ORIGINAL RESEARCH

Influence of Occlusal Stress on Implant Abutment Junction and Implant Bone Interface: A Finite Element Analysis Study

Arun Kharavela Mohanty[1], Thomas Varghese[2], Purnendu Bhushan[3], Rama Kanta Mahapatro[4], Ashika Bachira Kashi[5], Paul Kariyatty[6]

Abstract

Aim: The aim of the present study was to assess the occlusal stress on the implant–abutment junction and implant–bone interface of a long-span implant-supported prosthesis made of two different prosthetic materials.

Materials and methods: A computerized tomography of the mandible was used to get the finite element model of the bone. The comparative groups were made as follows: S1 and S2 – 3.7 × 11 mm (44 region) and 4.5 × 11 mm (47 region), S1A and S2A – screw-retained porcelain-fused-to-metal prosthesis, S1B and S2B – cement-retained porcelain-fused-to-metal prosthesis, S1C and S2C – screw-retained zirconia prosthesis, and S1D – cement-retained zirconia prosthesis. Maximum stress generated on the implant–abutment interface of all the prostheses under vertical and oblique load was assessed.

Results: For all the comparative groups, maximum level of stress was generated at the cervical level of the implant–bone interface in comparison to the apical and middle-third level under both vertical and oblique load. No statistically significant difference between zirconia and porcelain-fused-to-metal prosthesis was seen at the implant–abutment interface and the cervical third of the implant–bone interface. A significant difference was found between all screw-retained and cement-retained groups.

Conclusion: The present study concluded that the short implants in combination with standard-length implants using either porcelain-fused-to-metal or zirconia as prosthetic material in the form of long-span implant-supported prosthesis can be a viable treatment option in the posterior mandible.

Clinical significance: The accuracy of the diagnosis, examination, and knowledge of the site where the implant must be inserted, and the choice of superstructure is important for the stability and lifespan of the implant prosthesis.

Keywords: Finite element analysis, Implant abutment, Occlusal stress, Screw retained.

The Journal of Contemporary Dental Practice (2022): 10.5005/jp-journals-10024-3452

Introduction

A quality-of-life and general well-being are greatly influenced by having healthy teeth. The loss of teeth can have a significant impact on patient health by impairing normal masticatory function, esthetics, and speech. The edentulous space can be either bounded by teeth anteriorly and posteriorly or maybe a free-end which may be unilateral or bilateral in single or both arches. It has been noted that the incidence of free-end edentulism is more in the mandible than its maxillary counterpart, with an average of 31.3%. The treatment options for distal extension or free-end saddle edentulism are interim removable partial dentures, cast partial dentures, implant-supported removable or fixed prosthesis.[1]

Clinical evaluation of removable prosthesis for partial edentulous cases has shown a low survival rate of 60% after 5 years of insertion. This was found to be reduced to 35% after a period of 10 years. Therefore, alternative therapies like a fixed prosthesis that improve oral conditions and maintain the alveolar bone are advocated with the help of endosteal dental implants.[2]

Clinical studies have shown that patients with implant therapy demonstrated a higher level of eating enjoyment and improvement of speech, comfort, and overall satisfaction. The success of implant therapy depends on careful assessment, diagnosis, and understanding of the site, where implant placement is required. An endosteal implant can maintain bone width and height as long as the implant remains healthy.[3]

[1,3,4]Department of Prosthodontics, Kalinga Institute of Dental Sciences, Kalinga Institute of Industrial Technology (KIIT) Deemed to be University, Bhubaneswar, Odisha, India

[2]Department of Prosthodontics, College of Dentistry, Gulf Medical University, Ajman, United Arab Emirates

[5]Department of Prosthodontics, Coorg Institute of Dental Sciences, Virajpet, Kodagu, Karnataka, India

[6]Department of Prosthodontics, St. Gregorios Dental College, Chelad, Kothamangalam, Kerala, India

Corresponding Author: Ashika Bachira Kashi, Department of Prosthodontics, Coorg Institute of Dental Sciences, Virajpet, Kodagu, Karnataka, India, Phone: +91 9741669104, e-mail: drashikabk@gmail.com

How to cite this article: Mohanty AK, Varghese T, Bhushan P, *et al*. Influence of Occlusal Stress on Implant Abutment Junction and Implant Bone Interface: A Finite Element Analysis Study. J Contemp Dent Pract 2022;23(12):1190–1194.

Source of support: Nil

Conflict of interest: None

Another factor critical for the longevity and stability of the implant prosthesis is the superstructure selection. When loads are subjected to the superstructure, stresses are transferred to the bone–implant interface, implant, and prosthetic components, which might affect the survival of the restoration.[4] Metal ceramic

© The Author(s). 2022 Open Access This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (https://creativecommons.org/licenses/by-nc/4.0/), which permits unrestricted use, distribution, and non-commercial reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The Creative Commons Public Domain Dedication waiver (http://creativecommons.org/publicdomain/zero/1.0/) applies to the data made available in this article, unless otherwise stated.

restorations have been the gold standard for years in implant dentistry. Though at the stage of infancy, spotlight is now on zirconia as a viable option for restoration as it yields very favorable mechanical properties and reasonable esthetics.[5]

Keeping in mind the multiple factors that affect the longevity of long-span implant-supported prosthesis, this study is designed to investigate the effect of occlusal forces on the implant–abutment junction of a long-span fixed prosthesis supported by two standard-length implants and a combination of standard length and short implant in posterior mandible and also to compare and evaluate the effect of two different types of retention methods and prosthetic materials used in such long-span implant-supported prosthesis using three-dimensional (3D) finite element analysis (FEA).

Materials and Methods

The present study was conducted in the Department of Prosthodontics and Crown and Bridge, Faculty of Dental Sciences, Sri Ramachandra University, Chennai.

Preparation of Finite Element Models

A computerized tomography of the mandible was used to get the finite element model of the bone. A 3D tetrahedral structural solid finite elements pro/engineer wildfire 2.0 Software was used to model the bone, implant, abutment, and the occlusal surface material. A 3D finite element model of posterior section of the mandible with two titanium implants in the first premolar and second molar regions with two different retention systems (screw-retained prosthesis and cement-retained prosthesis) and two different prosthetic materials (porcelain-fused-to-metal and zirconia prosthesis) was used in this study.

Models were subjected to Analysis System Software (ANSYS) that was used for carrying out FEA and processing the results. The loads were applied at the coordinates once the models had been constructed.

All the materials used in the models were considered to be isotropic, homogeneous, and linearly elastic, and the osseointegration of the implants was accepted as 100%. Values of Young's modulus and the Poisson's ratio for each material were taken from the existing literature.

Material Properties of the Materials Used in the Model

Material	*Elastic modulus (GPa)*	*Poisson's ratio*
Cortical bone	13.7	0.3
Cancellous bone D2	5.5	0.3
Titanium	110	0.36
Zirconia	210	0.36
Co–Cr alloy	218	0.33
Porcelain	82.8	0.35
Cementing medium	7.3	0.35

The bone was modeled with a height of 20 mm. The thickness of cortical bone was modeled as 2 mm. The trabecular bone was modeled between the top and the bottom of cortical layers. These properties approximate the bone quality of the D2 type of bone, which was the most commonly observed bone density type in the posterior mandible of partially edentulous individuals.

Solid tapered, screw-type titanium implants of three different sizes were used. Standard-length implants of 3.7 × 11.5 mm and

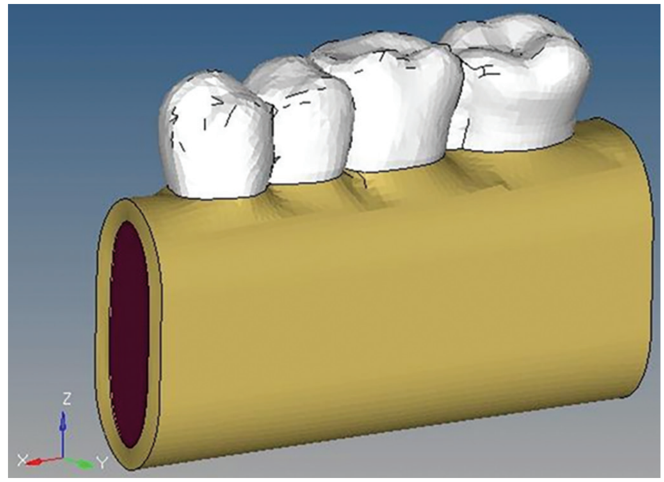

Fig. 1: Finite element model showing prosthesis, cortical, and cancellous bone

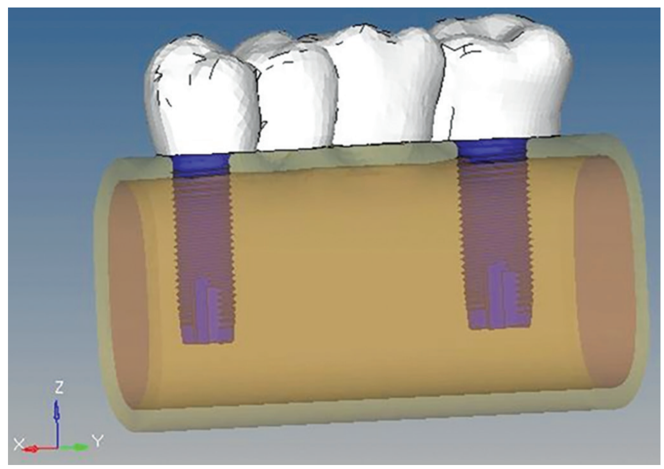

Fig. 2: Model of the prosthesis supported by two implants

4.5 × 11.5 mm and short implants of 4.5 × 8 mm were selected. All the implants were threaded with an internal hex connection.

A four-unit implant-supported fixed prosthesis was designed in 44, 45, 46, and 47 regions with implants being placed in the 44 and 47 regions. The prosthetic material used was porcelain-fused-to-metal and full-contour zirconia. The crown height of the premolars and molars was kept around 10 mm. The mesio-distal width of the premolars and molars was kept at 8 mm. The thickness of the cobalt chromium alloy was kept at 0.8 mm thickness and that of the feldspathic porcelain at 2 mm thickness. The thickness of the full-contour zirconia was set at 2 mm. Both type of retention systems, i.e., cement- and screw-retained types, were incorporated to the models. The cementing medium of about 50 microns was modeled (Figs 1 to 4).

Comparative Groups

S1 – 3.7 × 11 mm (44 region) and 4.5 × 11 mm (47 region)
S1A – Screw-retained porcelain-fused-to-metal prosthesis
S1B – Cement-retained porcelain-fused-to-metal prosthesis
S1C – Screw-retained zirconia prosthesis
S1D – Cement-retained zirconia prosthesis
S2 – 3.7 × 11 mm (44 region) and 4.5–8 mm (47 region)

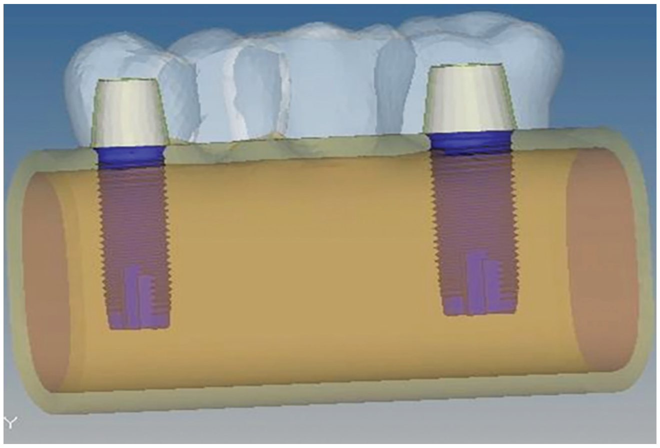

Fig. 3: Model of cement-retained prosthesis supported by two standard-length implants

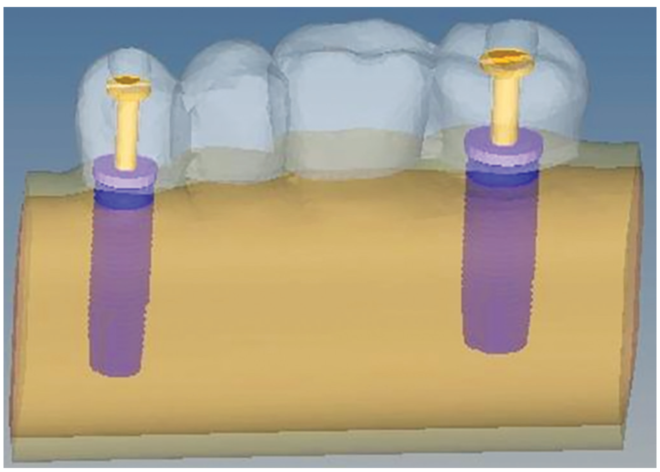

Fig. 4: Model of screw-retained prosthesis supported by two standard-length implants

S2A – Screw-retained porcelain-fused-to-metal prosthesis
S2B – Cement-retained porcelain-fused-to-metal prosthesis
S2C – Screw-retained zirconia prosthesis
S2D – Cement-retained zirconia prosthesis

Application of Load

The average biting force noted in the molar region was 250 N. Both axial and oblique forces were applied. The axial or vertical forces were applied along the long axis of the abutments. The oblique force was applied unilaterally at an angle of 30° to the long axis from the lingual aspect.

The forces were applied on the central groove of all the premolar and molar crowns.

Areas Assessed under Load

- Maximum stress generated on the implant–abutment interface of all the prostheses under vertical and oblique load.
- Maximum stress generated on the implant–bone interface at the cervical third, middle third, and apical third level of all the implants in all the situations under vertical and oblique load.

The results obtained were recorded, tabulated, and compared within the groups.

Table 1: Comparison of stress generated along implant–abutment interface in zirconia and porcelain-fused-to-metal prosthesis under both vertical and oblique load

AB with CD		*Mean*	*Std. deviation*	*p-value*
Distal vertical	CD	117.9	99.58010	0.886
	AB	143.7	128.54253	
Distal oblique	CD	131.5	95.41664	0.686
	AB	148.5	115.28618	
Mesial vertical	CD	207.1	174.63608	0.486
	AB	216.8	184.18138	
Mesial oblique	CD	207.8	162.12274	0.343
	AB	217.9	170.50304	

AB – Porcelain-fused-to-metal group; CD – Zirconia prosthesis group

Table 2: Comparison of stress generated along implant–abutment interface in standard-length group (S1) and standard and short implant combination group (S2) under both vertical and oblique load

S1, S2		*Mean*	*Std. deviation*	*p-value*
Distal vertical	S1	153.2	132.14569	0.343
	S2	108.4	89.92812	1.000
Distal oblique	S1	152.1	124.40282	
	S2	127.9	81.98329	
Mesial vertical	S1	214.8	176.30142	0.486
	S2	209.1	182.69918	
Mesial oblique	S1	212.8	166.67081	0.886
	S2	213.0	166.26555	

S1 – Standard-length implant combination group; S2 – Short- and standard-length implant group

Statistical Analysis

The collected data were analyzed with SPSS for windows, version 16.0, Chicago Inc. To describe the data, descriptive statistics mean and SD were used. To find the significant difference between the bivariate samples in paired groups, the Wilcoxon-signed rank test was used, and for the independent groups, the Mann–Whitney *U* test was used. $P \leq 0.05$ was considered statistically significant.

Results

Table 1 shows that there is no significant difference in the maximum stress generated between zirconia and porcelain-fused-to-metal at the implant–abutment junction under vertical and oblique load.

Table 2 shows no statistically significant difference in the stress values along implant–abutment interface in S1 and S2 groups under both vertical and oblique load.

Table 3 depicted that the *p*-value for all the comparative groups was found to be <0.05, i.e., 0.029. This show that there was a significant difference between cement-retained and screw-retained groups. The cement-retained prosthesis group shows significantly less stress values than the screw-retained group.

Table 4 reveals the comparison of maximum stress in the cervical level of implant–bone interface of the mesial and distal implants supporting zirconia and porcelain used to metal prosthesis under vertical and oblique load. But there was no significant difference in stress levels.

Table 5 shows that the *p*-value for mesial and distal implants under vertical loads was found to be >0.05. This suggests no

Table 3: Comparison of stress generated along implant–abutment interface in cement-retained and screw-retained prosthesis under both vertical and oblique load

AC with BD		*Mean*	*Std. deviation*	*p-value*
Distal vertical	AC	225.2	55.79735	0.029
	BD	36.4	4.96277	
Distal oblique	AC	228.5	40.67366	0.029
	BD	51.5	6.80686	
Mesial vertical	AC	367.3	10.34625	0.029
	BD	56.6	6.54064	
Mesial oblique	AC	356.9	10.03489	0.029
	BD	68.9	2.36476	

AC – Screw-retained prosthesis; BD – Cement-retained prosthesis

Table 4: Comparison of maximum stress produced in the cervical third of the implant–bone interface in zirconia prosthesis and porcelain-fused-to-metal prosthesis

AB with CD		*Mean*	*Std. deviation*	*p-value*
Distal vertical	CD	9.9	2.60859	0.886
	AB	10.5	2.84168	
Distal oblique	CD	32.6	12.74688	1.000
	AB	34.3	3.24378	
Mesial vertical	CD	16.3	4.50600	0.486
	AB	17.7	3.22711	
Mesial oblique	CD	53.9	26.87966	0.886
	AB	47.5	7.87464	

AB – Zirconia prosthesis group; CD – Porcelain-fused-to-metal prosthesis group

Table 5: Comparison of maximum stress produced in the cervical third of the implant bone interface of the implants supporting in screw-retained prosthesis and cement-retained prosthesis

AC with BD		*Mean*	*Std. deviation*	*p-value*
Distal vertical	AC	8.9	1.37900	0.343
	BD	11.5	2.96266	
Distal oblique	AC	39.2	4.33349	0.057
	BD	27.7	8.27916	
Mesial vertical	AC	15.0	2.75942	0.200
	BD	19.0	3.68996	
Mesial oblique	AC	65.1	13.60735	0.029
	BD	36.2	8.45149	

AC – Screw-retained prosthesis group; BD – Cement-retained prosthesis group

Table 6: Comparison of maximum stress produced in the cervical third of the implant bone interface of standard-length implants (S1) and combination of standard- and short-length implants (S2)

S1, S2		*Mean*	*Std. deviation*	*p-value*
Distal vertical	S1	11.9	2.44752	0.057
	S2	8.5	1.26792	
Distal oblique	S1	35.0	7.18200	0.886
	S2	31.8	10.79567	
Mesial vertical	S1	18.8	4.14833	0.200
	S2	15.2	2.42397	
Mesial oblique	S1	52.7	19.85453	0.886
	S2	48.7	20.17532	

S1 – Standard-length implant combination; S2 – Short- and standard-length implant combination

statistically significant difference in the cervical bone level of the mesial and distal implants under vertical load between that of the screw-retained and cement-retained.

Table 6 shows the comparison of maximum stress produced in the cervical third of the implant–bone interface of the standard lengths (S1) and short implants (S2) under vertical and oblique forces. *P*-value for the distal implants in S1 and S2 situation under vertical load was 0.057.

The inference of the present study indicates that the combination of short implants and standard-length implants with porcelain-fused-to-metal or zirconia as the prosthetic material can be a successful treatment option for the posterior mandible. This study also confirms that cement-retained prosthesis is comparatively better than screw-retained prosthesis.

Discussion

Though implant dentistry has shown remarkable results over the last few decades, however, restoring the mandibular posterior region still remains one of the most challenging tasks due to several complicating factors. The most frequent problem faced in this region is the bone resorption that often accompanies tooth loss resulting in a deficient posterior alveolar ridge and close proximity to the mandibular nerve, rendering implant placement difficult.[6]

In the view of these anatomical problems, the application of short implants was advocated. The use of short implants not only reduces the complexity of bone grafting and sinus lift procedures but also reduces the chances of mandibular nerve paresthesia or sinus perforation.[7] Various clinical studies have supported and justified the use of short implants in both maxillary and mandibular posterior regions.

The present study showed that there was a significant difference between cement-retained and screw-retained groups. The cement-retained prosthesis group shows significantly less stress values than the screw-retained group. Cho et al.[8] conducted a longitudinal study to compare the frequency of screw loosening in standard diameter (3.75 and 4.0 mm) implant prostheses to that of wide diameter (5.0 and 6.0 mm) implant prostheses that have been hand torqued and to see if using a torque driver could prevent or minimize the recurrence of this loosening. They concluded that wide-diameter implants showed 5.8% screw loosening, while standard-diameter implants showed 14.5% screw loosening after insertion.

Porcelain-fused-to-metal has been the gold standard for years in implant dentistry. But due to the increase in demand for esthetics by patients, the use of all ceramic crowns has become increasingly common. Zirconium dioxide (zirconia) has been in the limelight in prosthodontics due to its excellent mechanical properties and improved natural-looking appearance compared to metal ceramics.[9] Various studies have been undertaken to validate the use of zirconia in implant dentistry.

In a recent study, Barão et al.[10] evaluated the flexural strength of two different zirconia frameworks. It was concluded that zirconia framework systems can withstand biting force (even para functions) in posterior implant-supported bridges.

Finite element analysis has become an increasingly useful tool for the prediction of the effects of stress on the implant, its abutment and prosthesis, and the surrounding bone. A remarkable advantage of the finite element method is the chance to study areas that are difficult or impossible to access without any risks to a living subject of investigation.[11]

Three different types of implants were used in the present study. All the implants were solid tapered, screw-type titanium implants. Standard-length implants of 3.7 mm diameter with 11 mm length and 4.5 diameters with 11 mm length were selected. The 3.7 × 11 mm implant was selected to be used as the mesial implant and 4.5 × 11 mm implant as the distal implant. The diameters of 3.7 mm and 4.5 mm were selected keeping in mind the anatomy of the posterior mandibular bone model generated in this study. Similarly, Manicone et al.[11] suggest that the survival rate of implants 3.0–3.9 mm in diameter was 90.7%, whereas the survival rate of implants from 4 to 4.9 mm was 94.6% over a period of 3 years.

According to the study by Lops et al.,[12] the long-term prognosis of short implant (8 mm in height) was as high as 92.3% compared to 95.9% of standard implants after 20 years, confirming the high success rate of short implants.

Traditionally, porcelain-fused-to-metal has been used as the standard prosthetic material in implant dentistry. Keeping in mind the aim of this study to compare two different prosthetic materials, porcelain-fused-to-metal and full-contour zirconia were chosen. Studies suggest that the survival rate of zirconia-based single- and multiple-unit implant prosthesis is high. Short-term clinical data suggest that zirconia-based FDPs may be considered a viable option. Therefore, the increased use of zirconia in the oral environment renders it necessary to examine its use as a clinically successful restorative material in implant dentistry.[13,14]

The loading forces were applied, so as to show the two different occlusal states. Both axial and oblique forces of 250 N were applied along the long axis of the abutments. This value for vertical and oblique loading is in accordance with the clinical study by Morneburg and Proschel,[15] which was carried out to measure masticatory forces on implant-supported fixed prosthesis.

The limitation of the present study includes, despite the best efforts to model the structure accurately, the model has several limitations. It does not give an insight to the geometric behavior of the bone as a result of chewing forces. Masticatory forces are dynamic in nature, whereas this study was conducted under static loads. Bone is viscoelastic, anisotropic, and heterogeneous material, whereas, in the present study, it was assumed to be linearly elastic and homogenous in nature. The resultant stress values obtained may not be accurate quantitatively, though they are generally accepted qualitatively. The merging of the colors in the model makes it difficult to ascertain the definitive range. Hence, subjective variation cannot be eliminated.

Conclusion

The present study concluded that the short implants in combination with standard-length implants using either porcelain-fused-to-metal or zirconia as prosthetic material in the form of long-span implant-supported prosthesis can be a viable treatment option in the posterior mandible. This study also confirms that cement-retained prosthesis is comparatively better than screw-retained prosthesis.

References

1. Charyeva OO, Altynbekov KD, Nysanova BZ. Kennedy classification and treatment options: A study of partially edentulous patients being treated in a specialized prosthetic clinic. J Prosthodont 2012;21(3):177–180. DOI: 10.1111/j.1532-849X.2011.00809.x.
2. Kapur KK, Garrett NR, Hamada MO, et al. Randomized clinical trial comparing the efficacy of mandibular implant-supported overdentures and conventional dentures in diabetic patients. Part III: Comparisons of patient satisfaction. J Prosthtet Dent 1999;82(4): 416–427. DOI: 10.1016/s0022-3913(99)70028-4.
3. Zarb GA, Schmitt A. The edentulous predicament. I: A prospective study of the effectiveness of implant supported fixed prostheses. J Am Dent Assoc 1996;127(1):59–65. DOI: 10.14219/jada.archive.1996.0031.
4. Karl M, Graef F, Taylor TD, et al. In vitro effect of load cycling on metal-ceramic cement and screw-retained implant restorations**.** J Prosthet Dent 2007;97(3):137–140. DOI: 10.1016/j.prosdent.2007.01.001.
5. Zarone F, Russo S, Sorrentino R. From porcelain-fused-to-metal to zirconia: Clinical and experimental considerations. Dent Mater 2011;27(1):83–96. DOI: 10.1016/j.dental.2010.10.024.
6. Weber H-P, Sukotjo C. Does the type of implant prosthesis affect outcomes in the partially edentulous patient? Int J Oral Maxillofac Implants 2007;22(Suppl):140–172. PMID: 18437795.
7. Modi R, Mittal R, Kohli S, et al. Screw versus cement retained prosthesis: A review. Int J Adv Health Sci 2014;1(6):26–32. https://aimdrjournal.com/wpcontent/uploads/2021/06/DE7_RA_Ulfat-edit.pdf.
8. Cho S-C, Small P-N, Elian N, et al. Screw loosening for standard and wide diameter implants in partially edentulous cases: 3- to 7-year longitudinal data. Implant Dent 2004;13(3):245–250. DOI: 10.1097/01.id.0000140459.87333.f8.
9. Raigrodski AJ, Hillstead MB, Meng GK, et al. Survival and complications of zirconia based fixed dental prostheses: A systematic review. J Prosthet Dent 2012;107(3):170–177. DOI: 10.1016/S0022-3913(12)60051-1.
10. Barão VA, Delben JA, Lima J, et al. Comparison of different designs of implant-retained overdentures and fixed full-arch implant-supported prosthesis on stress distribution in edentulous mandible – A computed tomography-based three-dimensional finite element analysis. J Biomech 2013;46(7):1312–1320. DOI: 10.1016/j.jbiomech.2013.02.008.
11. Manicone PF, Rossi Iommetti P, Raffaelli L. An overview of zirconia ceramics: basic properties and clinical applications. J Dent 2007;35(11):819–826. DOI: 10.1016/j.jdent.2007.07.008.
12. Lops D, Bressan E, Pisoni G, et al. Short implants in partially edentulous maxillae and mandibles: A 10 to 20 years retrospective evaluation. Int J Dent 2012;351793:1–8. DOI: 10.1155/2012/351793.
13. Piconi C, Maccauro G. Zirconia as a ceramic biomaterial. Biomaterials 1999;20(1):1–25. DOI: 10.1016/s0142-9612(98)00010-6.
14. Rismanchian M, Shafiei S, Nourbakhshian F, et al. Flexural strengths of implant-supported zirconia-based bridges in posterior regions. J Adv Prosthodont 2014;6(5):346–350. DOI: 10.4047/jap.2014.6.5.346.
15. Morneburg TR, Proschel PA. Measurements of masticatory forces and implant loads: A methodologic clinical study. Int J Prosthodont 2002;15(1):20–27. PMID: 11887595.