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

Objectives: To demonstrate 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 *Methodology*: 24 finite element models were simulated representing the implants replacing of lower first and second mandibular molars. Short dental implants (Straumann®, Standard Plus, Roxolid®, SLActive®, Diameter 4.1 mm, Length 4 mm, Regular Neck (4.8 mm); Straumann®, Standard Plus, Roxolid®, SLActive®, Diameter 4.8 mm, Length 4 mm, Wide Neck (6.5 mm); Straumann®, Standard Plus, Titanium, SLA®, Diameter 4.1 mm, Length 6 mm, Regular Neck (4.8 mm), and Straumann®, Standard Plus, Titanium, SLA®, Diameter 4.8 mm, Length 6 mm, Wide Neck (6.5 mm)) were applied under various prosthetic conditions. The maximum principal stress of peri-implant structure and Von Mises stress of implant were evaluated when 400 N 90° axial load and 200 N 45° oblique load were applied. A type III bone was approximated and complete osseointegration was assumed. *Result and Discussion*: The FEA study generated maximum Von Mises stress at the cortical bone around the implant neck in all models. Average stress value was not significant difference in each model of the same implant length. More stress distribution values were observed in models which two implants were not splinted. When implants were splinted, stress values and concentration area decreased in the splinted sites and increased on the others in cortical and cancellous bone. *Conclusions*: The individualization of two restorations on two short dental implants demonstrated better stress distribution when compared to the splinted ones.

Keywords: *Short Dental Implant, Splinted Implants, Abutment, Bone, Stress Distribution, Finite Element Analysis*

1. Introduction

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 for 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 teeth in 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 (Draenert et al, 2014).

These procedures have disadvantages, for instance, the inappropriateness of surgery, high cost, and long treatment duration after a bone graft and implant installation (Assuncao et al, 2009). The studies of bone resorption occurred after a bone graft, which an increase in the vertical height is inexact (Urban et al, 2019). The authors conducting the bone graft resorption rate suggested that it was hard to acquire bones with optimal height and strength from a bone graft (Chee 2018; Gultekin et al, 2016). The guided bone regeneration mechanism studies also suggested that it was difficult to obtain bones with optimal strength from a bone graft (Liu and Kerns 2014).

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. A systematic review not only affirmed that extra-short implants (<6 mm) with 5 years of follow-up exhibited an acceptable survival rate, but also suggested splinting extra-short implants reduced prosthetic complication and implant failure (Ravida et al, 2019). Nonetheless, some researchers claimed that splinted prostheses involved 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 and 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, which are 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. (Geng, Tan, and Liu 2001)

Due to a lack of supporting evidence on the above issues, it results in this study intending to study mechanical measurement of splinted and non-splinted of two crowns on two dental implants by the Finite Element Analysis (Assuncao et al, 2009; Geng, Tan, and Liu 2001; Toniollo et al, 2012). 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 implants, dental 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 the 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.

2. Objectives

To demonstrate 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.

3. Materials and Methods

3.1 Three-dimensional Object Scan

All implants and abutments will be scanned using the Micro-CT object scanner (Skyscanner 1173, Bruker Company, Belgium) (Fig.1) at the Faculty of Dentistry, Mahidol University to generate dimensional data under 130 kV.

3.2 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 implant and abutment scan files as configurations. The implant and 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.

3.3 Finite Element Model Design

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

a. A three-dimensional type III bone model (Juodzbalys and Kubilius 2013; Jomjunyong et al, 2017) was defined by establishing boundary conditions of 20x12x12 mm with the cortical bone thickness of 1 mm. on the outside and trabecular bone contained inside (Fig. 2)(Bahadirli (Bahadirli et al, 2018; de Moraes et al, 2013).b. All dental implants (Straumann®, Standard Plus, Roxolid®, SLActive®) are assumed to be completely osseointegrated to the rough surface and the smooth surface which will be placed above the bone.

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

d. 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 (Fig.2).

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

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

3.4 Nodes and Elements

Twenty four finite element models will be constructed with two different implant diameters: 4.1 mm and 4.8 mm; two different extra-short 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 1.

Table 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 400N and 45° oblique loading 200N) on the occlusal surface relative to the plane of occlusion (Lemos et al, 2018; Bozkaya, Muftu, and Muftu 2004; Takaki, Vieira, and Bommarito 2014; van der Bilt et al, 2008). One-way Anova was used to statistically analysed in the studies.

4. Results and Discussion

The maximum stress values on the implant abutment for each model were shown in Table 2. Some examples of the stress distribution on the implant fixtures were shown in Figure 3 and 4. 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 an implant fixture was found in non-splinted crowns with the 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 fourth model (Ø4.8, 6 mm in length) can be loaded the most. The next one is the third model (Ø4.8, 4 mm in length), followed by the second model (Ø 4.1, 6 mm in length) and the first model (Ø 4.1, 4 mm in length) respectively.

On the comparison between the splinted crown and non-splinted 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 separated or non-splinted crown, the force was spread around each implant fixture while the connected area of the split or splinted crown received the less force that was concentrated on the outside of the implant as seen from the area in the red area in figure 3 and 4.

Table 2 Comparison of stress values of axial and oblique loading on the implant fixture with different implant diameters

			Splinted crowns		Separated crowns	
Diameter (mm)	**Length (mm)**	**Crown height (mm)**	**Axial loading (MPa)**	**Oblique loading (MPa)**	**Axial loading (MPa)**	**Oblique loading (MPa)**
4.1	4	4	68.40	97.52	59.77	101.33
		6	68.09	136.19	59.16	135.51
		8	67.74	172.40	59.16	170.03
	6	6	62.51	124.33	43.75	120.98
		9	59.78	175.86	46.77	168.26
		12	58.54	213.96	47.81	*212.71
4.8	4	4	40.15	41.73	34.30	41.40
		6	40.32	56.12	43.75	55.97
		8	40.36	71.10	34.65	70.91
	6	6	36.23	47.20	31.55	47.88
		9	36.23	66.49	31.56	66.67
		12	36.19	85.92	34.73	85.66

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 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.

When compared among different diameter implants of the implants with the same length, Ø4.1 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.

Increased in crown height with same implant length significantly increased C: R ratio and stress value. On the contrary, the same diameter implant with the longer implant resulted in a less C: R ratio without increasing the stress. Unless in the case of a 12-mm height*, the 6 mm-long implant has maximum stress in the oblique force exceeding the standards that the titanium implant can accept (Szafrańska et al, 2019).

Figure 1 Micro-CT object scanner (Skyscanner 1173, Bruker Company, Belgium)

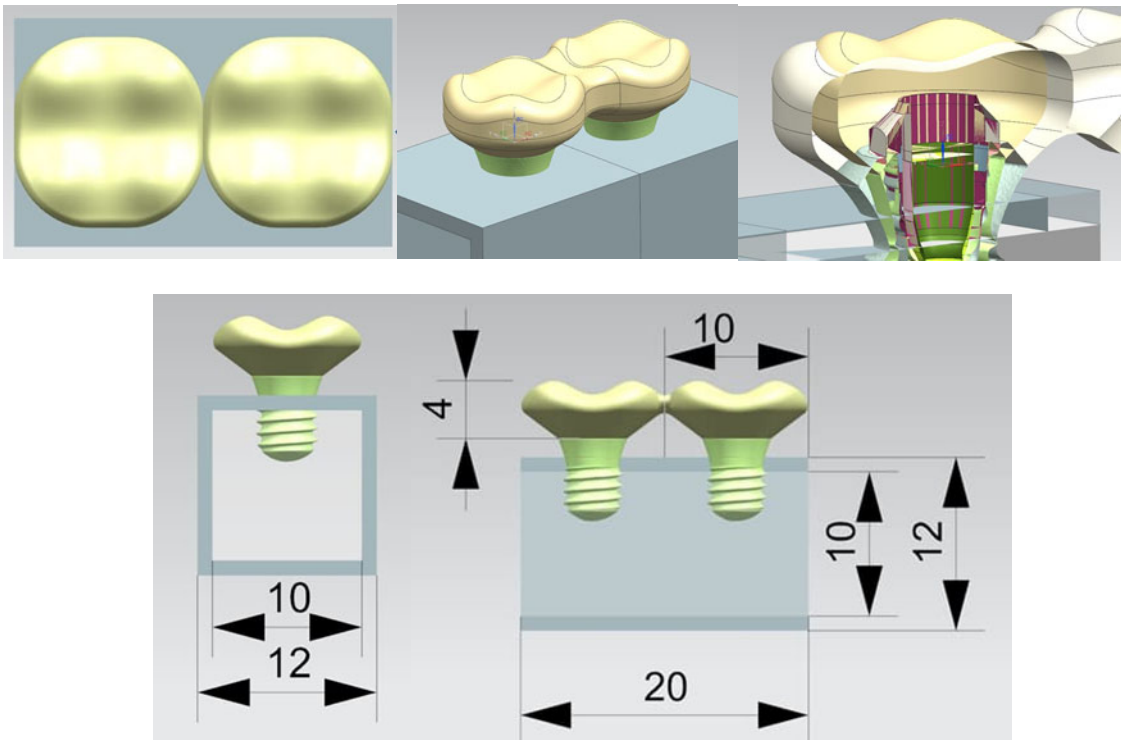

Figure 2 Examples of the double-unit implant-supported prosthesis is created in a molar-tooth shape with the symmetrical occlusal table

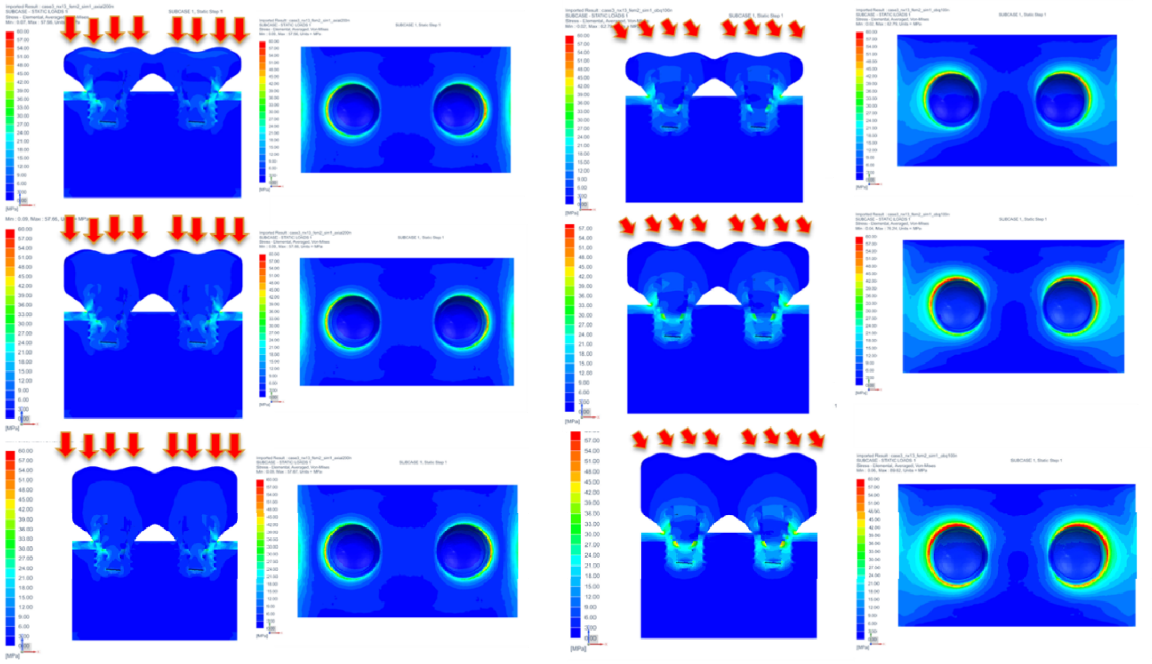

Figure 3 Splinted crowns model on diameter 4.8 mm length 4.0, crown height 4, 6, 8 respectively under axial and oblique forces.

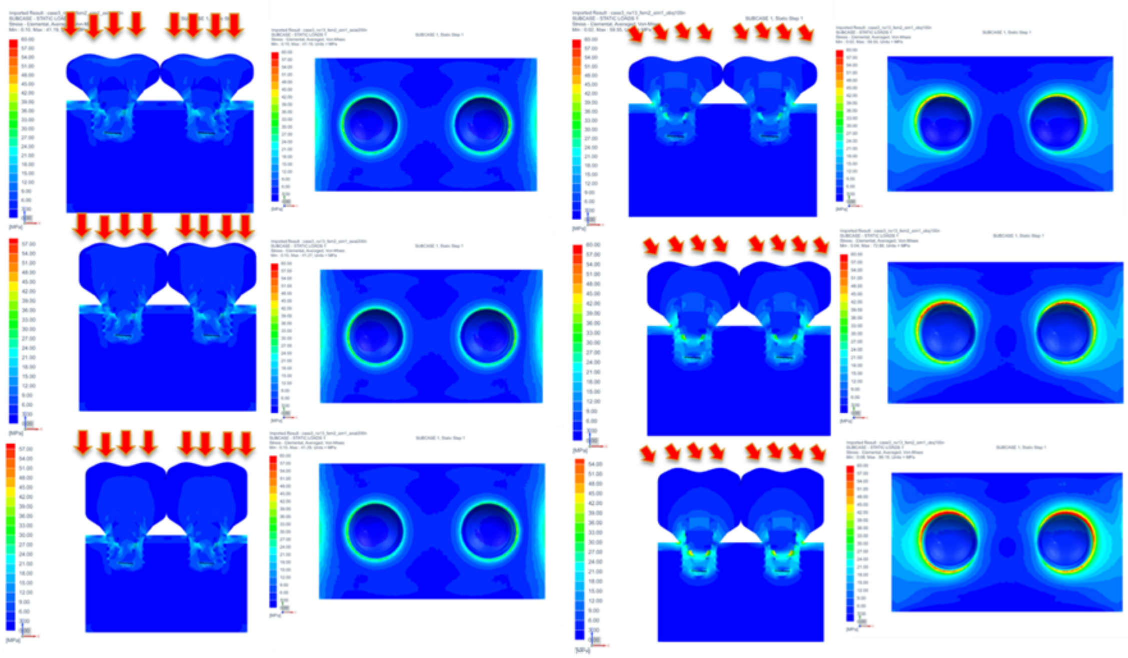

Figure 4 Non-splinted crowns model on diameter 4.8 mm length 4.0, crown height 4, 6, 8 respectively under axial and oblique forces.

The 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. (Teixeira et al, 1998). 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 of crestal bone loss (Baggi et al, 2008). 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.

The larger implant diameter also revealed significant lower stress distribution (Table 2), under both axial (90°) and oblique (45°) loading. Moreover, the 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 the bigger implant has more surface contact area to share the force to the surrounding structure. (Baggi et al, 2008)

The design of the restoration in this study was the 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 the natural tooth shape especially on the lower molar tooth which usually presents with the asymmetry occlusal table and also with mesio-distal width greater than bucco-lingual width (Magne, Gallucci, and Belser 2003).

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 or 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 (Szafrańska et al, 2019).It was found that stress value increased significantly with the increase in the crown-root ratio for every implant length, while no significant difference was observed amidst splinting and separating implants. However, other studies reported stress reduction in splinting models (Weerapong et al, 2019; Verri et al, 2014; Ramos Verri et al, 2015). The screw-retained type was selected over the cement-retained abutment to avoid a 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 implants and abutments, since the size of each component is tiny, a 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 the dental implant and implant abutment, the contact area between the dental implant and implant abutment, also the human bone were complicated and difficult to combine precisely and need software to compensate the shape of the model; this factor might affect the outcome.

Another study by Yang et al. (Yang, Maeda, and Gonda 2011) focusing 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.

5. 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 the implant fixture and surrounding bone. Connecting two crowns on two implants does not reduce the force loading on the implant on average but increases the force concentration on the connected site and reduces the 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 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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