



Influence of Crown-to-Implant Ratio on Stress Concentration of Fixed Dental Prosthesis in Shortened Dental Arch Concept

Hamiyet Güngör*

Faculty of Dentistry, Ankara University, Turkey

Abstract

Purpose: The aim of this study was to evaluate the effect of crown-to-implant (C/I) ratio on the stress distributions in bone and implant under axial and oblique loads by using three-dimensional (3-D) finite element analysis (FEA) method in case of surgical procedures couldn't be applied especially to the geriatric patients.

Material and methods: Three maxillary bone models were created using with FEA methods. 4.1 x 10 mm ITI dental implants were embedded in first premolar site and one implant supported two-unit fixed dental prostheses were modeled. Shortened dental arch (SDA) concept was also modeled as a treatment option by means of implant supported fixed dental prosthesis. Three different (C/I) ratios (1/1, 1.5/1, and 2/1) were modeled in this study with a 6 mm cantilever extension. 300 N axial and oblique loads were applied to the all fixed dental prosthesis. The highest stress values were recorded and evaluated both in bone and implant.

Results: The determined highest stress in cortical bone was -73.6 MPa under axial loads and -142.4 MPa under oblique loads for 2/1 C/I ratios. The highest von Mises stress value in implant was 312.7 MPa under axial load and 451.1 MPa under oblique load for the highest C/I ratio. With the increasing C/I ratio, stresses were increased both in bone and implant structure.

Conclusion: Within the limitations of this FEA study, increasing C/I ratio increases the stress distribution in bone and implant. One implant supported two-unit cantilever fixed dental prosthesis may be one of the alternative treatment choices for the geriatric patients but this FEA study should be supported with the clinical studies.

Keywords: Dental implants; Crown-to-Implant ratio; Finite element analysis; Geriatric patients

Introduction

Dental implants have been accepted as a successful treatment procedure for partially and totally edentulous jaws [1]. However, bone density and anatomic structures (maxillary sinus etc.) must be considered carefully when the edentulous region is located in the posterior maxilla [2]. Adequate and ideal bone volume for correct positioning of implants can be created in the posterior maxilla by bone augmentation or sinus floor elevation [3]. However, these surgical procedures are associated with increased rate of complications and healing time, especially in older patients. Moreover, surgical procedures may not be the best option for every patient [4], and tooth- or implant-supported cantilever fixed dental prostheses (FDP) may be an alternative when augmentation procedures are not possible [5]. When premolar or molar teeth are missing in the posterior maxilla, the first premolar site is suggested as the ideal location for implant insertion because of sinus pneumatization [2]. The shortened dental arch (SDA) concept can be applied using one implant-supported distal cantilever FDP. According to this concept, bilateral occlusal support extending to the second premolar preserves oral function and prevents temporomandibular joint disorders. The age of the patient and lack of parafunctional habits are the most important factors while applying SDA concept [6]. After extraction of posterior teeth and alveolar bone resorption at the posterior maxilla, increased crown length is inevitable and may create excessive stress at the bone-implant interface [7]. Prosthetic complications may occur in implant-supported FDP because of excessive stress [8].

Although determining the maximum stresses at the bone-implant interface and within the implant structure itself is difficult, it is very important for implant-supported cantilever FDPs with different crown-to-implant ratios. Estimation of the stress occurring in living

tissue using a three-dimensional (3-D) modeling system will increase the clinical success of dental materials [8]. Using the 3-D finite element analysis (FEA) method, live tissues can be mimicked and the areas of stress concentration and magnitude of stress can be evaluated [9]. This study aimed to evaluate the stress concentration at the bone-implant interface and implant structure of one implant-supported distal cantilever FDPs with different crown-to-implant ratios when exposed to axial and oblique loads.

Materials and Methods

Three 3-D FEA models were created using the computer program Rhinoceros 4.0 (Rhinoceros 4.0, McNeel, Seattle, WA, USA) and an analysis program (Algor Fempro, Algor, Inc., Pittsburgh, PA). The missing maxillary molar and second premolar and pneumatized maxillary sinus were modeled using this method, and the first premolar site was identified as the ideal location for implant insertion. Thereafter, a 4.1 x 10-mm solid dental implant (ITI; Institute Straumann AG, Waldenburg, Switzerland) was selected and modeled, along with one implant-supported two-unit cantilever FDPs with three different C/I ratios (1/1, 1.5/1, and 2/1). The distal cantilever length was 6 mm for each model, and D3 bone density was used to simulate the maxillary

*Corresponding author: Hamiyet güngör, Faculty of Dentistry, Ankara University, Turkey, Tel: (0312) 212 60 40; E-mail: hgakca@gmail.com

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bone [10]. The Young's modulus and Poisson's ratios are shown in Table 1 [11]. Cobalt-Chromium (Wiron 99; Bego, Bremen, Germany) and feldspathic porcelain was used to model the FDPs and 100% osseointegration was assumed to occur at the bone-implant interface [12]. The numbers of elements were 225576, 210988, and 20093, and the numbers of nodes were 45588, 43036, and 41293. In this study, the porcelain thickness was 2 mm, metal thickness was 0.8 mm, and the cement layer thickness was not considered [11]. All materials used in this study were assumed to be homogeneous, isotropic, and linear elastic [10]. 300 N axial and oblique loads (45 degrees) were applied to the implant-supported FDP [13]; the von Mises and minimum and maximum principal stresses were evaluated to assess the stress concentration in the models.

Results

The highest von Mises stresses for implant and the highest minimum and maximum principal stresses for all FEA models are presented in Tables 2 and 3. The stresses were located on the buccal, distal, and palatal sides of the implant neck in both cortical and cancellous bone for all C/I ratios under axial and oblique loads. The highest stress values for cortical bone were -73.6 MPa under axial load and -142.4 MPa under oblique loads, whereas the corresponding values for cancellous bone were -4.2 MPa and -7.9 MPa, respectively. All the highest values were observed at the highest C/I ratio (2/1). Additionally, when the change in stress values was evaluated in cortical bone, the stresses were seen to increase with C/I. Under axial loads, when C/I ratio increased from 1/1 to 1.5/1 and 2/1, the stresses were seen to increase by 8.2 % and 16%, respectively. The corresponding values under oblique load were 18% and 35.7%. As the absolute values of minimum principal stresses were higher than the absolute values of maximum principal stresses, only the effect of the minimum principal stresses were considered in this study. However, both values are listed in Tables 2 and 3.

Von Mises stress values were localized from the neck of the implant to the first thread in each model. The highest von Mises stress value was 312.7 MPa under axial load and 451.1 MPa under oblique load for 2/1 C/I ratio. When this ratio changed from 1/1 to 1.5/1 and 2/1, the von Mises stresses increased by 4.2 % and 8.5%, respectively, under

Material Type	Young's Modulus (GPa)	Poisson's Ratio
Porcelain [11]	68.9	0.28
Implant [11]	110	0.35
Cr-Co [11]	218	0.33
Cortical Bone [11]	13.7	0.3
Cancellous Bone [11]	1.37	0.3

Table 1: Mechanical properties of the different tissues and materials used for finite element analysis.

axial load. The corresponding values under oblique load were 12.7% and 25.8%.

Discussion

Fixed and removable dental prostheses, resin-bonded FDPs, and implant-supported prostheses are the most common treatment options for partially edentulous patients. In cases where the edentulous site occurs in the posterior maxilla, implant-supported FDPs have been considered as the treatment of choice [14]. However, the anatomical structures of the posterior region of the jaws, such as maxillary sinus and mandibular canal, and bone density must be taken into consideration during dental implant procedures. In case of maxillary sinus pneumatization, sinus lift and grafting procedures may be performed [15].

The aim of this study was to evaluate the stress concentration of one implant-supported distal cantilever FDPs with three different C/I ratio placed in the first premolar site of the maxillary jaw model using the FEA method. The FEA is a mathematical and reliable tool that can be used to accurately measure the stress at the bone-implant interface and within the implant structure itself. Both two-dimensional and 3-D FEA can be used, although 3-D FEA provides more realistic and reliable results. The stress pattern in bone is evaluated using maximum and minimum principal stress values, whereas the stress pattern in dental implants is evaluated using von Mises stress values [16]. In the FEA method, absolute values are used to determine stress variations, and higher value has been considered for the study result [17]. Axial and oblique loadings were used to mimic real occlusion [18], and a 300-N load was chosen for all models in this study based on the literature [19].

Dental implant-supported FDPs are one of the most common treatment options for posterior edentulism in older patients. However, it may not always be possible to insert an adequate number of implants because of anatomical limitations in the posterior maxilla, such as the maxillary sinus. In these situations, the SDA concept suggested by Kayser may be preferred as an alternative. According to this concept, the presence of bilateral second premolar teeth can help to preserve oral functions and prevent temporomandibular joint dysfunction [6]. This concept can also be applied with a cantilever FDP when the second premolar teeth are absent. Excessive maxillo-mandibular disorders, open bite, or parafunctional habits are contraindications for the SDA concept. Moreover, this concept is also unsuitable in young patients [20].

In this study, ITI implants were inserted in the first premolar site because of the presence of a pneumatized maxillary sinus, and one-implant-supported two-unit distal cantilever FDPs were modeled by applying the FEA method to the SDA concept. Sasse et al. compared

C/I	CL (mm)	Minimum Principal Stress		Maximum Principal Stress		von Mises Stress
		Cortical Bone	Cancellous Bone	Cortical Bone	Cancellous Bone	Implant
1/1	6	-63.4	-3.6	6.2	2.9	288
1,5/1	6	-68.6	-3.9	6.9	3.1	300.3
2/1	6	-73.6	-4.2	7.7	3.3	312.7

C/I: Crown-to-implant ratio CL: Cantilever length

Table 2: Minimum principal, maximum principal and von Mises stress values (MPa) under axial loads.

C/I	CL (mm)	Minimum Principal Stress		Maximum Principal Stress		von Mises Stress
		Cortical Bone	Cancellous Bone	Cortical Bone	Cancellous Bone	Implant
1/1	6	-104.9	-5.7	14.4	3.5	358.5
1,5/1	6	-123.8	-6.8	18.4	4.2	404.2
2/1	6	-142.4	-7.9	14.4	4.9	451.1

Table 3: Minimum principal, maximum principal and von Mises stress values (MPa) under oblique loads.

the tooth-supported cantilever group and non-cantilever group in SDA and reported that cantilever FDPs could be used successfully for patients with SDA [20]. An increased crown length is inevitable after tooth extraction in the posterior maxilla because of the rapid alveolar bone resorption pattern seen in this region [2]. This may lead to excessive non-axial loading, resulting in technical complications. The increased crown height functions as a lever arm and causes excessive stresses in the peri-implant crestal bone, leading to bone resorption and prosthetic complications [21]. Although there are different C/I ratios in literature, C/I ratio can be 2/1 or more [14,21]. Blanes et al. in their systematic review suggested that C/I ratios had no effect on crestal bone loss and implant failure and that there was insufficient evidence of technical complications in implant-supported prostheses [21]. A ten-year prospective study reported that C/I ratio ranged between 2 and 3 in the posterior region of the jaws [14]. Conversely, other studies have reported that the C/I ratio may cause mechanical and technical complications as well as alveolar bone loss [22].

According to our results, the increased C/I ratio affected the stress concentration in cortical and cancellous bone as well as the implant under axial and oblique loads. The stress was seen to increase under

oblique loads to a greater extent than that under axial loads (Figures 1 and 2). Minimum principal stresses were considered for cortical bone because of their high absolute values. Moreover, oblique loads were found to be more significant than axial loads and, therefore, they must be considered carefully when planning implant-supported cantilever dental prostheses.

One of the main reasons for technical or mechanical complications is the presence of cantilever extensions in implant-supported FDPs [23]. These extensions are used to provide longer FDPs in bone sites where grafting procedures cannot be performed as well as to achieve time and cost effectiveness [24]. Various systematic reviews focusing on mechanical and technical complications have reported that the presence of bruxism is one of the most important risk factors for cantilever FDPs [23]. In a seven-year prospective study, Romeo et al. evaluated the effect of cantilever types, cantilever extension length, and opposing occlusion on the cantilever FDP. They found that distal cantilever extensions were more successful (100%) than mesial cantilever extensions (97.1%). According to our results, implant-supported cantilever FDPs exhibited medium prognosis compared to implant-supported FDPs [15].

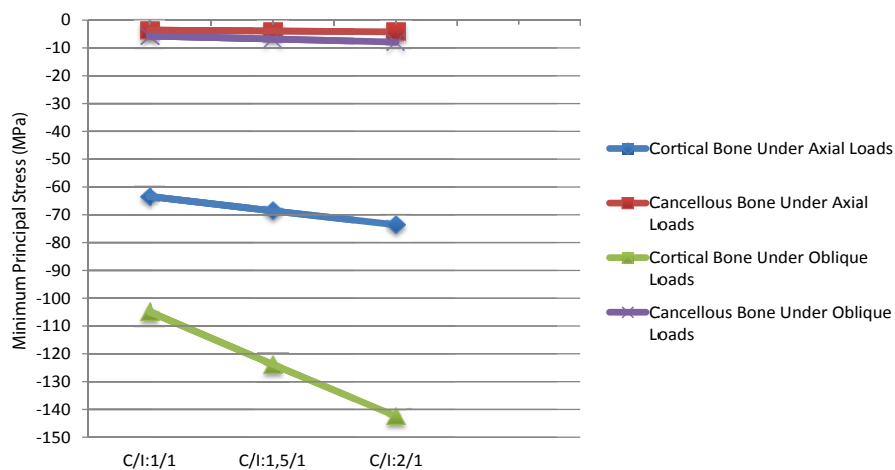


Figure 1: Minimum principal stress values (MPa) in bone under axial and oblique loads.

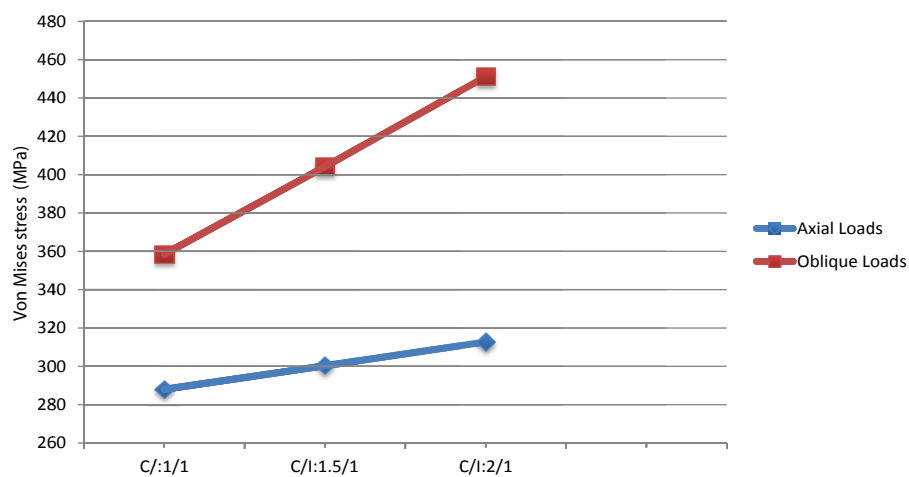


Figure 2: von Mises stress values in implant under axial and oblique loads.

Conclusion

Within the limitations of this 3-D FEA study, the effects of *C/I* ratio on one implant-supported distal cantilever FDPs was evaluated using the SDA concept, and the following conclusions were drawn:

- Increasing the *C/I* ratios of distal cantilever FDP increases the maximum stress values in cortical and cancellous bone and implants.
- The stress values (minimum and maximum principal and von Mises) observed under axial loads are lower than those observed under oblique loads.
- Changes in stress values because of increased *C/I* ratios were more significant under oblique loads.

One implant-supported two-unit distal cantilever FDPs may be an alternative treatment option for older patients. However, this FEA study should be supported by future clinical studies.

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