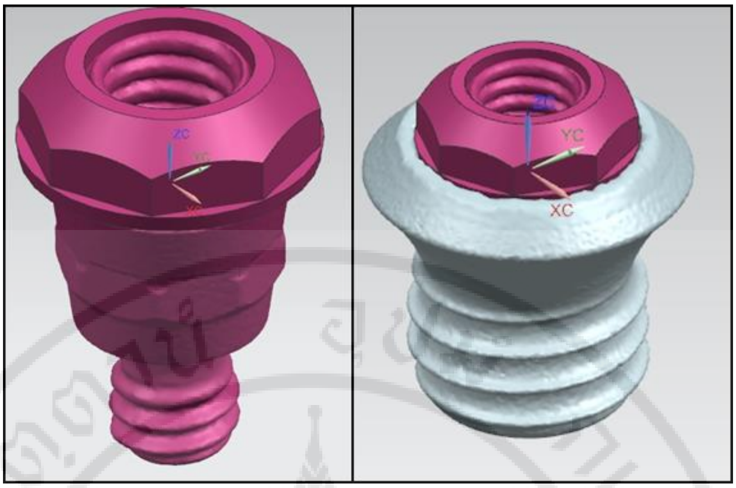

Figure 3.2 Three-Dimension data of Dental Implant and Abutment

3.6.2 Three-dimensional Finite Element Analysis

After 3-dimensional data of all the components in the experiment are ready, all the data will be sent for model design. In this study, 3-dimensional finite element models will be created according to the dental implants and abutments scan files as configurations. The implant/bone models in this study will be established and analyzed using the NX Nastran® software (Siemens PLM Software®, version 11.0) which allows pre- and post-processing of finite element models, importation of geometries, mesh generation, the configuration of mechanical properties and material models, and simulation of physical performance.

3.6.3 Finite Element Model Design

All finite element models will be built according to the following situations.

3.6.1 A three-dimensional type III bone model[39, 40] was defined by establishing boundary conditions of 20x12x12 mm^3 with the cortical bone thickness of 1 mm. on the outside and trabecular bone contained inside. [Figure.3.3][35, 36]

3.6.2.All dental implants(Straumann®, Standard Plus, Roxolid®, SLActive®) are assumed to be completely osseointegrated to the rough surface and the smooth surface will be placed above the bone.

3.6.3 An implant abutment is screwed properly to the dental implant.

3.6.4 The double-unit implant-supported prosthesis is created in a molar-tooth shape with the symmetrical occlusal table with the restoration margin at the widest part of the neck of the dental implant.[Figure.3.4]

3.6.5 Cement-retained crowns were simulated utilizing Zirconia as the restoration material in this study. For this study, cement thickness was considered irrelevant

3.6.6 All materials are considered homogenous, isotropic, and linear.

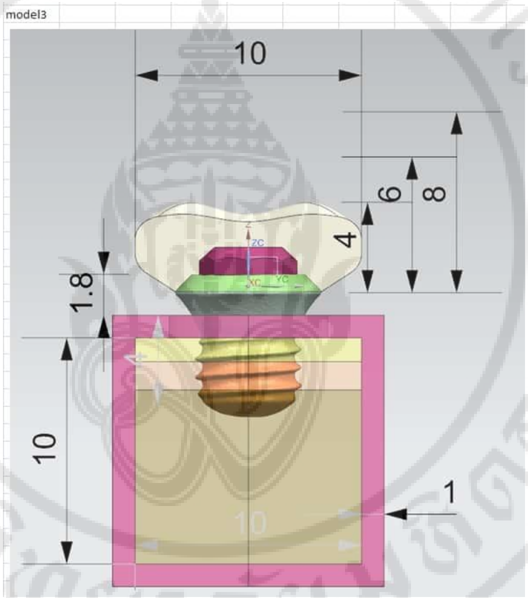

Figure 3.3 Finite Element Model Design

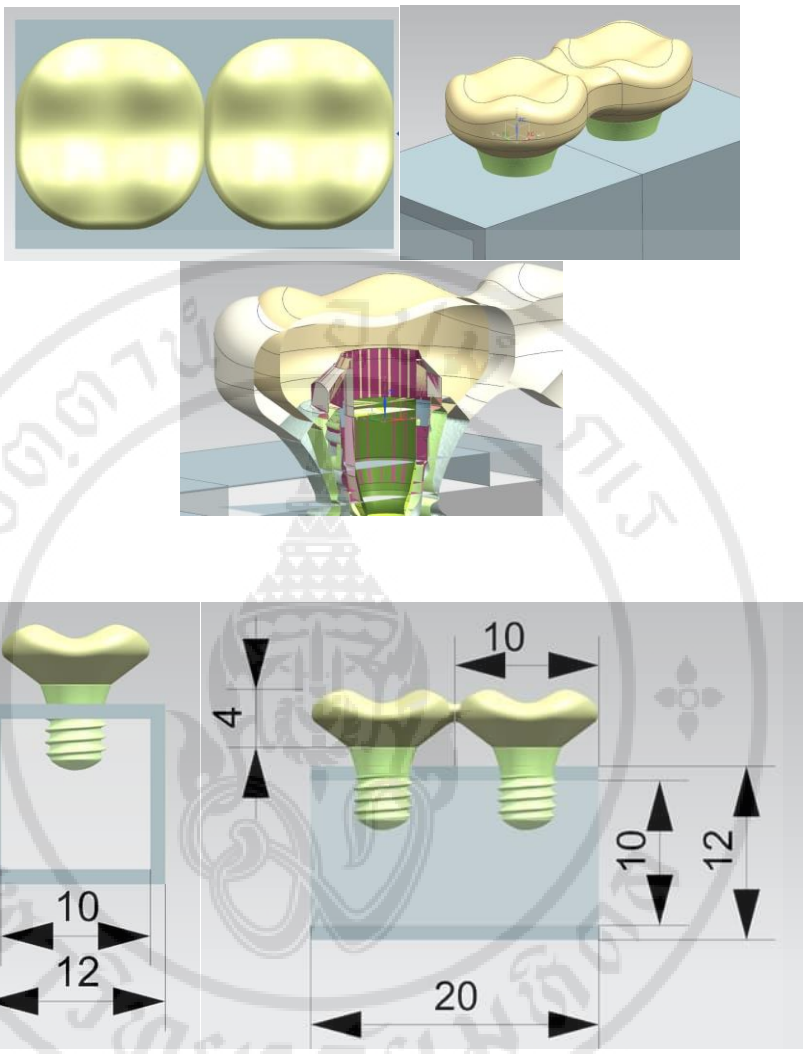

Figure 3.4 Examples of the double-unit implant-supported prosthesis is created in a molar-tooth shape with the symmetrical occlusal table

3.6.4 Nodes and Elements

24 finite element models will be constructed with two different implant diameters 4.1 mm and 4.8 mm; two different implant lengths: 4 mm and 6 mm; and three different crown-implant ratios: 1:1, 1.5:1 and 2:1. The number of nodes and elements are shown in Table 2.

Table 3.1 Nodes and Elements

Implant Diameter at 4.1 mm Implant Length at 4 mm			**Implant Diameter at 4.8 mm Implant Length at 4 mm**		
Crown Height	**Nodes**	**Elements**	**Crown Height**	**Nodes**	**Elements**
4 mm	151549	721395	**4 mm**	212985	999964
6 mm	153428	730744	**6 mm**	218212	1025732
8 mm	154707	737770	**8 mm**	222763	1051220
Implant Diameter at 4.1 mm Implant Length at 6 mm			**Implant Diameter at 4.8 mm Implant Length at 6 mm**		
Crown Height	**Nodes**	**Elements**	**Crown Height**	**Nodes**	**Elements**
6 mm	157065	702457	**6 mm**	183801	839534
9 mm	159272	713972	**9 mm**	190801	878960
12 mm	161496	725323	**12 mm**	197393	916451

There are totally 48 experimental states according to the 12 different finite element models from two implant diameters (4.1 mm and 4.8 mm), two implant lengths (4 mm and 6 mm), three crown-implant ratios (1:1, 1.5:1 and 2:1), and two different external loadings (90° axial loading 200N each and 45° oblique loading 100N each) on the occlusal surface relative to the plane of occlusion [14, 41, 42] as demonstrated in Figure 3.5.

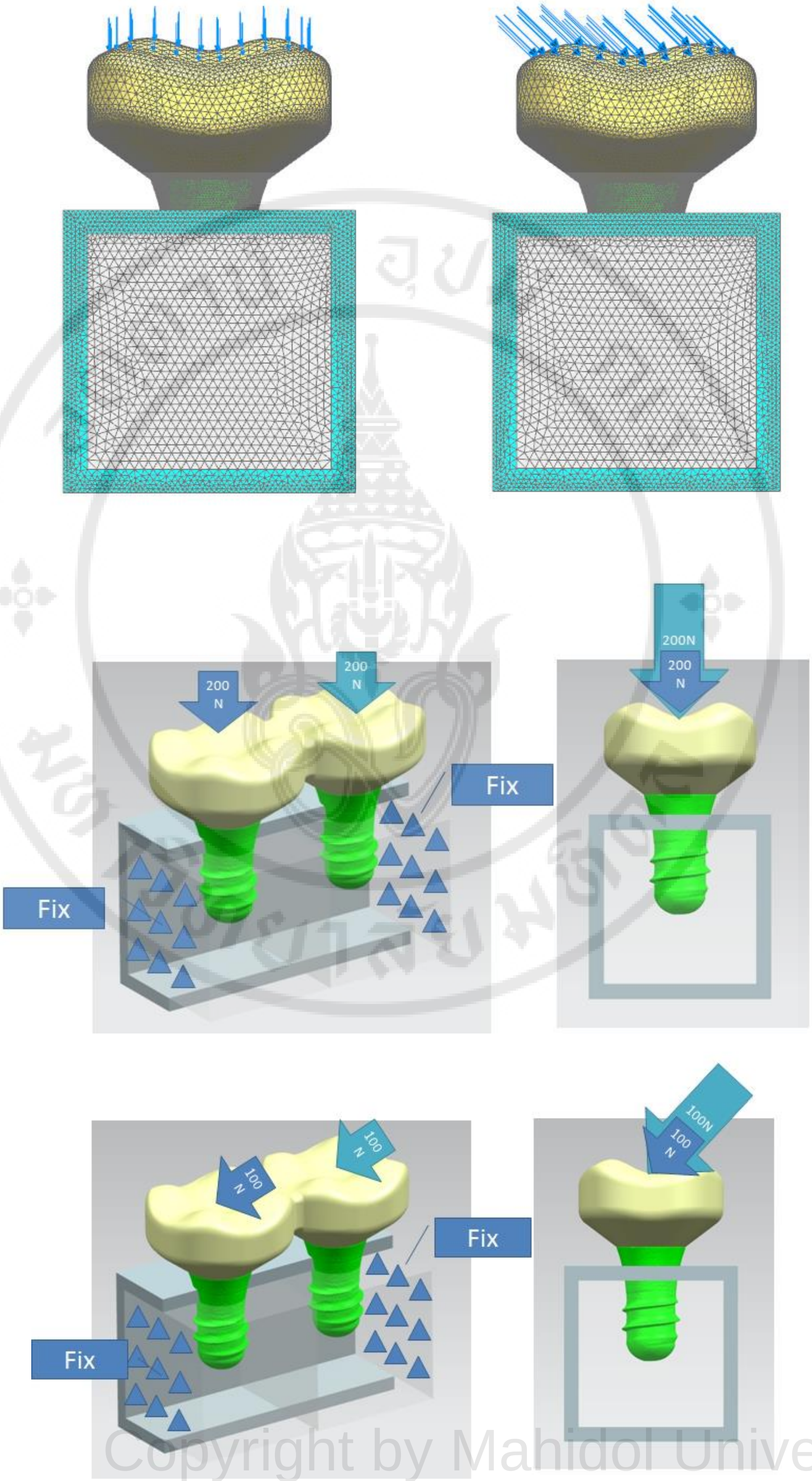

Figure 3.5 Axial and Oblique Loading Directions for Each Finite Element Model

With the above conditions, the finite element analysis software can simulate and records the stress values. The focus of this study is at the implant abutments and crestal bone because these areas are often related to mechanical and biological complications.

3.7 Data Collection and Statistical Analysis

The data that will be evaluated includes

- The Principal Stress values of axial and oblique loading on cortical and trabecular bone and the equivalent von Mises stress values for implants and abutments in megapascals (MPa).

The study used descriptive analysis. As this study was a experimental study which was done by elaborate simulation(Micro-CT Scanner (Skyscanner 1173, Bruker Company, Belgium) and certified computer calculation program(Three-dimensional Finite Element Analysis Software (NX Nastran® software, Siemens PLM Software®, version 11.0), the authors assumed that there was one result under same valuables in same situation. Thus, there was one sample for each situation.

CHAPTER IV
RESULTS

4.1 Stress value on the implant fixture

The maximum stress values on the implant abutment for each model were shown in Table 4.1. Some examples of the stress distribution on the implant fixtures were shown in Figure 9 and Figure 10. In term of stress distribution, the blue color indicates the area with low stress values, and the red color indicates the area with high stress values. The lowest stress value (39.82 MPa) on implant fixture was found in non-splinted crowns with implant diameter 4.8 mm, 6 mm length, and crown 12 mm height with axial (90°) loading. The maximum stress value of the implant is in the splinted crown model at 12 mm of the crown height while the implant is 6 mm long; the tensile strength is at 213.96 MPa in the oblique direction.

On average, the stress is very high when receiving an oblique force and not significantly different when receiving an axial force. The ability to load, compared among the 4 models, the 4th model (Ø4.8, 6 mm in length) can be loaded the most. The next one is the 3rd model (Ø4.8, 4 mm in length), followed by the 2nd model (Ø 4.1, 6 mm in length) and the 1st model (Ø 4.1, 4 mm in length) respectively.

On the comparison between the connected crown and non-connected crown, we found that the maximum stress value did not differ significantly in the same size implant. However, when considering the Finite Element Analysis, the affected area was different. In the case of the separate or non-connected crown, the force was spread around each implant fixture while the connected area of the split or connected crown received the less force that was concentrated on the outside of the implant as seen from the area in the red circle in Figure 8 and Figure 9.

Table 4.1 Maximum stress values of axial and oblique loading on splinted implant crowns

Diameter (mm)	**Length (mm)**	**Crown height (mm)**	**Axial loading (MPa)**	**Oblique loading (MPa)**
4.1	4	4	68.40	97.52
		6	68.09	136.19
		8	67.47	172.40
	6	6	62.51	124.33
		9	59.78	175.86
		12	58.54	213.96
4.8	4	4	40.15	41.73
		6	40.32	56.12
		8	40.36	71.10
	6	6	36.23	47.20
		9	36.23	66.49
		12	36.19	85.92

The comparison of stress values of axial and oblique loading on the implant fixture with different implant diameters for each model was shown in Table 4.2. With the same implant length and crown height, an implant with a wider diameter always showed fewer stress values in both axial and oblique loads.

Table 4.2 Maximum stress values of axial and oblique loading on non-splinted implant crowns

Diameter (mm)	Length (mm)	Crown height (mm)	Axial loading (MPa)	Oblique loading (MPa)
4.1	4	4	59.77	101.33
		6	59.16	135.51
		8	59.16	170.03
	6	6	43.75	120.98
		9	46.77	168.26
		12	47.81	212.71
4.8	4	4	34.30	41.40
		6	34.64	55.97
		8	34.65	70.91
	6	6	31.55	47.88
		9	31.56	66.67
		12	34.73	85.66

Table 4.3 Comparison of stress values of axial and oblique loading on implant fixture with different implant diameters

			Separated crowns		**Splinted crowns**	
Length (mm)	**Crown height (mm)**	**Diameter (mm)**	**Axial loading (MPa)**	**Oblique loading (MPa)**	**Axial loading (MPa)**	**Oblique loading (MPa)**
4	4	4.1	59.77	101.33	68.40	97.52
		4.8	34.30	41.40	40.15	41.73
	6	4.1	59.16	135.51	68.09	136.19
		4.8	43.75	55.97	40.32	56.12
	8	4.1	59.16	170.03	67.47	172.40
		4.8	34.65	70.91	40.36	71.10
6	6	4.1	43.75	120.98	62.51	124.33
		4.8	31.55	47.88	36.23	47.20
	9	4.1	46.77	168.26	59.78	175.86
		4.8	31.56	66.67	36.23	66.49
	12	4.1	47.81	212.71	58.54	213.96
		4.8	34.73	85.66	36.19	85.92

When compared among different diameter implants of the implants with the same length, Ø 4.1 mm has more maximum stress concentration than Ø4.8 mm. This means that Ø4.8 mm or a greater diameter can help distribute the force better.

The same diameter implant with the longer implant resulted in a greater C: R ratio without increasing the stress. Unless in the case of a 12 mm high, the 6 mm-long implant has maximum stress in the oblique force exceeding the standards that the titanium implant can accept [43] .

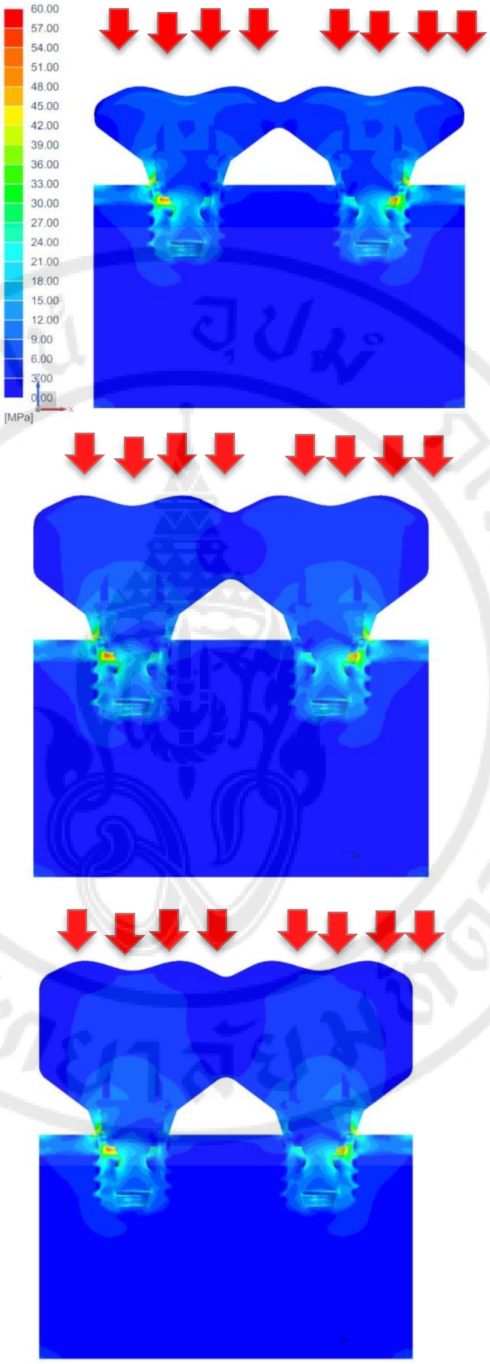

Figure 4.1 Stress distribution around dental implant fixture and abutment in splinted crown models from axial (90°) loading for splinted crowns implant diameter 4.1 mm, length 4 mm, crown height 4, 6, 8 mm respectively.

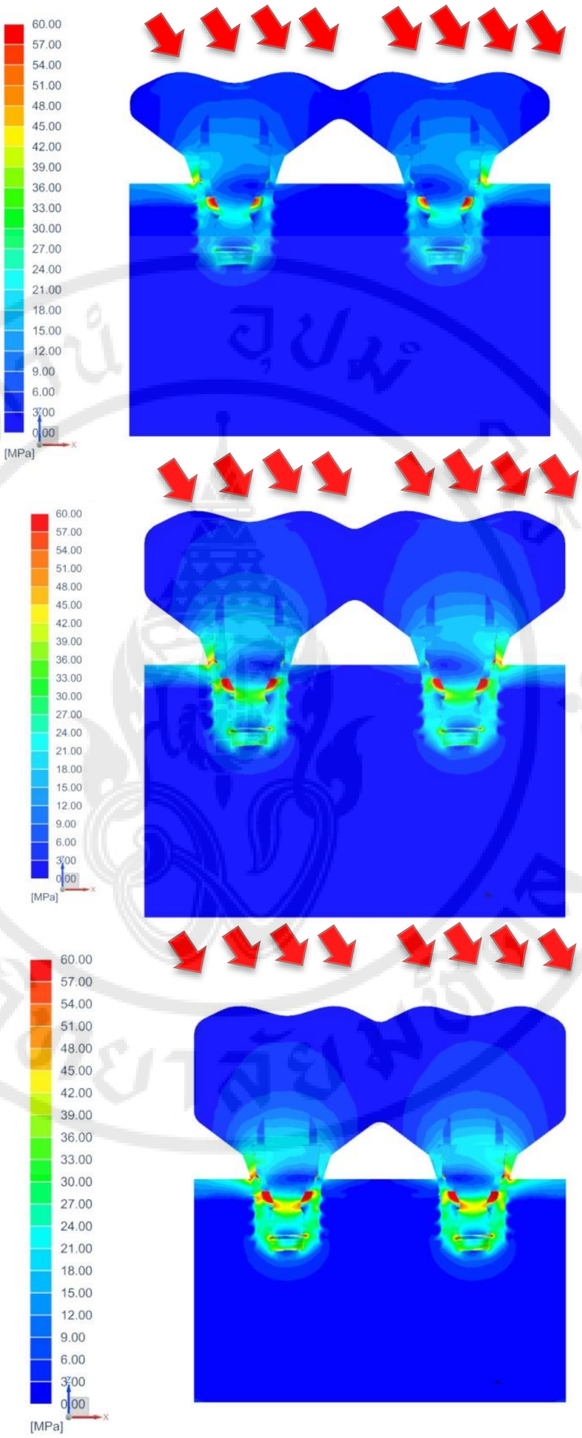

Figure 4.2 Stress distribution around dental implant fixtures and abutments in splinted crown models from oblique (45°) loading for implant diameter 4.1 mm, length 4 mm, crown height 4, 6, 8 mm

4.2 Stress value on crestal bone

Table 4.4 showed the stress distribution in the crestal bone of each model. The lowest stress value on the crestal bone of 51.36 MPa was found in the implant diameter at 4.8 mm, with the length at 6 mm and the crown height at 6.9 mm with axial loading (90°). The highest stress value at 142.47 MPa was found in the implant diameter at 4.1 mm with the length at 6 mm and the crown height at 12 mm. Some parts of the simulation of the force affecting the crestal bone in some cases were shown in Figure 4.2, 4.3 Table 4.4 and Table 4.5 showed a comparison of the force both axial loading and oblique loading (45°).

Table 4.4 Maximum stress values of axial and oblique loading on crestal bone on splinted implant crowns

Diameter (mm)	**Length (mm)**	**Crown height (mm)**	**Axial loading (MPa)**	**Oblique loading (MPa)**
4.1	4	4	67.92	85.26
		6	69.28	107.01
		8	69.24	129.14
	6	6	61.34	90.54
		9	59.94	120.37
		12	61.62	142.47
4.8	4	4	57.56	62.79
		6	57.66	76.24
		8	57.67	89.62
	6	6	51.36	60.55
		9	51.36	75.81
		12	51.40	91.88

The comparison of stress values of axial and oblique loading on crestal bone with different implant diameters for each model was shown in Table 4.4 The diameter of the wider implant will always give less stress value in the implant with the same length and the same crown height. On the contrary, for the variety length of implants in the same diameter, the results were within similar range.

Table 4.5 Maximum stress values of **axial and oblique loading on crestal bone with non-splinted** implant crowns

Diameter (mm)	**Length (mm)**	**Crown height (mm)**	**Axial loading (MPa)**	**Oblique loading (MPa)**
4.1	4	4	53.82	83.40
		6	53.81	105.62
		8	53.82	127.79
	6	6	49.99	89.81
		9	49.77	111.32
		12	49.56	145.98
4.8	4	4	41.19	59.55
		6	41.27	72.88
		8	41.29	86.18
	6	6	40.00	58.79
		9	40.00	74.76
		12	39.82	91.15

Table 4.6 Comparison of stress values of axial and oblique loading on crestal bone with different implant diameters in separated and splinted models

			Separated crowns		**Splinted crowns**	
Length (mm)	**Crown height (mm)**	**Diameter (mm)**	**Axial loading (MPa)**	**Oblique loading (MPa)**	**Axial loading (MPa)**	**Oblique loading (MPa)**
4	4	4.1	53.82	83.40	67.92	85.26
		4.8	41.19	59.55	57.56	62.79
	6	4.1	53.81	105.62	69.28	107.01
		4.8	41.27	72.88	57.66	76.24
	8	4.1	53.82	127.79	69.24	129.14
		4.8	41.29	86.18	57.67	89.62
6	6	4.1	49.99	89.81	61.34	66.67
		4.8	40.00	58.79	51.36	60.55
	9	4.1	49.77	111.32	59.94	120.37
		4.8	40.00	74.76	51.36	75.81
	12	4.1	49.56	145.98	61.62	142.47
		4.8	39.82	91.15	51.40	91.88

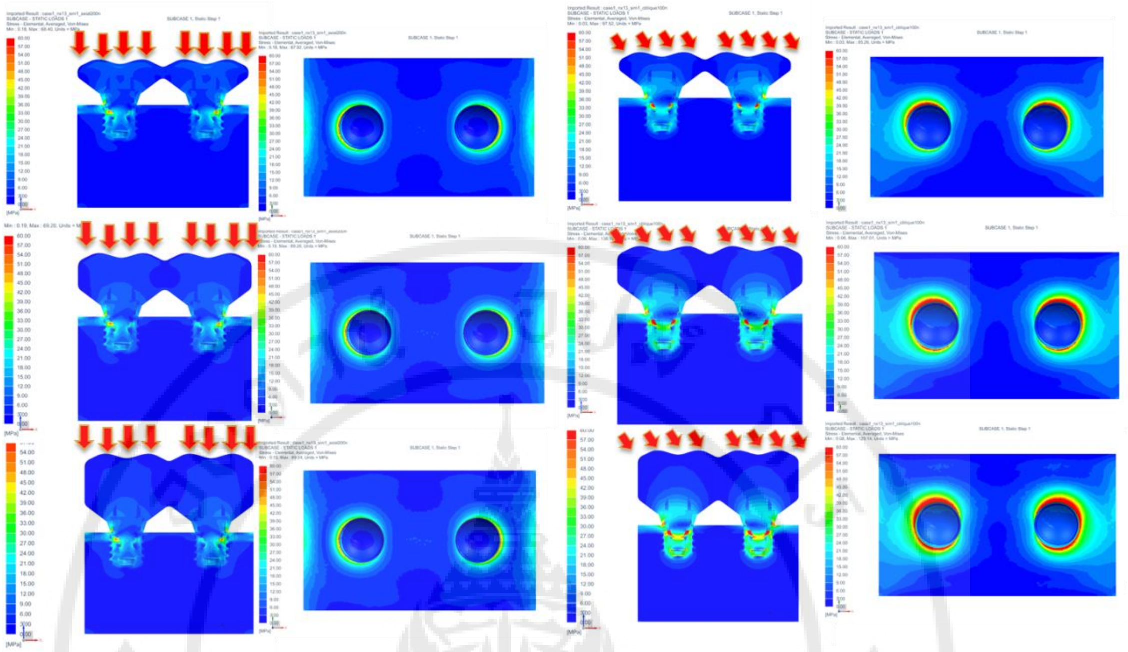

Figure 4.3 Connected crowns model on diameter 4.1 mm length 4.0 ,crown height 4,6,8 respectively under axial and oblique forces.

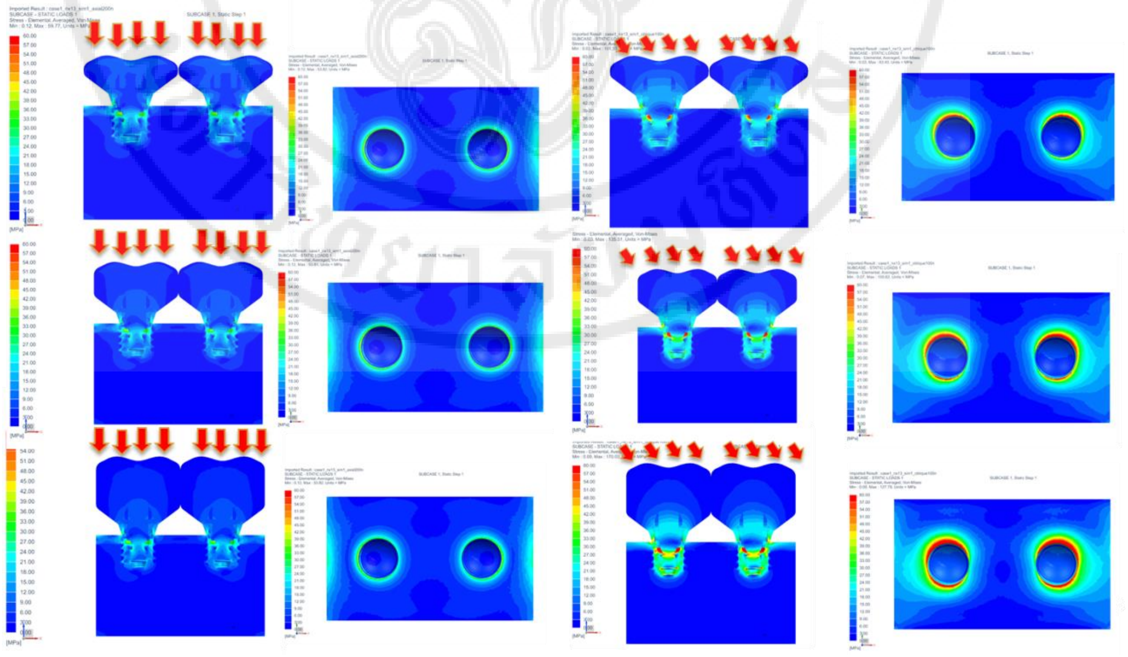

Figure 4.4 Non-connected crowns model on diameter 4.1 mm length 4.0 ,crown height 4,6,8 respectively under axial and oblique forces.

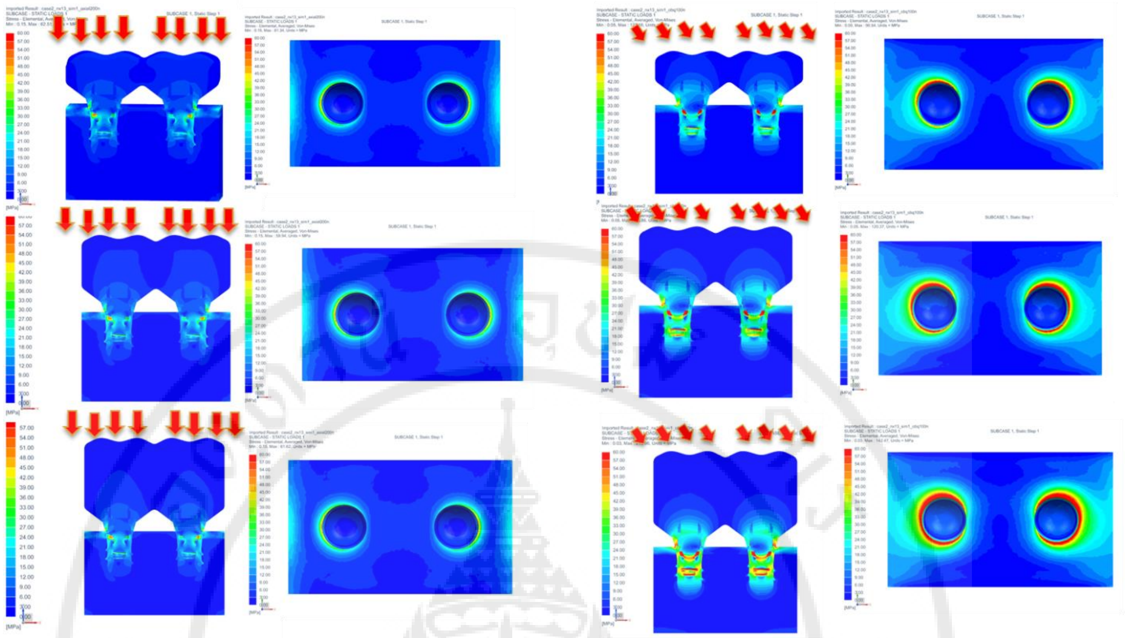

Figure 4.5 Connected crowns model on diameter 4.1 mm length 6.0 ,crown height 6,9,12 respectively under axial and oblique forces.

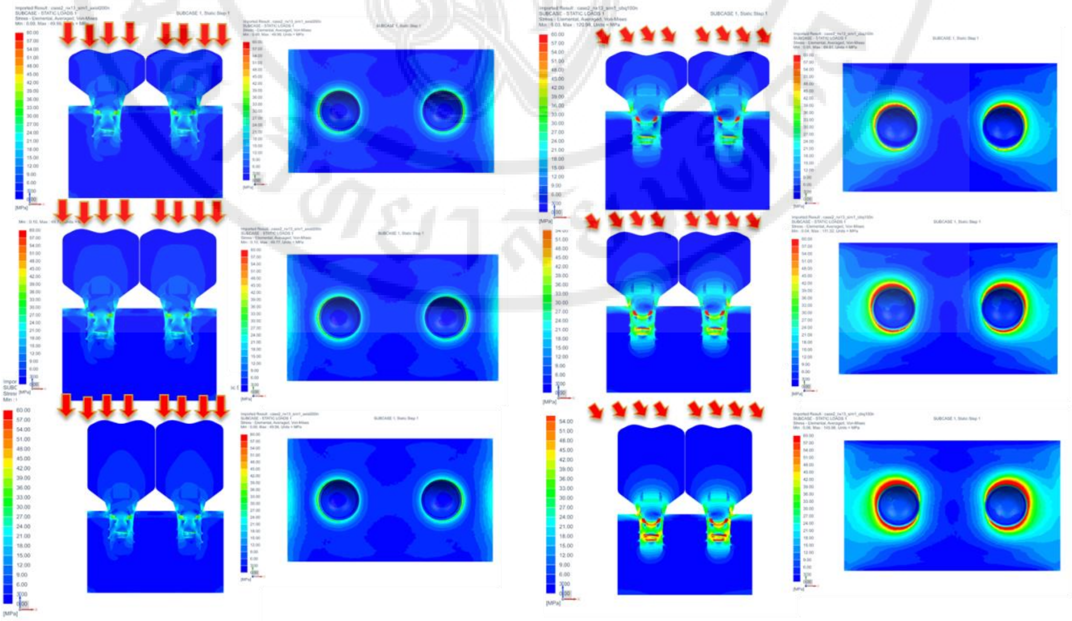

Figure 4.6 Non-connected crowns model on diameter 4.1 mm length 6.0 ,crown height 6,9,12 respectively under axial and oblique forces.

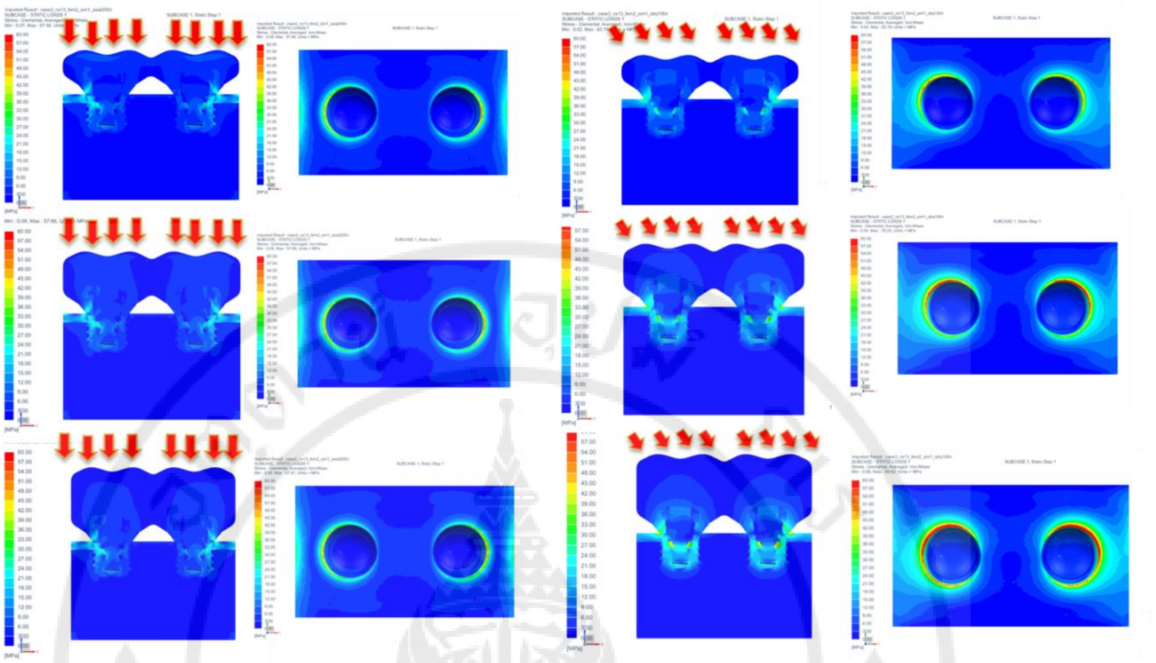

Figure 4.7 Connected crowns model on diameter 4.8 mm length 4.0, crown height 4,6,8 respectively under axial and oblique forces.

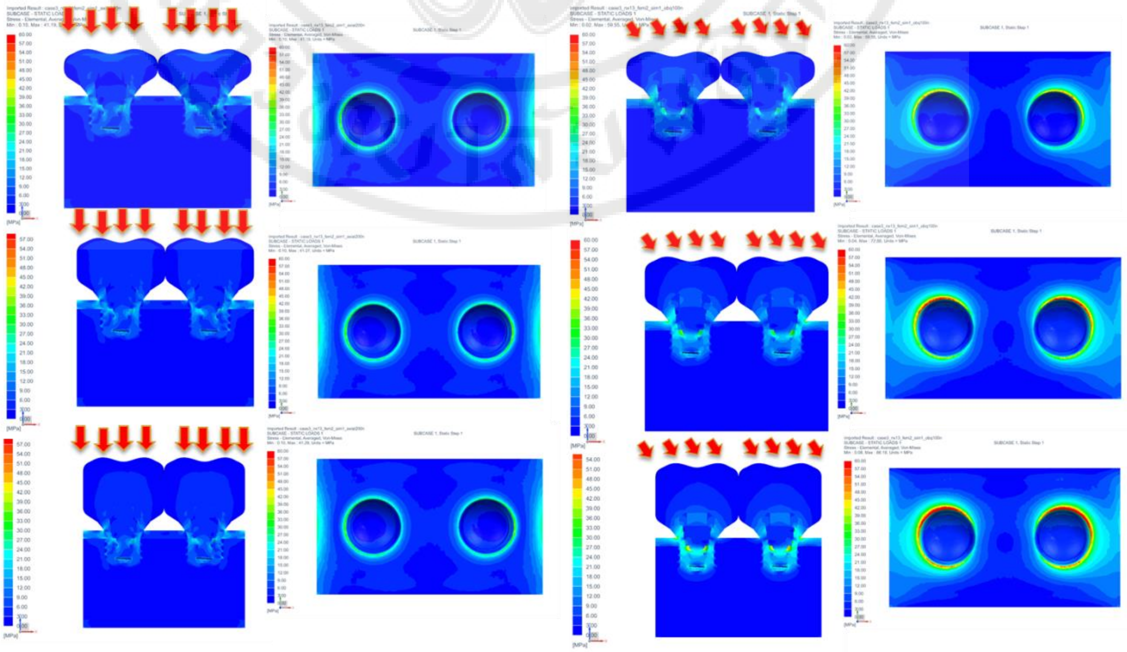

Figure 4.8 Non-Connected crowns model on diameter 4.8 mm length 4.0, crown height 4,6,8 respectively under axial and oblique forces.

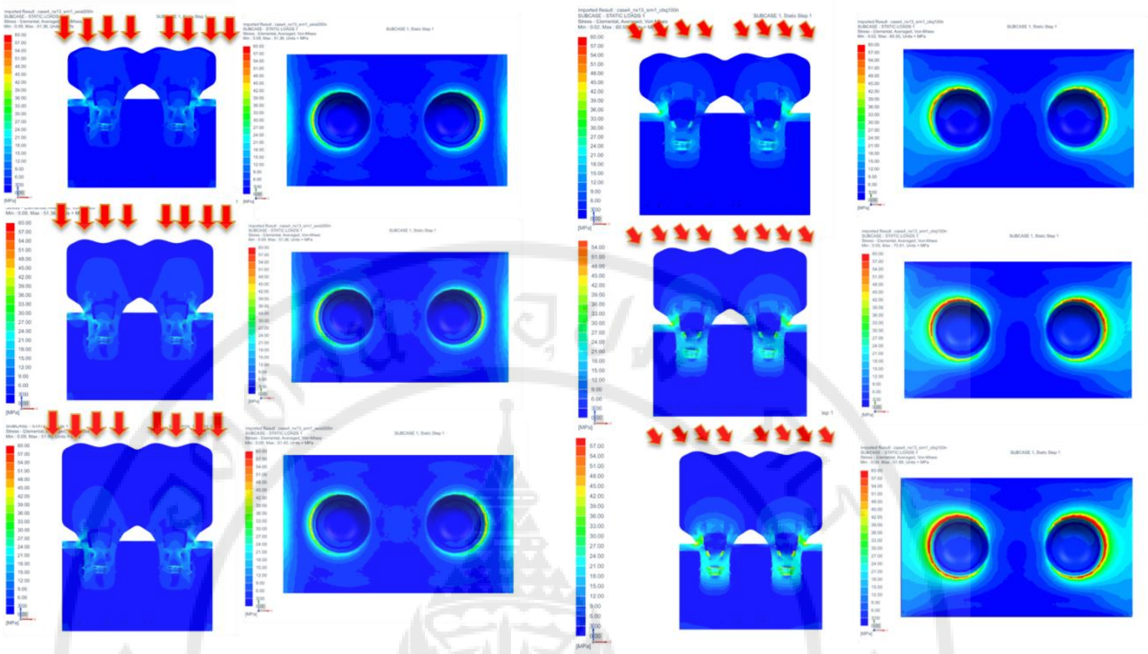

Figure 4.9 Connected crowns model on diameter 4.8 mm length 6.0 ,crown height 6,9,12 respectively under axial and oblique forces.

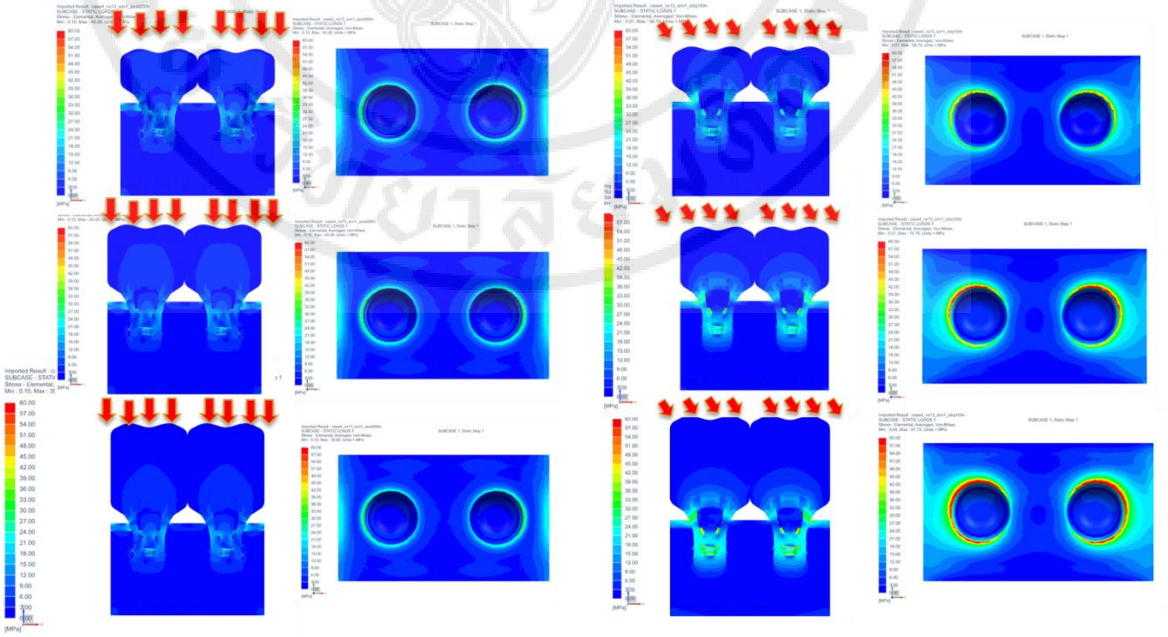

Figure 4.10 Non-Connected crowns model on diameter 4.8 mm length 6.0 ,crown height 6,9,12 respectively under axial and oblique forces.

CHAPTER V

DISCUSSION

48 experimental states were analyzed according to 12 finite element models. Mandibular bone segment (bone type III) was assumed with a rectangular block with sufficient height regarding to the previous study by Teixeira et al.[44] , as long as the height of bone is sufficient, there was no difference between simulated models and the whole human mandibular in terms of stress values and distribution characteristics. All the models were completely divided into fine elements and nodes to achieve the most reliable result.

The crestal bone (cortical bone) can withstand the stress at 60 MPa. If it exceeds, there will be an opportunity for crestal bone loss[45, 46] . If the titanium is loaded exceeding 275 MPa by default of the software, it can be seen that the inside of the finite element model becomes red, which indicates that a fracture likely occurs. In this study authors were only concerned with the length of the implant and the prosthetic design and found certain differences. Since variation in bone types and height clinically[39, 47] , further validating clinical study is suggested for optimal consideration.

Under axial (90°) loading, the increase in crown height of short dental implant showed slight increase within acceptable range in stress concentration around implant abutment or crestal bone [Table 4.1 – 4.6], but strongly increase stress concentration around implant abutment and crestal bone under oblique (45°) loading [Table 4.1-4.6], the same phenomenon also reported in dental implant with regular length. [36, 37] For oblique (45°) loading, the increase of crown-implant ratio from 1:1 to 1.5:1 had increase stress values on implant abutment in a range of 22.38-39.08% and 21.42-41.44%, from 1.5:1 to 2:1 the stress values had increase in a range of 18.24-26.41% and 17.54-26.58%, and from 1:1 to 2:1 the stress values had increase in a range of 44.72-67.80% and 42.73-76.78% in non-connected and connected models, respectively. This stress can directly transfer from implant abutment to the abutment screw, which can cause screw loosening or fracture of the screw leads to mechanical complications. [36]

Larger implant diameter also revealed lower stress distribution (Table 4, 6), under both axial (90°) and oblique (45°) loading. Moreover, a wider diameter implant always showed lower stress value in comparison to the narrower implant within the same condition. This result might come from the fact that a bigger implant has more surface contact area to share the force to the surrounding structure. [45]

The design of the restoration in this study was symmetrical occlusal table to avoid the factor of asymmetry tooth shape that might compromise the result from the direction of oblique occlusal loading. According to this configuration of the restoration, the results might not represent natural tooth shape especially on the lower molar tooth which usually presents with asymmetry occlusal table and also with mesio-distal width greater than bucco-lingual width. [48]

Materials of the implants used in this study, Titanium and Roxolid®, were not taken in account of difference due to same surface, SLA, were achieved by Micro-CT Scanner (Skyscanner 1173, Bruker Company, Belgium).

The screw-retained type was selected over the cement-retained abutment to avoid cement thickness factor between the abutment and the restoration in the finite element models, which might affect the stress distribution study. Though, distinct abutment forms between Straumann® RN (regular neck) and WN (wide neck) have to be noted. Another is in the process to obtain precision models of dental implant and abutment, since the size of each component is tiny, regular three-dimensional scanning device was unable to obtain appropriate data, so Micro-CT scanning device was chosen in order to obtain precise data for each component which increase cost and also increase size of the files thus increase time to simulate each model. Finally, the process to simulate the combination of dental implant and implant abutment, the contact area between the dental implant and implant abutment, also the human bone are complicated and difficult to combine precisely and need software to compensate the shape of the model, this factor might affect the outcome.

Connecting and not connecting the crown on the implant was indifferent in the force but the force distribution. That is to say, if there is no connection, the force distribution is better than the splinted/connected crown at all distances. In short, connecting the crown cannot cause a reduction of the maximum stress on the cortical bone from the simulation. In some cases, it may cause more stress on the edge and cause the implant to receive more force of the axial load. The stress concentration occurring outside of the splinted crown model may result in an outer implant fracture or crestal bone resorption in the future. [43]

It was found that stress value increased significantly with the increase in the crown-root ratio for every implant length, while small difference was observed amidst splinting and separating implants. In addition, the authors' recommendation to not exceed 2:1 crown-root ratio. However, other studies reported stress reduction in splinting models. Jomjunyong et al. reported not only positive effect on splinting model when compare to non-splinting, but also reduced stress value17-20% in both standard and short dental implant. [12, 21, 37]

Another study by Yang et al[49] focus on splinted restorations on short implants also confirmed that while no significant differences were found in both splinting and non-splinting implants, strain value increased along with implant diameter size. To sum up, in the area with a limited height with adequate mesio- distal and bucco-lingual width, it is recommended to choose a wider implant first.

CHAPTER VI
CONCLUSION

With the limitations of this study, connecting implants together do not have a significant effect on stress distribution. Thus, the individualization of two restorations on two short dental implants demonstrates better stress distribution when compared to the splinted ones. The crown-implant ratio has a strong effect on stress values under oblique (45°) loading but has a less significant effect under axial (90°) loading. The increase of the crown-implant ratio creates more stress on implant fixture and crestal bone, which can lead to mechanical and biological complications. Connecting two crowns on two implants does not reduce force loading on the implant on average but increases force concentration on the connected site and reduces force concentration to the outer ring. Thus, a risk leads to loss of crestal bone on around splinted crowns. From authors' recommendation, minimizing crown-implant ratio is preferred. Larger diameter dental implants should also be considered as an important factor to minimize the stress on the dental implant. Dentists are recommended to carefully evaluate if the increase C/I ratio is unavoidable.

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