IDR International Dental Research

Int Dent Res 2024; 14(S1): 12-20
https://doi.org/10.5577/indentres.568

Original Article Open Access

Analysis of stress distribution in implant-supported prostheses with custom abutments at different angles of 20 degrees: A finite element analysis

Merve Karagöz[1], Meryem Erdoğdu[1], Reza Mohammadi[2], Ali Rıza Tunçdemir[1]

[1] Necmettin Erbakan University, Faculty of Dentistry, Department of Prosthodontics, Konya, Türkiye

[2] Necmettin Erbakan University, Faculty of Dentistry, Konya, Türkiye

Received: 16 October 2024

Accepted: 13 November 2024

Correspondence:

Dr. Merve KARAGÖZ
Necmettin Erbakan University, Faculty of Dentistry, Department of Prosthodontics, Konya, Türkiye.
E-mail: mrvkrgoz@gmail.com

How to cite this article:

Karagöz M, Erdoğdu M, Mohammadi R, Tunçdemir AR. Analysis of stress distribution in implant-supported prostheses with custom abutments at different angles of 20 degrees: A finite element analysis. Int Dent Res 2024;14(S1):12-20.
https://doi.org/10.5577/indentres.568

Abstract

Aim: Implants may not always be placed parallel to each other. In such cases, implants can be made more parallel by adjusting the angles with custom abutments. Different cementation materials can be used for cement-retained abutments. The bonding and stress resistance values of materials used in the cementation of implant-supported prostheses vary. The aim of this study is to demonstrate the stress distribution values of restorations bonded with different cementation materials in finite element analysis (FEA).

Methodology: In this study, a maxillary edentulous jawbone was designed using the SolidWorks program. Two implants were placed in the regions of teeth #14 and #16. Implant data were obtained from the Bilimplant company. A 20-degree angled custom abutment and implant-supported prosthesis were designed using the Exocad program. Standard Tesellation Language (STL) files were transferred to SolidWorks to obtain Standard for the Exchange of Product Model Data (STP) files. The created prosthesis design was then transferred to the ABAQUS program for finite element analysis. Subsequently, using five different cementation materials (glass ionomer cement, dual-cure resin cement (Ivoclar), dual-cure resin cement (RelyX), polycarboxylate cement, and self-cure resin cement), stress distribution values of implant-supported prosthesis components were recorded as von Mises stress (VMS) values.

Results: The results indicate higher stress values with glass ionomer cement and lower values with polycarboxylate cement. Stress distribution increases posteriorly but does not differ significantly based on cement type. The lowest stress on implant screws was found with glass ionomer, but the highest stress varied. Cortical bone stress is lowest with glass ionomer cement.

Conclusion: No significant difference was found in stress values among different cement types. Stress increases in implants, abutments, and cements due to forces applied posteriorly, while anteriorly, retention screw stress increases. The choice of cementation material does not significantly impact stress in implant components or the surrounding tissues.

Keywords: Finite element analysis, implant, cement, custom abutment, Von Mises stress

Introduction

An implant is a prosthetic component made of alloplastic materials that is placed beneath the mucosal or periodontal layer to support and/or retain fixed or removable prostheses (1).

Dental implant systems typically consist of two main components: the abutment and the implant screw. These components are connected by tightening the screw to a specific torque value, depending on the selected material and connection design, thus forming a secure connection (1).

An abutment is a part of a tooth, a portion of a tooth, or a component of a dental implant system that is involved in supporting or retaining a prosthesis (2). The abutment is the part of the implant that protrudes into the oral cavity and comes in various types and forms, including standard stock abutments, cast custom abutments, or computer-generated custom abutments. The selection of the abutment type depends on factors such as the clinical case, the clinician's experience, and the patient's preference (3).

Implants placed within the jawbone restore function by replacing lost teeth while minimizing bone resorption. In cases involving anatomical challenges or the need for bone grafting, achieving ideal implant placement can be more difficult. In situations where implants cannot be placed parallel to each other, angled/special abutments can be used to overcome this challenge (4).

Implant surgery often requires sinus lift procedures and hard and soft tissue grafting either before or during the procedure. These procedures are time-consuming and costly, and some patients may prefer to avoid additional surgical procedures. In such cases, the position and angle of dental implants may be less than ideal. The use of angled or tapered abutments or multi-unit frameworks in these patients represents alternative approaches to restoring function and aesthetics (5).

The most commonly used retention types in implant-supported prostheses are screw-retained or cement-retained restorations. Both have advantages and disadvantages that have been noted by various authors over the years (6).

Restorations made with screw-retained abutments are secured onto the abutment by screwing them in and then covering the screw with an intermediary material. If the screw access hole of anterior teeth can be positioned lingually rather than on the incisal edge, a screw-retained restoration can be used. This allows for the implant abutment to be accessed and torqued again. This type of restoration is preferred in cases where aesthetics are not critical, especially in the posterior region, where vertical space is limited, and when the top of the implant is positioned 3 mm or deeper inside the gumline (7).

Cement-retained abutments are one of the most commonly used types of abutments. They offer aesthetic and clinical advantages over screw-retained implants, especially in areas where aesthetics are crucial, in regions with thin mucosa, and when the implant's top is less than 2-3 mm deep within the gumline. Cement-retained abutments do not have screw access holes, allowing for a more natural restoration of implants that are not perfectly parallel to natural teeth.

Cementing agents are materials used to ensure the stability of fixed prostheses throughout their lifespan in the oral cavity. Various cementation materials can be used for cement-retained abutments. The main distinction in cement usage lies between permanent and temporary cement types.

In cement-retained implant prostheses, two types of cement can be used: temporary or permanent. The choice of cement depends on the loading protocol, required retention, and retrievability. Both temporary and permanent cements have their own advantages and disadvantages, and the choice of cement type varies based on the patient's needs. Temporary cement is used in situations where less retention is required; during staged loading; when there is adequate abutment height, width, and taper; when the fit accuracy of the superstructure is crucial; or when retrievability is necessary. Another advantage of temporary cement is that it is easier to remove. Some authors suggest that temporary cementation may be more suitable for restorations supported by multiple implants (8).

While zinc oxide is considered a temporary cement, glass ionomer, resin cement, zinc phosphate, and polycarboxylate cements are considered permanent cements. The bonding and stress resistance values of materials used in the cementation of implant-supported prostheses vary (6).

The selection of an appropriate dental cement for cement-retained implant-supported prostheses depends largely on the material's retention and tensile strength. However, in the restoration of anterior teeth, aesthetics become equally important. The retention and aesthetics of the restoration depend on the interaction of the cement with the abutment or prosthesis materials. Various studies have evaluated the aesthetics and retention of various abutment-prosthetic combinations to determine the best-performing cement for each combination (9).

In general, according to many studies comparing the tensile strengths of different temporary and permanent cements, the following cements are listed in order from the least to the greatest retention: zinc oxide (with or without eugenol), polycarboxylate, glass ionomer, resin-modified glass ionomer, zinc phosphate, and resin cements (10).

In situations where it is challenging to place the implant in an ideal position to move the screw access channels away from the aesthetic zone, custom abutments can be used. The aesthetic development of implant restoration involves using a flexible composite combined with an opaque material. Easy access to the back of the mouth is possible for patients with limited jaw movement, particularly for cement-retained restorations (11). Implant angulations not only create aesthetic concerns but also affect the stress on implants and surrounding tissues (5).

The aim of this study was to demonstrate the stress distribution values of restorations bonded with different cementation materials using finite element analysis. The null hypothesis was that there would be no difference in stress distribution values in the cementation of angled abutments with different cements.

Materials and Methods

For this study, the jaw of an edentulous patient was mimicked, and the maxillary jawbone (including mucosa, trabecular, and cortical bone) was designed using the SolidWorks program (SolidWorks Corp., Waltham, MA, USA). After obtaining Standard for the Exchange of Product Model Data (STP) files, implant files (3.7 mm in diameter and 10 mm in length) were positioned at teeth #14 and #16. Following the acquisition of Standard Tesellation Language (STL) files, the prosthesis design was created using the Exocad program (Dental Cad3.1 Rijeka, EXOCAD, Darmstadt, Germany) (Fig. 1). The obtained STL files were imported into Geomagic Design X software (Geomagic Design X 2020.0), where necessary adjustments, such as smoothing, were made. Subsequently, STP files were generated. The produced prostheses were then fitted onto the models over the implants, and in cement-retained models, the cement gap was set to 40 micrometers.

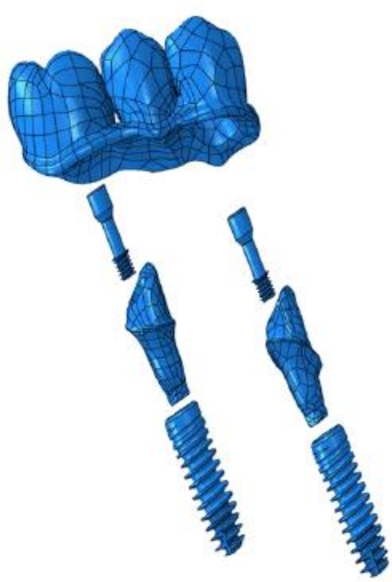

Figure 1. Implant-abutment-screw-restoration

The final version of the obtained model was saved as an STP file and transferred to the ABAQUS program (2020 Dassault Systems Simulation Corp., Johnston, RT, USA) for finite element analysis (Figs. 2 and 3).

In the Abaqus program, material properties were provided for components in Table 1 and Table 2, and connections between components were established in the interaction section. The connections between the substructure and superstructure, bones, and mucosa and between the implant and bone, which mimicked osseointegration, were defined as "ties," while the connections between screw parts were simulated by specifying a torque property (Material properties are presented in Tables 1 and 2).

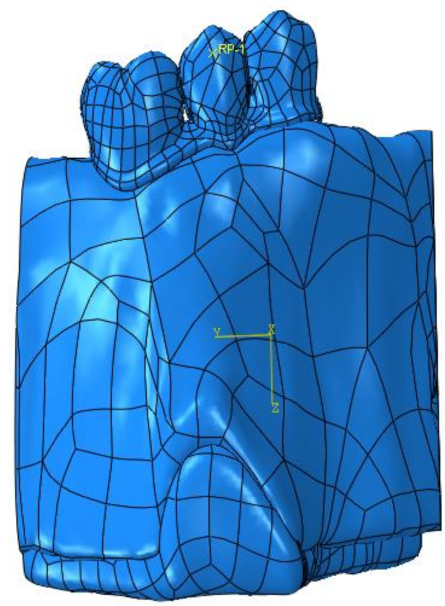

Figure 2. External view of the restoration

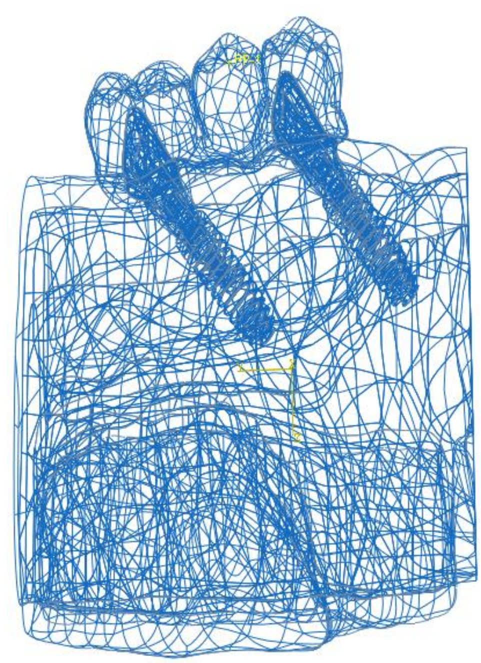

Figure 3. Drawing of the design with implants placed in the bone

Subsequently, in the load and boundary condition section, a vertical load of 150 N with a 30-degree inclination from the palatal to the buccal direction was applied to the occlusal table. The maxillary jawbone was constrained as ENCASTRE (fully restrained in all directions, including translation and rotation). The implants were assumed to have fully osseointegrated with the bone, and the implant components were completely constrained in the X, Y, and Z directions on the implant surface. The contact type used to define the integration quality between the abutment, fixture, and abutment screw interface was chosen as frictional, and the frictional coefficient was set to 0.3.

The equation for the tightening torque is as follows:

$$T = K \times D \times F, \quad (1)$$

where TTT represents the tightening torque of the screw (N·cm), DDD is the diameter of the screw (m), FFF is the preload force of the screw (N), and KKK is the screw factor (or torque coefficient), typically having a value of 0.2 (12).

Using equation (1), the preload force of the screw can be calculated when the tightening torque is applied to the abutment screw. For example, when the tightening torque value is 25 N·cm, the preload force FFF value is calculated to be 781 N (13).

Subsequently, using five different cement materials (glass ionomer cement (CI), dual-cure resin cement (Ivoclar DCRI, Vivadent, Schaan, Liechtenstein), dual-cure resin cement (RelyX DCRR, 3M ESPE, St. Paul, MN, US), polycarboxylate cement (PC), and self-cure resin cement (SCR), the stress distribution values of the implant-supported prosthesis components were recorded in terms of von Mises stress (vMS) values (14-17).

Table 1. Material properties assigned to the model

Material	Young's Modulus(E MPa)	Poisson's Ratio (ν)	Shear Modulus (G MPa)
Cortical Bone	E_x 12,600 E_y 12,600 E_z 19,400	υ_{xy} 0.300 υ_{yz} 0.253 υ_{xz} 0.253 υ_{yx} 0.300 υ_{zy} 0.390 υ_{zx} 0.390	G_{xy} 4,850 G_{yz} 5,700 G_{xz} 5,700
Trabecular Bone	E_x 1,148 E_y 210 E_z 1,148	υ_{xy} 0.055 υ_{yz} 0.010 υ_{xz} 0.322 υ_{yx} 0.010 υ_{zy} 0.055 υ_{zx} 0.322	G_{xy} 68 G_{yz} 68 G_{xz} 4,340
Bone Graft	3,450	0.31	
Mucoza	2.8	0.40	
Titanium	110,000	0.33	
Feldspathic Porcelain	82,800	0.28	

Table 2. Material properties of the cements used

Materials	Elastic modulus (GPa)	Poisson's ratio
Dual-cure resin cement/RelyX	7.7	0.30
Dual-cure resin cement/Ivoclar	8.3	0.35
Self-cure resin cement	4.9	0.27
Glass ionomer cement	20.1	0.3
Polycarboxylate cement	5.11	0.35

Results

In the obtained results (Table 3), glass ionomer cement showed a higher vMS value compared to other cements, and polycarboxylate cement showed the lowest value. When comparing implant #14 with implant #16, as the direction moved posteriorly, the stress distribution increased, but there was no significant difference in the forces applied to the implants based on the type of cement used. The lowest values for implant screws were observed in glass ionomer cement for both groups, while differences were observed in the highest values. When comparing abutments, the lowest values were observed in prostheses where glass ionomer cement was used. Regarding the vMS values observed in cortical bone, the lowest value was again observed in prostheses cemented with glass ionomer cement (Figs. 4-8).

Table 3. Obtained vMS values

	Glass ionomer cement	Dual-cure resin cement - Ivoclar	Dual-cure resin cement - RelyX	Polycarboxylate cement	Self-cure resin cement
Prosthetic restoration	263.5	241.4	231.4	220.7	206.3
Implant 4	25.30	25.27	25.26	25.24	25.23
Implant 6	42.01	42.18	42.22	42.33	42.39
Cement 4	40.43	26.79	27.55	21.70	23.33
Cement 6	93.59	62.45	63.37	52.26	54.23
Abutment 4	151.7	152.3	152.4	152.8	152.9
Abutment 6	386.2	387.3	387.5	388.3	388.6
Abutment screw 4	10.97	10.99	10.99	11.00	11.01
Abutment screw 6	6.151	6.174	6.180	9.165	6.204
Trabeculer bone	15.03	15.05	15.06	15.07	15.08
Cortical bone	23.29	23.32	23.32	23.34	23.35

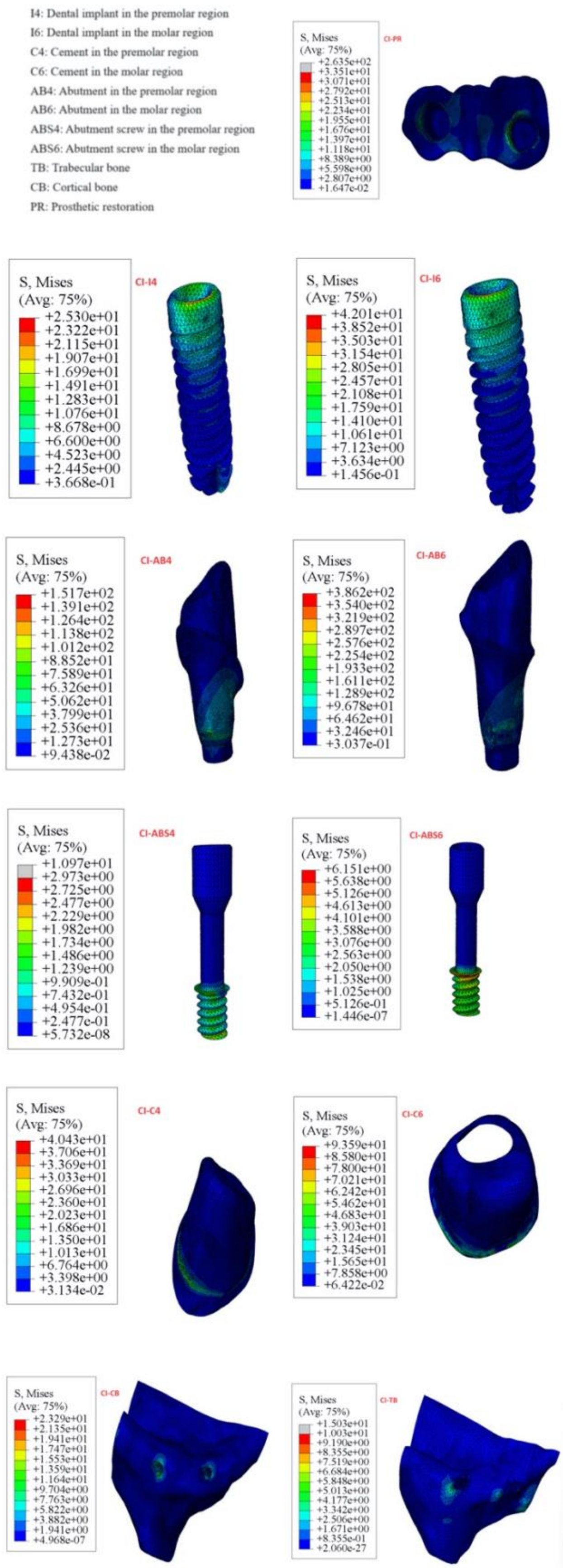

Figure 4. Restoration using glass ionomer cement

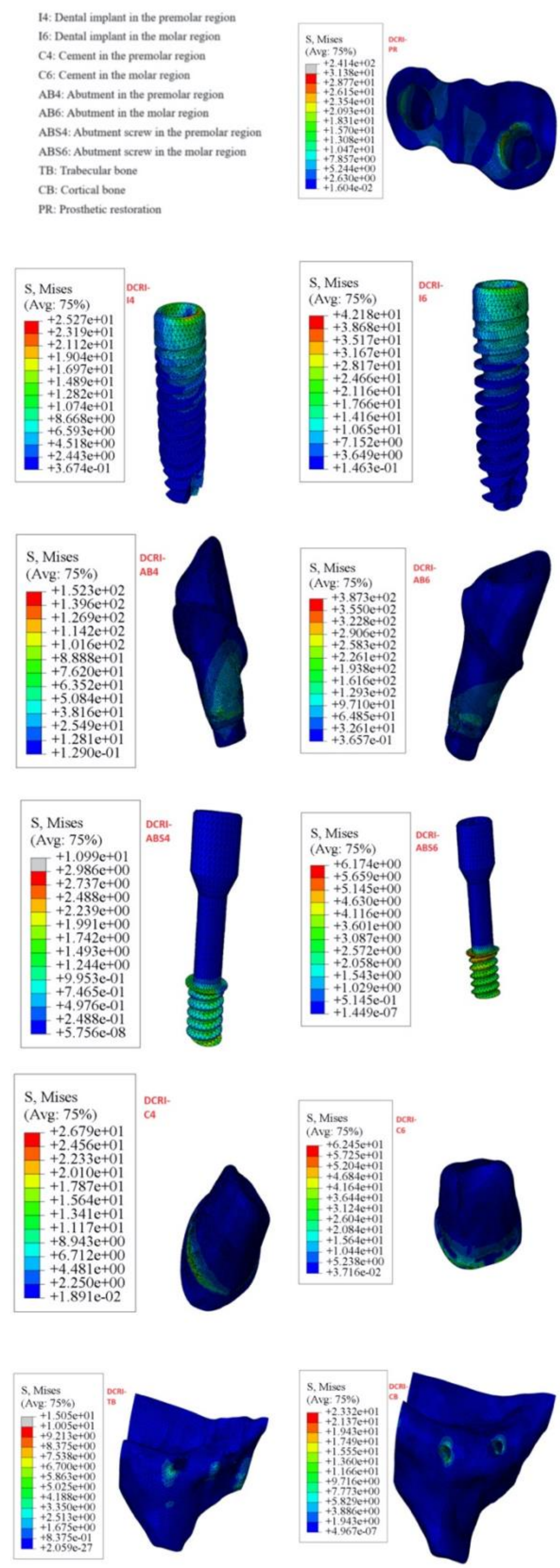

Figure 5. Restoration using dual-cure resin cement - Ivoclar

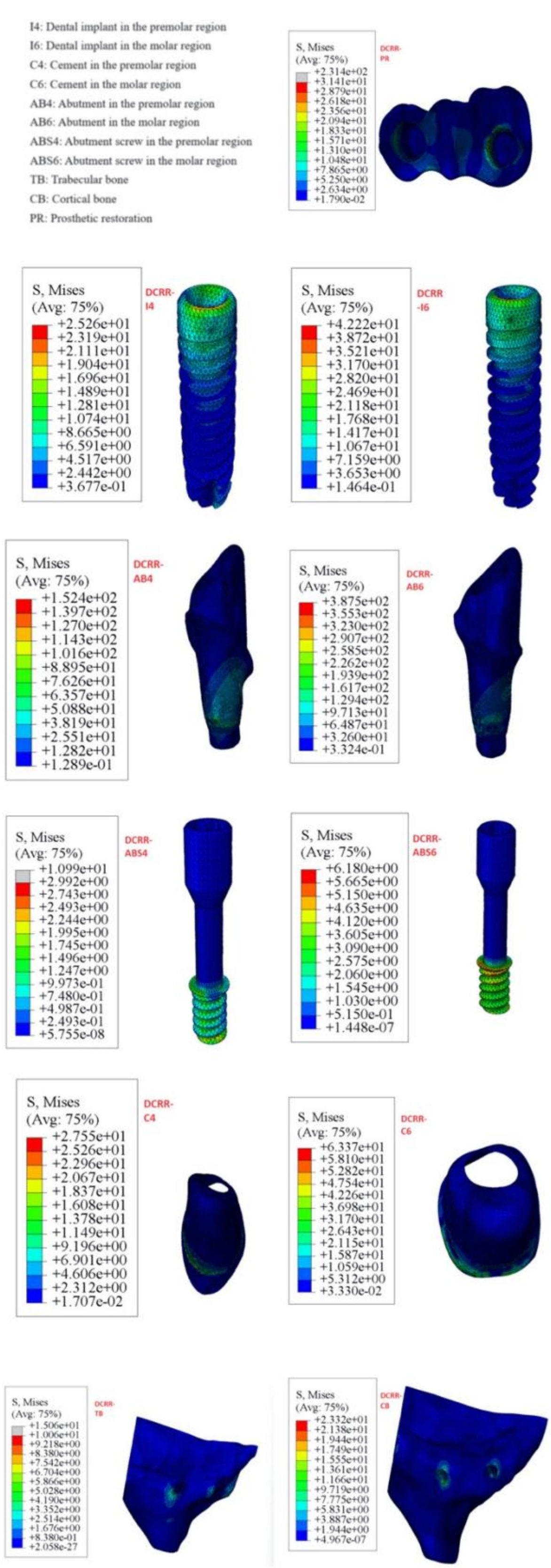

Figure 6. Restoration using dual-cure resin cement - RelyX

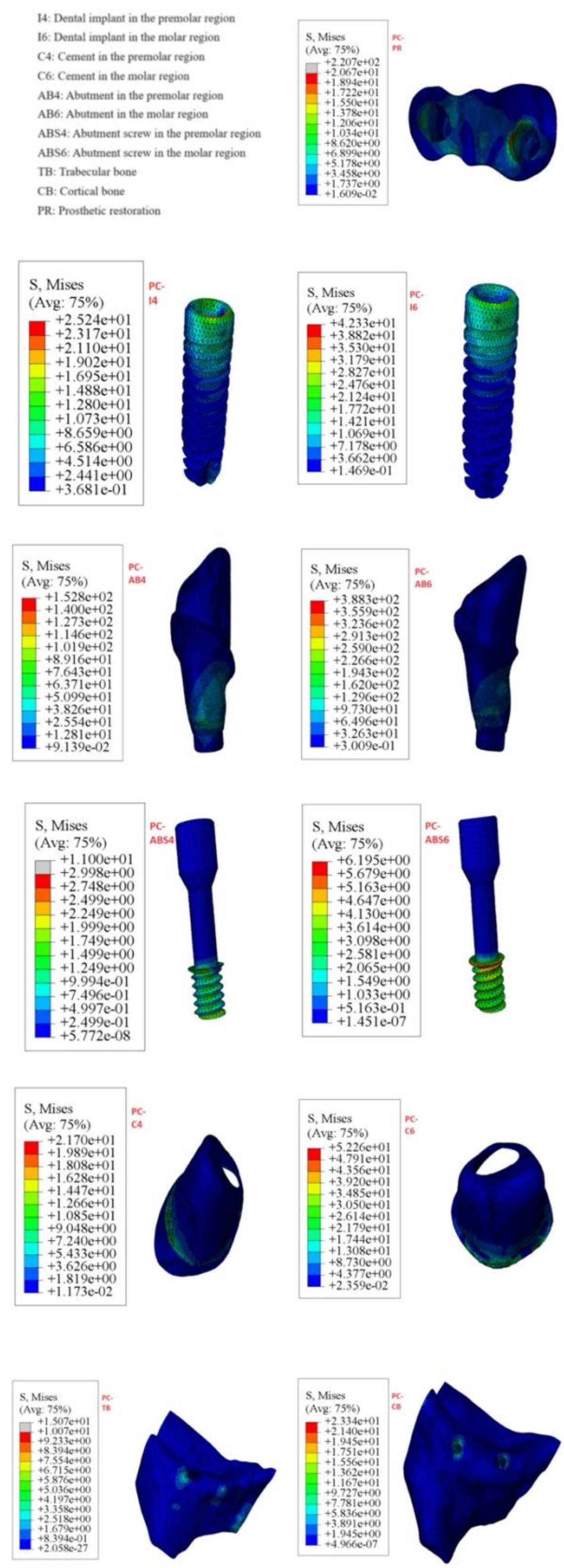

Figure 7. Restoration using polycarboxylate cement

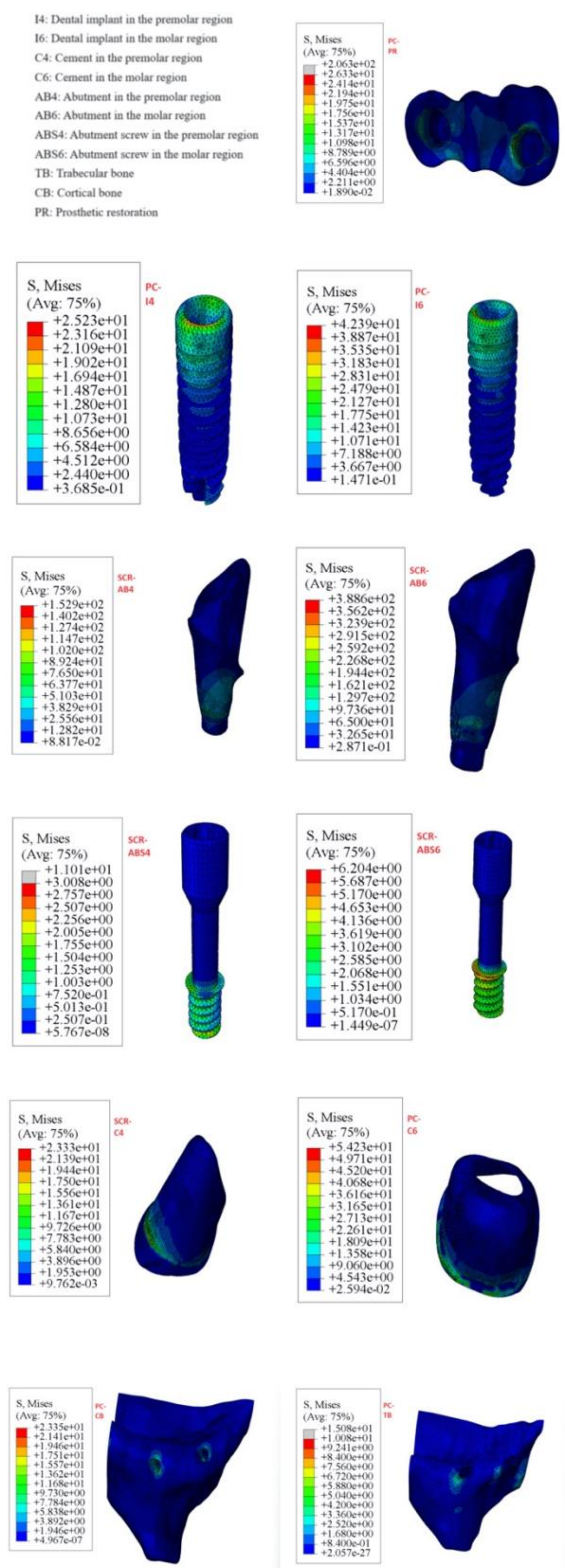

Figure 8. Restoration using self-cure resin cement

Discussion

The study results showed that although the stress distribution values were close to each other, they yielded different results. Thus, the null hypothesis has been rejected.

Cement-retained implant-supported prostheses are widely utilized for their ease of application and cost-effectiveness. Despite the simplicity of manufacturing cement-retained prostheses, their retention differs between implant-supported and tooth-supported prostheses (9).

According to a survey conducted by Tarica et al. resin-modified glass ionomer cement emerged as the most preferred cement for implant-supported prostheses in dental schools across the United States. Following closely behind is zinc oxide eugenol, with traditional glass ionomer cement being the next popular choice. Polycarboxylate and acrylic urethane were reported as the least utilized materials (18).

In many finite element studies, the stress distributions of cements have been investigated. In a study conducted in 2023 on endocrowns and onlays, stresses generated by two different types of cement, namely dual-cure and light-cure, were analyzed using finite element analysis. While no significant difference was observed between the two types of cement on the endocrown, it was found that in the case of onlay restorations, the light-cured cement exhibited better stress distribution both on the restoration and on the enamel surface (14).

In another study conducted in Korea in 2015 (17), a finite element analysis was performed using four different cements on monolithic zirconia. Zinc phosphate, polycarboxylate, glass ionomer, and resin cements were utilized in this study. The highest stress on the crown and cement layer was observed with polycarboxylate and phosphate cements. It was observed that materials with lower elastic modulus resulted in lower stress distribution and transferred less stress to the prepared tooth. For monolithic zirconia crowns, the use of resin cements was recommended due to their lower elastic modulus (17). Similar to the findings of the study conducted by Ha SR (17), we also observed high stress in the cement when glass ionomer cement with a high elastic modulus was used in the restoration in our study. However, inversely proportional to this, low stress was observed in other materials.

It can be speculated that the cement may have an additional function of creating a suspension effect against occlusal loads to protect other components. In this context, the higher stress observed in the cement may indicate that it absorbs more load, leading to less observed stress in other components.

Conclusion

The results indicate that there was no significant difference in the VMS values according to the type of cement used. This finding suggests that the choice of cement material did not have a pronounced effect on the stress distribution of the surrounding tissues and implants.

Furthermore, it was observed that while the values increased posteriorly in implants, abutments, and cements, there was a reverse trend in the retention screw values, showing an anterior increase. These results imply that the applied forces may exert varying effects depending on the placement position.

Overall, significant differences in VMS values among restorations using different cements were not observed. This suggests that the selection of cement materials used in implant components, restorations, and surrounding biological tissues may not significantly affect the stress distribution.

Disclosures

Acknowledgments: This study has been presented at the Necmettin Erbakan University 3rd International Dentistry Congress in Konya, Türkiye, held between May 24-26, 2024.

Peer-review: Externally peer-reviewed.

Author Contributions: Conception – M.K.; Design – M.K., A.R.T.; Supervision – M.E.; Materials – M.K., M.E.; Data Collection and/or Processing – M.E., R.M.; Analysis and/or Interpretation – M.E.; Literature Review – R.M., A.R.T.; Writer – M.K.; Critical Review – M.E., A.R.T.

Conflict of Interest: No conflict of interest was declared by the authors.

Funding: The authors declared that this study has received no financial support.

References

1. Misch CE. Implant dentistry. Dentistry today. 2002;21:62.
2. The Glossary of Prosthodontic Terms 2023: Tenth Edition. The Journal of prosthetic dentistry. 2023;130:1-3. https://doi.org/10.1016/j.prosdent.2023.03.003
3. Priest G. Virtual-designed and computer-milled implant abutments. Journal of oral and maxillofacial surgery : official journal of the American Association of Oral and Maxillofacial Surgeons. 2005;63:22-32. https://doi.org/10.1016/j.joms.2005.05.158
4. Turkyilmaz I. Restoring severely angled implants with custom abutments and a screw-retained fixed dental prosthesis. Journal of dental sciences. 2019;14:107-8. https://doi.org/10.1016/j.jds.2018.07.003
5. Chronaios D, Spyropoulou PE, Razzoog ME, Sierraalta M. Material options for restoring intentionally misaligned implants on maxillary edentulous arch: a clinical report. The Journal of prosthetic dentistry. 2013;109:145-8. https://doi.org/10.1016/S0022-3913(13)60033-5
6. Reda R, Zanza A, Cicconetti A, Bhandi S, Guarnieri R, Testarelli L, et al. A Systematic Review of Cementation Techniques to Minimize Cement Excess in Cement-Retained Implant Restorations. Methods and protocols. 2022;5(1):9. https://doi.org/10.3390/mps5010009
7. Ma S, Fenton A. Screw- versus cement-retained implant prostheses: a systematic review of prosthodontic maintenance and complications. The International journal of prosthodontics. 2015;28:127-45. https://doi.org/10.11607/ijp.3947
8. Bhoyar A, Jain A, Parlani S, Pandey HJIJOHD. Selection of luting agent in implant retained prosthesis: A review. International Journal of Oral Health Dentistry. 2016;2:19-25. https://doi.org/10.5958/2395-499X.2016.00003.4
9. Almehmadi N, Kutkut A, Al-Sabbagh MJDC. What is the best available luting agent for implant prosthesis? Dental Clinics of North America. 2019;63:531-45. https://doi.org/10.1016/j.cden.2019.02.014
10. Nematollahi F, Beyabanaki E, Alikhasi MJJoP. Cement selection for cement-retained implant-supported prostheses: A literature review. Journal of Prosthodontics. 2016;25:599-606. https://doi.org/10.1111/jopr.12361
11. Hamed MT, Abdullah Mously H, Khalid Alamoudi S, Hossam Hashem AB, Hussein Naguib G. A Systematic Review of Screw versus Cement-Retained Fixed Implant Supported Reconstructions. Clinical, cosmetic and investigational dentistry. 2020;12:9-16. https://doi.org/10.2147/CCIDE.S231070
12. Jörn D, Kohorst P, Besdo S, Rücker M, Stiesch M, Borchers L. Influence of lubricant on screw preload and stresses in a finite element model for a dental implant. The Journal of prosthetic dentistry. 2014;112:340-8. https://doi.org/10.1016/j.prosdent.2013.10.016
13. Alqahtani AR, Desai SR, Patel JR, Alqhtani NR, Alqahtani AS, Heboyan A, et al. Investigating the impact of diameters and thread designs on the Biomechanics of short implants placed in D4 bone: a 3D finite element analysis. BMC oral health. 2023;23:686. https://doi.org/10.1186/s12903-023-03370-8
14. Wicaksono S, Prasetia W, Muryani A, Dirgantara T, Mahyuddin AI. Finite element stress analysis of dental cement application on endocrown and onlay restoration. Australian Endodontic Journal. 2023;49:665-74. https://doi.org/10.1111/aej.12800
15. Gönder HY, Fidancıoğlu YD, Fidan M, Mohammadi R, Karabekiroğlu S. Comparison of Resin Cement's Different Thicknesses and Poisson's Ratios on the Stress Distribution of Class II Amalgam Restoration Using Finite Element Analysis. Applied Sciences. 2023;13:4125. https://doi.org/10.3390/app13074125
16. Guler MS, Guler C, Belduz Kara N, Odabasi D, Bekci ML. The stress distribution of a primary molar tooth restored with stainless steel crown using different luting cements. BMC oral health. 2024;24:269. https://doi.org/10.1186/s12903-024-04038-7
17. Ha SR. Biomechanical three-dimensional finite element analysis of monolithic zirconia crown with different cement type. The journal of advanced prosthodontics. 2015;7:475-83. https://doi.org/10.4047/jap.2015.7.6.475
18. Tarica DY, Alvarado VM, Truong ST. Survey of United States dental schools on cementation protocols for implant crown restorations. The Journal of prosthetic dentistry. 2010;103 (2):68-79. https://doi.org/10.1016/S0022-3913(10)00016-8