



An evaluation of the stress effect of different occlusion concepts on hybrid abutment and implant supported monolithic zirconia fixed prosthesis: A finite element analysis

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PURPOSE. The aim of this study is to evaluate the effects of canine guidance occlusion and group function occlusion on the degree of stress to the bone, implants, abutments, and crowns using finite element analysis (FEA). **MATERIALS AND METHODS.** This study included the implant-prosthesis system of a three-unit bridge made of monolithic zirconia and hybrid abutments. Three-dimensional (3D) models of a bone-level implant system and a titanium base abutment were created using the original implant components. Two titanium implants, measuring 4 × 11 mm each, were selected. The loads were applied in two oblique directions of 15° and 30° under two occlusal movement conditions. In the canine guidance condition, loads (100 N) were applied to the canine crown only. In the group function condition, loads were applied to all three teeth. In this loading, a force of 100 N was applied to the canine, and 200-N forces were applied to each premolar. The stress distribution among all the components of the implant-bridge system was assessed using ANSYS SpaceClaim 2020 R2 software and finite element analysis. **RESULTS.** Maximum stress was found in the group function occlusion. The maximum stress increased with an increase in the angle of occlusal force. **CONCLUSION.** The canine guidance occlusion with monolithic zirconia crown materials is promising for implant-supported prostheses in the canine and premolar areas. [J Adv Prosthodont 2021;13:216-25]

KEYWORDS

Canine guidance occlusion; Finite element analysis; Group function occlusion; Hybrid abutments; Monolithic zirconia

INTRODUCTION

Since Brånemark's discovery of dental implants, implants have become an integral part of dental practice, and their use has grown rapidly in recent years.¹

The choice of crown material is an important criterion for implant-support-

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ed prostheses. The technique of using ceramic crowns on implants has been successfully proven in the long term.² Zirconia with monocrystalline homogeneity, low corrosion, low thermal conductivity, and good radiopacity have favorable physical, mechanical, biological, and chemical properties.³ The zirconia-based substructure can be classified into two main types: bilayer, in which prosthesis is covered with a strong zirconia shield veneer; and single-layered, in which the entire prosthesis consists of zirconia in monolithic form. Traditional veneer crowns are esthetic, but the risk of veneer chipping is high. In contrast, monolithic zirconia minimizes the risk of chipping.⁴

Currently, a variety of dental abutment materials are available, including metal and ceramic abutments, which are widely used in clinical practice.⁵ The gray color of titanium abutment material can cause discoloration of the mucosa around the implant, which can undermine the esthetic effect of the final restoration.⁶ In cases in which the gingiva is thin and transparent, the use of ceramic abutments has been suggested, depending on the esthetic requirements.⁷ Compared to titanium abutments, zirconia abutments have advantages, including improved esthetics, translucency, ease of construction, adaptation, and biocompatibility.⁸ However, significant differences in physical properties between zirconia abutment and titanium implants have caused harmful effects and fracture formations in the abutment-implant interface. These results have led to the development of a hybrid abutment consisting of a titanium base structure screwed to the implant and a ceramic coping bonded with resin cement to the titanium base structure. These abutments provide an improved esthetic result without adversely affecting the stability of the implant.⁹

One of the most important criteria for implant success is occlusion.¹⁰ Physiological differences between the natural tooth and the dental implant cause the implant to be affected differently by occlusal forces. Unlike the natural tooth around the implant, the implant has no periodontal ligament; therefore, it acts on the stomatognathic system, dissipating the masticatory load incident on the prosthetic crown after osseointegration.¹¹ Occlusal overload causes crestal bone loss, increasing the depth of the anaerobic sul-

cus and the risk of disease in the peri-implant area. It is also considered one of the main causes of peri-implant bone loss and implant prosthesis failure.¹² If the dental implant distributes the occlusal forces around it homogeneously, the bone around the implant is well protected, and occlusion-related failures are prevented.¹ To achieve dental occlusion, the skeletal and muscular systems work simultaneously to produce mandibular movement that transfers force to the prosthesis, teeth, implants, and supporting bone.¹³

The implant-protected occlusion that Misch and Bidez proposed in 1994 ensures a longer life for both the implant and the prosthesis and is crucial for reducing the occlusal load on the implant by providing maximum intercuspation.¹⁰ When the forces are distributed only to the anterior segments, reduced muscle activity, in turn, reduces the overall occlusal force magnitude. Consequently, all movements on the implant-protected occlusion should not involve posterior contacts.¹⁴ In cases where anterior teeth are not periodontally healthy, group function occlusion is preferred to avoid protrusive movements in the anterior region.¹⁵

In the fields of medicine and dentistry, FEA can evaluate the behavior of any structure or tissue undergoing a certain force and stimulation and can analyze biomechanical changes in tissues. FEA allows for the measurement of stress distribution inside the bone during chewing, which is impossible to carry out *in vivo*.¹⁶

The principles of implant occlusion are still controversial. Few studies have compared the mechanical effects of canine guidance occlusion and group function occlusion in implant-supported fixed prostheses. The aim of this study is to compare the stress values after the application of canine guidance occlusion and group function occlusion in implant-supported fixed restorations using hybrid abutment and monolithic zirconia crown material with FEA. The null hypothesis is that group function occlusion application causes more stress increases than canine guidance occlusion does.

MATERIALS AND METHODS

Firstly, a maxillary segment with a 3-unit fixed partial

denture (FPD) supported by 2 endosseous implants between canine and second premolar area was simulated with a 3D FE model. ANSYS SpaceClaim 2020 R2 (ANSYS Inc, Canonsburg, PA, USA) was used for designing of the models in the study. Implants were located in the canine, second premolar area and they were considered to be completely osseointegrated with the bone. Crown models were anatomically modeled using with the STL data obtained from the Dental Wings DW-7140 (Dentalwings Inc., 7 series, Montreal, QC, Canada) Computed Tomography (CT) data of Straumann Group. The size and morphology of teeth were adjusted according to the measurements given by Stanley and designed in computer environment (Fig. 1).¹⁷ ANSYS Mechanical 2020 R2 finite element analysis program (ANSYS Inc, Canonsburg, PA, USA) was used in the simulation processes of the study.

Each model included monolithic zirconia crown, hybrid abutment, titanium base, screw, resin cement, titanium implant and bone. Two dental implants of the same size (4 × 11 mm) of the company Medentica Microcone (Bone level, Microcone Medentika, Medentika GmbH, Hügelsheim, Germany) were used at bone level of the #13 and #15 teeth area for the three-unit fixed bridge. Two identical Ti-base (Medentika RI, Medentika GmbH, Hügelsheim, Germany) abutments with total length of 1.1 mm were also used. Standard titanium screw was preferred. Monolithic zirconia thickness used in this study were 1.5 mm for crown material.

The abutment and implant were connected by screw. The implant abutment connection was simu-

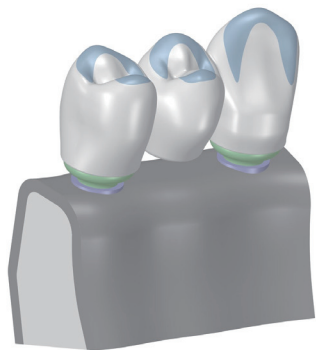


Fig. 1. General view of the bridge model.

lating adaptation characteristics of an internal hexagonal connection. For hybrid abutment, the contact between Ti-base and monolithic zirconia was provided with 0.025 mm resin cement (RelyX ARC, 3M ESPE AG, Seefeld, Germany). The connection between abutment and crown was also provided with 0.025 mm resin cement (RelyX ARC, 3M ESPE AG, Seefeld, Germany).¹⁸ For the 3-unit fixed prosthesis, the connector thickness in monolithic zirconia was set to 7 mm² for each connector area as in the manufacturer's instructions (Lava Plus, 3M ESPE, London, ON, Canada). The model was created from a hybrid abutment consisting of monolithic zirconia on a Ti-base abutment and a monolithic zirconia superstructure (Lava Plus, 3M ESPE, London, ON, Canada) (Fig. 2).

All materials used in the models were considered to be isotropic, homogeneous, and linearly elastic. In addition, the bone-implant interface was accepted as 100% bone-implant contact (100% osseointegrated). Different Young's modulus and Poisson's ratios were

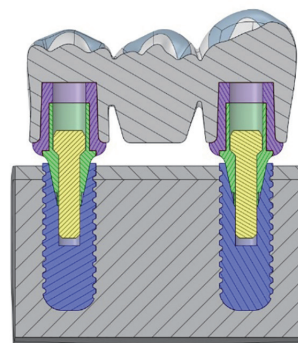


Fig. 2. Modeling of the prosthesis.

Table 1. The elastic modulus and Poisson's ratios of the materials

Material	Young's modulus (MPa)	Poisson's ratio
Cement ¹⁹	8300	0.24
Ti-base abutment ²⁰	114000	0.33
Monolithic zirconia ¹⁸	210000	0.35
Titanium screw ²⁰	114000	0.33
Titanium implant ²¹	103400	0.35
Cortical bone ¹¹	13700	0.3
Spongious bone ¹¹	1370	0.3

used for the all the materials and presented Table 1.

The number of elements and nodes of the model is shown in Table 2. Hexahedral 20 elements were preferred for 0.6 mm maximum element size screw and resin cement models, and tetrahedral 10 element types were preferred for all other models. The mesh view of the bridge model is shown in detail in Fig. 3.

A preloading force of 100 N was applied for screw fixation. In order to evaluate the application of canine and group function guidance occlusion, force applied on the crowns and the regions on the crown were determined by reference to the occlusion criteria. The loads were applied in two oblique directions of 15° and 30° and in two occlusal movement conditions. In the canine guidance condition, the loads (100 N) were only applied to the canine (Fig. 4). In the group function condition, the loads were applied to all the three

Table 2. Elements and nodes

Model	Elements	Nodes	Element quality
Model	408915	658025	0.80129

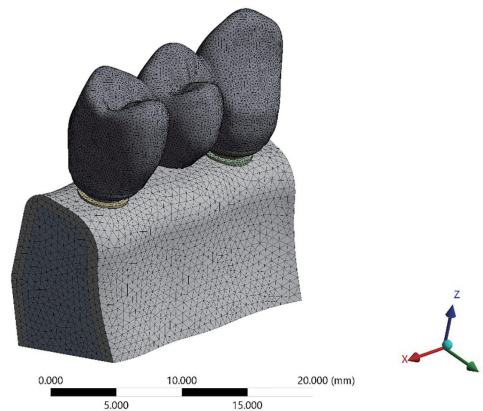


Fig. 3. Meshing geometric models.

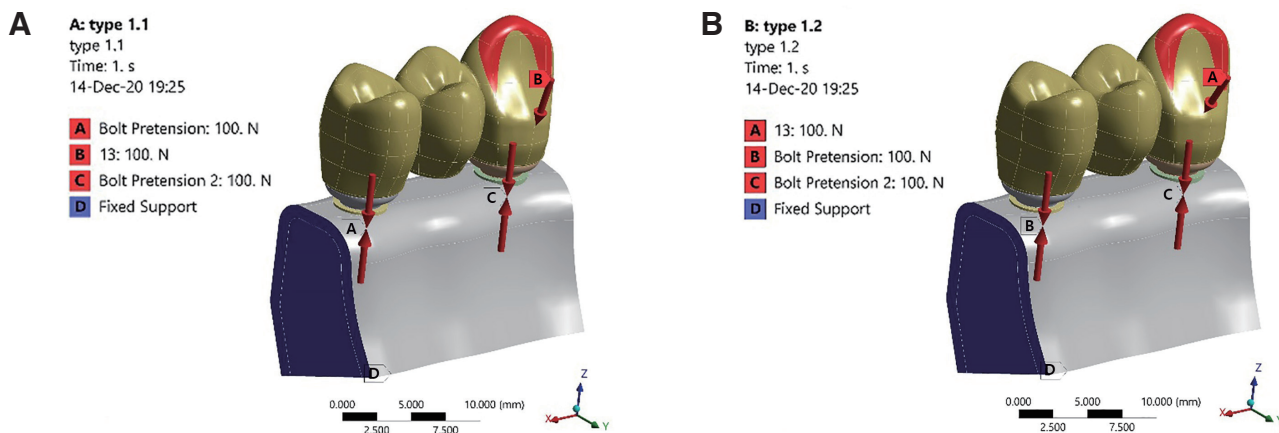


Fig. 4. (A) Canine guidance occlusion application force applied at an angle of 15°, (B) canine guidance occlusion application force applied at an angle of 30°.

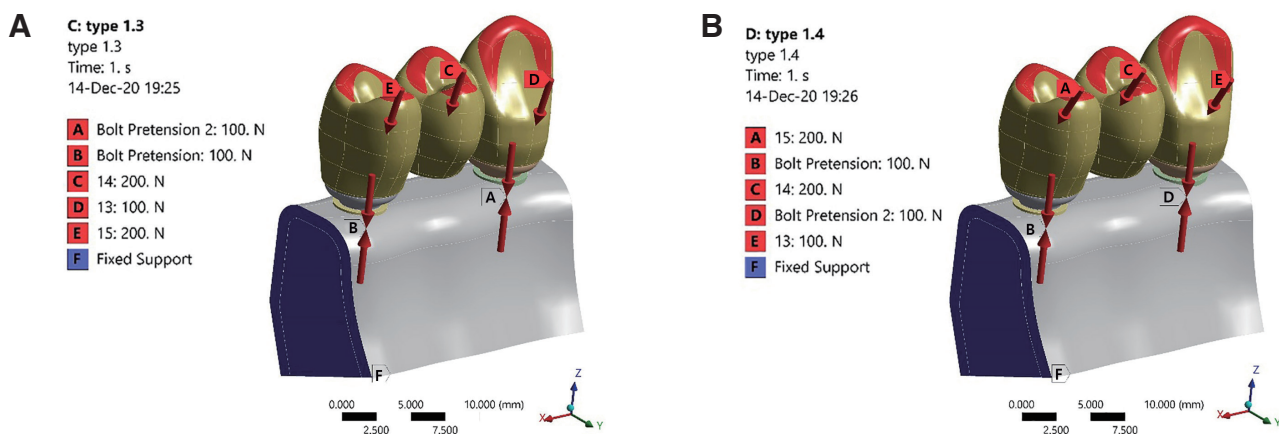


Fig. 5. (A) Group function occlusion application force applied at an angle of 15°, (B) force applied at an angle of 30°.

Table 3. Loading conditions

	Occlusion	Degree of force application	#13 crown	#14 crown	#15 crown
1	Canine guidance	15	100 N	----	----
2	Canine guidance	30	100 N	----	----
3	Group function	15	100 N	200 N	200 N
4	Group function	30	100 N	200 N	200 N

teeth (Fig. 5). In this loading, a force of 100 N was applied to the canine, and 200 N forces were applied to each premolar (Table 3).¹⁸

Since the stress values obtained in the finite element analysis results are formed as a result of mathematical calculations without variance, statistical analysis cannot be performed. Analyses are made by carefully evaluating and interpreting the cross-sectional images and the amount and distribution of stress in the nodes.

Maximal principle stresses were calculated for brittle materials like bone; and von Mises stresses were recorded for ductile materials like implants, abutments, and abutment screws, which contain titanium.²² In our study, maximum von Mises/principle stress values for each component were recorded for

both occlusion conditions after the loading.

RESULTS

In all groups, stresses on the abutments were observed and concentrated in the neck of the abutments. When all the groups were examined, it was observed that the highest von Mises stress values on the crown were in the connector between #13 and #14 crowns. In the canine guidance condition, the higher stress concentrations occurred in the cervico lingual region that contacts the canine implant platform, and, in group function, the higher stress concentrations occurred in the cervico lingual region that contacts the canine and premolar implant platform (Fig. 6, Fig. 7). The stress on the screw is higher in the case

Fig. 6. (A) As a result of the force applied at an angle of 15° in the case of occlusion with canine guidance Von Mises stress distribution in the superstructure, (B) Von Mises stress distribution in the bone, (C) Von Mises stress distribution in the #13 abutment, (D) Von Mises stress distribution in the #15 abutment.

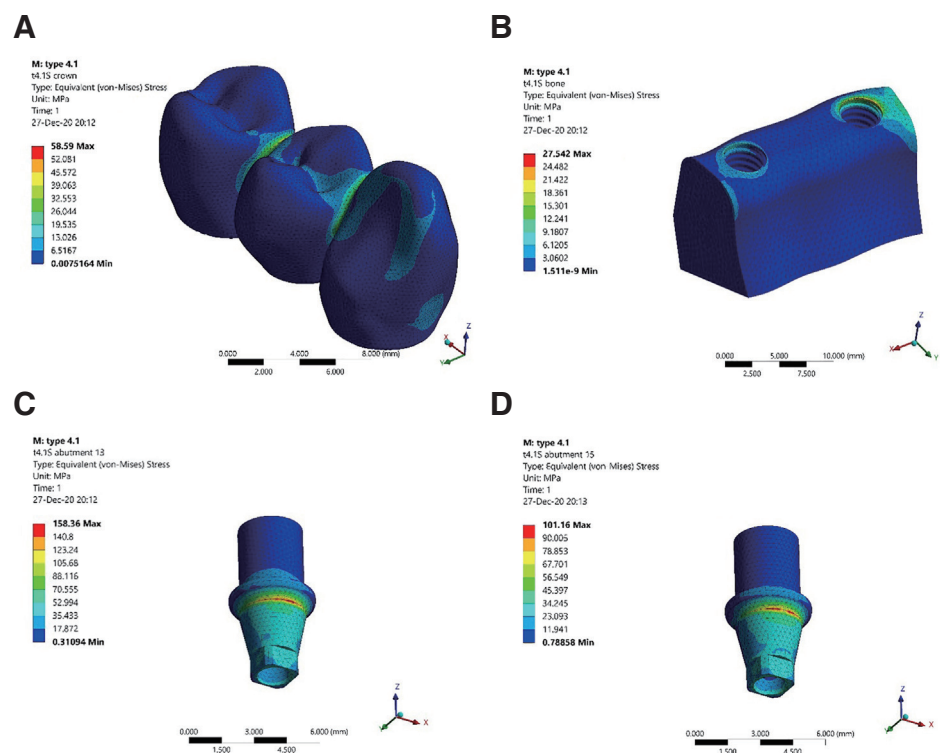


Fig. 7. (A) As a result of the force applied at an angle of 15° in the case of occlusion with group function Von Mises stress distribution in the superstructure, (B) Von Mises stress distribution in the bone, (C) Von Mises stress distribution in the #13 abutment, (D) Von Mises stress distribution in the #15 abutment.

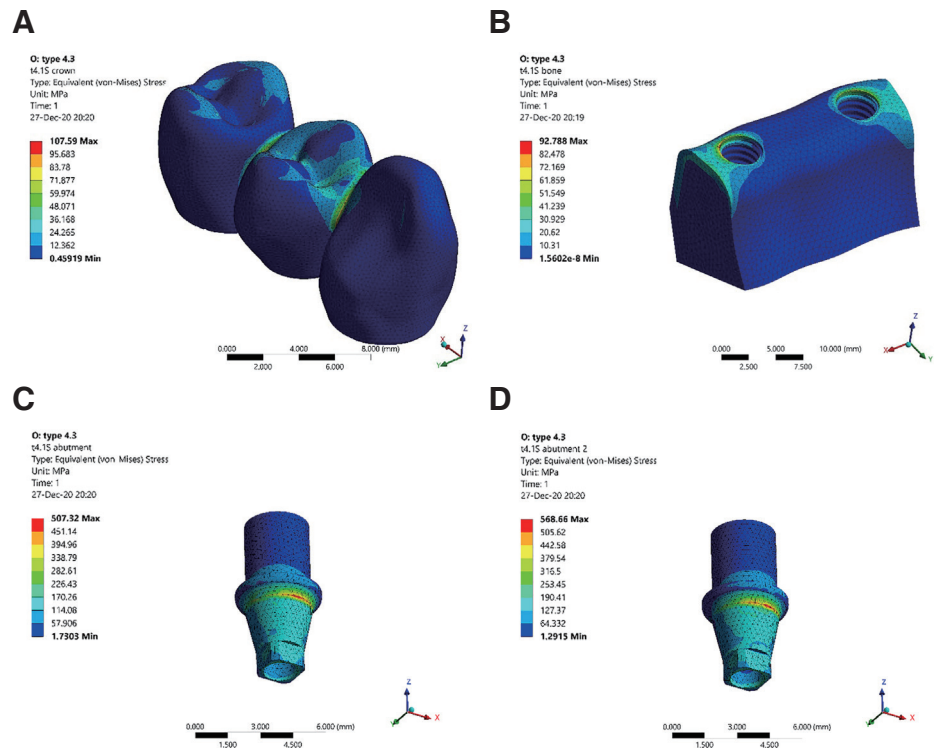


Table 4. Maximum principal stress (MPa) on the implant-bridge system (unit: MPa)

Occlusion	#13 screw	#15 screw	#13 abutment	#15 abutment	Crown	Bone
Canine guidance 15°	154	150	158.36	101.16	58.59	27.542
Canine guidance 30°	167	153	242.25	170.64	110.52	39.179
Group function 15°	182	218	507.32	568.66	107.59	92.788
Group function 30°	220	273	854.95	940.45	167.34	137.5

of group function occlusion. All the stress values are presented in Table 4. The results of the current study are that all recorded maximum stress values found in the group function loading is higher than the canine guidance one.

DISCUSSION

Based on the obtained data, the null hypothesis tested in this study was accepted. When the stress values occurring in the bone, abutment and superstructure materials around the implant were compared, the highest values were observed in the group function occlusion.

The high complexity of biomaterial properties, mi-

crostructural details, and dental anatomy make the biomechanical analysis challenging in experimental and clinical studies.²³ Since the components in the dental implant-bone system are geometrically complex, FEA has been seen as the most suitable tool to analyze them.²⁴

A finite element analysis model can be 2D or 3D. In 2D models, out-of-plane deformations, strains and stresses are meaningless and artificial constraints cause more errors in the analysis. Therefore, using 3D models to analyze biological or biocompatible structures produces more realistic results than 2D models.²⁵ Therefore, 3D models are used in this study.

FEA gives more successful results with ideal and realistic modeling of implants and surrounding tissues.

In order to obtain accurate and detailed results, the number of elements must be selected appropriately. As the number of elements increases, the accuracy of the results also increases. Reducing the number of elements ensures a shorter analysis time and results in more general information.^{26,27} The number of elements in this study is 408915. This value is higher than many studies.^{11,24,22}

In this study, the materials were assumed to be isotropic and homogeneous because it is assumed in most of the studies that the materials are isotropic, homogeneous, and linear and have an elastic material behavior characterized by only 2 material constants (Young's modulus and Poisson's ratio).^{25,26,28} As in this study, most of the finite element analysis studies admit that the osseointegration of the bone-implant interface is 100%, indicating that the trabecular and cortical bones are perfectly bonded to the implant surface.²⁵ These factors are the limitations of the FEA studies, and these limitations should be taken into account in these results.

The loads were applied in two oblique directions of 15° and 30° in two occlusal movement conditions after occlusion with canine guidance and group function in this study. Fanuscu *et al.* investigated the effect of different quality bones and axial or oblique loading on stress in their study and reported that loading type affected load distribution more than variations in bone, and oblique loading caused more stress.²¹ Oblique loading causes a greater concentration of stress compared to axial loading, and studies have suggested that oblique loading is associated with more realistic loading.^{29,30}

Occlusion is one of the most important factors that should be carefully evaluated in implant treatment, and overloading due to improper occlusion is one of the reasons why implant treatment is unsuccessful.³¹ Clinically, a poorly developed occlusion in implant-supported prosthesis could have a detrimental effect on the supporting bone and associated prosthetic components.³² The ideal implant occlusion allows for controlled stress around the implant components, provides a prosthetically and biologically acceptable bone-to-implant interface, and ensures long-term stability of the marginal bone and prosthesis.³³ However, many authors have shown that

the direction or magnitude of occlusal forces does not appear to have an effect on the stability of supporting implants and bone. Engel *et al.* conducted a study on 379 patients who had worn implant restorations for many years and reported that occlusal wear had no statistical effect on vertical peri-implant bone loss or Periotest values.³⁴ In a long term study of implant-supported fixed prostheses, smoking and poor oral hygiene had a greater effect on peri-implant bone loss than factors associated with occlusal loading, such as bite force, bruxism and cantilever length.³⁵ With these conflicting results, the effect of occlusal loads on implant-supported prosthetic restorations and bone requires further investigation.

There are few studies comparing guideline for occlusion in implant-supported fixed restorations. In implant-supported fixed prostheses in the posterior region, the lateral forces on the implants decrease with the preference of anterior guidance and the first contact with the natural tooth. Group function occlusion is recommended instead of canine guidance occlusion when the anterior teeth cannot provide sufficient support and are periodically compromised.³⁶

Robati Anaraki *et al.*,¹⁸ in their FEA study comparing canine guidance occlusion and group function occlusion, observed that the maximum stress in the group function occlusion model was significantly higher compared to the canine guidance occlusion.¹⁸ In another FEA study showing similar results to our study, an excessive increase in stresses was observed when group function occlusion was applied instead of canine guidance. Leja *et al.*³⁷ reported that the appearance of cervical lesions was higher in group function subjects than in canine guidance subjects. Tokiwa *et al.*³⁸ support this result with their study, and they reported that more cervical lesions were observed in patients with group function than patients with canine guidance occlusion in their study. Misch and Silc³⁹ emphasized that the canine tooth area, which is one of the important positions for implant placement, is important for reducing the strength in the prosthesis. In this position of the arc, the magnitude of the force increases and the direction of the force is changed. Therefore, when these teeth are included in implant restorations, it has been suggested that an implant be placed in these areas. In contrast to these

results, in a study comparing the difference between canine guidance and group function occlusion with a large sample size ($n = 56$) and short observation period (2 - 3 months), canine guidance was reported to be a risk factor for gold screw loosening.³³ The results of the current study observed that the stress values in the group function occlusal pattern was higher than the canine guidance one.

Bite forces increase in the posterior regions and two thirds of the masseter and temporalis muscle fibers remain relaxed due to the absence of posterior contacts.⁴⁰ Different bite forces were considered in this study, so two different force magnitudes were used to present canine guidance and group function occlusion. In this study, while the total force is higher in the group function occlusion, the force applied to the canine region is the same in both occlusion types. It was observed that the stress values in the canine region were higher in group function occlusion.

Bruxism can eliminate canine and incisal guidance. The result is usually a relatively flat occlusion plane instead of a canine guidance occlusion, or highly worn teeth with group function occlusion.⁴¹ The results of this study showed that canine sparing occlusion is associated with less stress. It should not be forgotten that this study is a FEA study. Since studies on occlusion guidance are scarce, more studies are needed. In addition, it should be kept in mind that restorations with canine preservative occlusion can transform into group function occlusion over time due to reasons such as tooth grinding, tooth loss, tooth erosion.

CONCLUSION

Within the limitation of this study, it was concluded that; oblique loading causes more stress concentration and is associated with more realistic loading. Changing occlusal loads affected the stress values on the bone. Maximum stress increased with increasing the angle of occlusal force. With group function occlusion application, the stress values on the bone and implant components are higher than the stress values after occlusion canine guidance application.

REFERENCES

1. Reddy MS, Sundram R, Eid Abdemagyd HA. Application of finite element model in implant dentistry: a systematic review. *J Pharm Bioallied Sci* 2019;11: S85-S91.
2. Datte CE, Tribst JP, Dal Piva AO, Nishioka RS, Bottino MA, Evangelhista AM, Monteiro FMM, Borges AL. Influence of different restorative materials on the stress distribution in dental implants. *J Clin Exp Dent* 2018; 10:e439-44.
3. Guess PC, Att W, Strub JR. Zirconia in fixed implant prosthodontics. *Clin Implant Dent Relat Res* 2012;14: 633-45.
4. Zhang Y, Lawn BR. Evaluating dental zirconia. *Dent Mater* 2019;35:15-23.
5. Lops D, Stellini E, Sbricoli L, Cea N, Romeo E, Bresnan E. Influence of abutment material on peri-implant soft tissues in anterior areas with thin gingival biotype: a multicentric prospective study. *Clin Oral Implants Res* 2017;28:1263-8.
6. Molina A, Sanz-Sánchez I, Martín C, Blanco J, Sanz M. The effect of one-time abutment placement on interproximal bone levels and peri-implant soft tissues: a prospective randomized clinical trial. *Clin Oral Implants Res* 2017;28:443-52.
7. Yildirim M, Fischer H, Marx R, Edelhoff D. In vivo fracture resistance of implant-supported all-ceramic restorations. *J Prosthet Dent* 2003;90:325-31.
8. Egilmez Ferhat, Yildirim Bicer Arzu Zeynep, Ergun Gulfem. Zirconia ceramics and their use in dental implantology. *Cumhuriyet Dent J* 2010;13:72-80.
9. Conejo J, Kobayashi T, Anadioti E, Blatz MB. Performance of CAD/CAM monolithic ceramic Implant-supported restorations bonded to titanium inserts: a systematic review. *Eur J Oral Implantol* 2017;10:139-46.
10. Swaminathan Y, Rao G. Implant protected occlusion. *IOSR J Dent Med Sci* 2013;11:20-5.
11. Tribst JPM, Dal Piva AMO, Anami LC, Borges ALS, Bottino MA. Influence of implant connection on the stress distribution in restorations performed with hybrid abutments. *J Osseointegration* 2019;11:507-12.
12. Verma M, Nanda A, Sood A. Principles of occlusion in implant dentistry. *J Int Clin Dent Res Organ* 2015;7:27-33.
13. Delgado-Ruiz RA, Calvo-Guirado JL, Romanos GE. Ef-

- fects of occlusal forces on the peri-implant-bone interface stability. *Periodontol* 2000 2019;81:179-93.
14. Graves CV, Harrel SK, Rossmann JA, Kerns D, Gonzalez JA, Kontogiorgos ED, Al-Hashimi I, Abraham C. The role of occlusion in the dental implant and peri-implant condition: a review. *Open Dent J* 2016;10:594-601.
 15. Sheridan RA, Decker AM, Plonka AB, Wang HL. The role of occlusion in implant therapy: a comprehensive updated review. *Implant Dent* 2016;25:829-38.
 16. Chang Y, Tambe AA, Maeda Y, Wada M, Gonda T. Finite element analysis of dental implants with validation: to what extent can we expect the model to predict biological phenomena? A literature review and proposal for classification of a validation process. *Int J Implant Dent* 2018;4:7.
 17. Stanley JN. Wheeler's dental anatomy, physiology and occlusion. 11th ed., Elsevier-Health Science, Las Vegas, USA; 2019. p. 13.
 18. Robati Anaraki M, Torab A, Mounesi Rad T. Comparison of stress in implant-supported monolithic zirconia fixed partial dentures between canine guidance and group function occlusal patterns: a finite element analysis. *J Dent Res Dent Clin Dent Prospects* 2019;13:90-7.
 19. Gungor MA, Dundar M, Karaoglu C, Sonugelen M, Artun CC. The effect of margin design on stress distribution on all-ceramic materials: a finite element. *Ege Univ Faculty Dent J* 2005;26:145-53.
 20. de la Rosa Castolo G, Guevara Perez SV, Arnoux PJ, Badih L, Bonnet F, Behr M. Mechanical strength and fracture point of a dental implant under certification conditions: a numerical approach by finite element analysis. *J Prosthet Dent* 2018;119:611-9.
 21. Cattaneo PM, Dalstra M, Melsen B. The finite element method: a tool to study orthodontic tooth movement. *J Dent Res* 2005;84:428-33.
 22. Göre E, Evlioğlu G. Assessment of the effect of two occlusal concepts for implant-supported fixed prostheses by finite element analysis in patients with bruxism. *J Oral Implantol* 2014;40:68-75.
 23. Lin D, Li Q, Li W, Swain M. Dental implant induced bone remodeling and associated algorithms. *J Mech Behav Biomed Mater* 2009;2:410-32.
 24. Bankoğlu Güngör M, Yılmaz H. Evaluation of stress distributions occurring on zirconia and titanium implant-supported prostheses: a three-dimensional finite element analysis. *J Prosthet Dent* 2016;116:346-55.
 25. DeTolla DH, Andreana S, Patra A, Buhite R, Comella B. Role of the finite element model in dental implants. *J Oral Implantol* 2000;26:77-81.
 26. Geng JP, Tan KB, Liu GR. Application of finite element analysis in implant dentistry: a review of the literature. *J Prosthet Dent* 2001;85:585-98.
 27. Srirekha A, Bashetty K. Infinite to finite: an overview of finite element analysis. *Indian J Dent Res* 2010;21:425-32.
 28. Fanuscu MI, Vu HV, Poncelet B. Implant biomechanics in grafted sinus: a finite element analysis. *J Oral Implantol* 2004;30:59-68.
 29. Pesqueira AA, Goiato MC, Filho HG, Monteiro DR, Santos DM, Haddad MF, Pellizzer EP. Use of stress analysis methods to evaluate the biomechanics of oral rehabilitation with implants. *J Oral Implantol* 2014;40:217-28.
 30. Rezende CE, Chase-Diaz M, Costa MD, Albarracin ML, Paschoeto G, Sousa EA, Rubo JH, Borges AF. Stress distribution in single dental implant system: three-dimensional finite element analysis based on an in vitro experimental model. *J Craniofac Surg* 2015;26:2196-200.
 31. Morneburg TR, Pröschel PA. In vivo forces on implants influenced by occlusal scheme and food consistency. *Int J Prosthodont* 2003;16:481-6.
 32. Wood MR, Vermilyea SG; Committee on Research in Fixed Prosthodontics of the Academy of Fixed Prosthodontics. A review of selected dental literature on evidence-based treatment planning for dental implants: report of the Committee on Research in Fixed Prosthodontics of the Academy of Fixed Prosthodontics. *J Prosthet Dent* 2004;92:447-62.
 33. Koyano K, Esaki D. Occlusion on oral implants: current clinical guidelines. *J Oral Rehabil* 2015;42:153-61.
 34. Engel E, Gomez-Roman G, Axmann-Krcmar D. Effect of occlusal wear on bone loss and Periost value of dental implants. *Int J Prosthodont* 2001;14:444-50.
 35. Brägger U, Aeschlimann S, Bürgin W, Hämmerle CH, Lang NP. Biological and technical complications and failures with fixed partial dentures (FPD) on implants and teeth after four to five years of function. *Clin Oral Implants Res* 2001;12:26-34.

36. Kim Y, Oh TJ, Misch CE, Wang HL. Occlusal considerations in implant therapy: clinical guidelines with biomechanical rationale. *Clin Oral Implants Res* 2005;16:26-35.
37. Leja W, Hilbe M, Stainer M, Kulmer S. Non-carious cervical lesions in relation to the occlusion type and the inclination of the individual guiding elements. *Germany Dent J* 1999;54:412-4.
38. Tokiwa O, Park BK, Takezawa Y, Takahashi Y, Sasaguri K, Sato S. Relationship of tooth grinding pattern during sleep bruxism and dental status. *Cranio* 2008;26:287-93.
39. Misch CE, Silc JT. Using implant positions: treatment planning canine and first molar rules. *Dent Today* 2009;28:66, 68, 70-1.
40. Misch CE. *Dental implant prosthetics*. 1st ed., St. Louis: Elsevier Mosby. 2005. p. 15.
41. Christensen GJ. Now is the time to observe and treat dental occlusion. *J Am Dent Assoc* 2001;132:100-2.