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Stress distribution in peri-implant bone, implants, and prostheses: 3D-FEA of marginal bone loss and prosthetic design

Distribuição de estresse no osso peri-implantar, implantes e próteses: análise 3D-FEA de perda óssea marginal e design protético

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ABSTRACT

Objective: In response to the demand for dental implants, extensive research has been conducted on methods for transferring load to the surrounding bone. This study aimed to evaluate the stresses on the peripheral bone, implants, and prostheses under scenarios involving of the following variables: prosthesis designs, vertical bone heights, load angles, and restorative materials. **Material and Methods:** Three implants were inserted in the premolar and molar regions (5-6-7) of the two mandibular models. Model 1 represented 0 mm marginal bone loss and Model 2 simulated 3 mm bone loss. CAD/CAM-supported materials, hybrid ceramic (HC), resin-nano ceramic (RNC), lithium disilicate (LiSi), zirconia (Zr), and two prosthesis designs (splinted and non-splinted) were used for the implant-supported crowns. Forces were applied vertically (90°) to the central fossa and buccal cusps and obliquely (30°) to the buccal cusps only. The stresses were evaluated using a three-dimensional Finite Element Analysis. **Results:** Oblique loading resulted in the highest stress values. Of the four materials, RNC showed the low stress in the restoration, particularly in the marginal area. The use of different restorative materials did not affect stress distribution in the surrounding bone. The splinted prostheses generated lower stress magnitude on the bone, and while more stress on the implants were observed. **Conclusion:** In terms of the stress distribution on the peri-implant bone and implants, the use of different restorative materials is not important. Oblique loading resulted in higher stress values, and the splinted prosthesis design resulted in lower stress.

KEYWORDS

Biomechanics; Dental implant; Finite element analysis; Prosthodontics; Restorative dentistry.

RESUMO

Objetivo: Em resposta à demanda por implantes dentários, extensa pesquisa foi realizada sobre métodos para transferir carga ao osso circundante. Este estudo buscou avaliar os estresses no osso periférico, implantes e próteses em cenários que envolvem as seguintes variáveis: designs de próteses, alturas ósseas verticais, ângulos de carga e materiais restauradores. **Material e Métodos:** Três implantes foram inseridos nas regiões dos pré-molares e molares (5-6-7) de dois modelos de mandíbula. O Modelo 1 representou perda óssea marginal de 0 mm e o Modelo 2 simulou perda óssea de 3 mm. Materiais suportados por CAD/CAM, cerâmica híbrida (HC), cerâmica nano-resina (RNC), dissilicato de lítio (LiSi), zircônia (Zr) e dois designs de próteses (sintetizadas e não-sintetizadas) foram utilizados para as coroas suportadas por implantes. Forças foram aplicadas verticalmente (90°) à fossa central e cúspides bucais e obliquamente (30°) apenas às cúspides bucais. Os estresses foram avaliados usando Análise de Elementos Finitos tridimensional. **Resultados:** Cargas oblíquas resultaram nos valores mais altos de estresse. Entre os quatro materiais, RNC mostrou baixo estresse na restauração, especialmente na área marginal. O uso de diferentes materiais restauradores não afetou a distribuição de estresse no osso circundante.

Próteses sintetizadas geraram menor magnitude de estresse no osso, enquanto mais estresse nos implantes foi observado. **Conclusão:** Em termos de distribuição de estresse no osso peri-implantar e implantes, o uso de diferentes materiais restauradores não é crucial. Cargas oblíquas resultaram em valores mais altos de estresse, e o design de prótese sintetizada resultou em menor estresse.

PALAVRAS-CHAVE

Biomecânica; Implante dentário; Análise de elementos finitos; Prótese dentária; Odontologia restauradora.

INTRODUCTION

In clinical dentistry, implant-supported prostheses are the first option to consider for restoring edentulous areas because of their biocompatibility, predictable long-term results, and favorable mechanical properties [1]. The entire procedure involves substantial costs and complexity. Therefore, long-term success of an implant is crucial for the integrity of the surrounding bone. Given the structural differences between natural teeth and implants, one of the main factors in implant success is how stress is transferred to the alveolar bone [2]; the lack of periodontal ligaments around an implant causes forces to be transferred directly to the bone [3,4]. Excessive loads can cause fatigue failure of an implant, resulting in damage to the prosthesis and abutment, and resorption of the peri-implant bone [5]. Parameters such as the mechanical properties of restorative materials and implants, direction of forces, and design of the prosthesis may affect stress formation and distribution on the implant and surrounding bone tissues [6].

Three-dimensional (3D) finite element analysis (FEA) is a practical method that evaluates the stress distribution in areas of complex geometry, such as the interface between an implant and bone [7]. This method provides consistent results measuring stress, compression, and displacement in implants and structures during rehabilitation; therefore, FEA is a promising noninvasive technique [8]. This approach involves subdividing the intricate mechanical model into smaller segments, enabling researchers to anticipate and validate stress distribution at the potential bone-implant interface [9].

Computer-aided design/computer-aided manufacturing (CAD/CAM) enables clinicians to create monolithic models of various materials with varying elastomeric properties that can be applied to implant-supported prostheses. The use of CAD/CAM technology enables the production of a diverse range of materials with different rigidities, from zirconia to resin-matrix ceramics, thus affording clinicians the opportunity to select and utilize their preferred materials [7].

There have been a number of studies conducted to identify materials [7,10-13] and prosthesis designs [12-17] that can tolerate stress in implant-supported fixed prostheses. However, the results have shown conflicting results and to date no optimal solution has been identified. Despite the abundance of the electronic literature, a thorough analysis of stress occurrences in implant-supported prostheses across various scenarios is lacking. To address this gap, this study offers an unprecedented and meticulous evaluation, distinguishing itself from previous research in the field. This study evaluated the stress distribution in implants, peripheral bone, and prostheses by using the 3D FEA method to model different restorative material types, load angles, prosthesis designs, and bone heights. The primary objective is to provide clinicians with the most effective means of reducing stress placed on the peri-implant bone, prosthesis, and implants.

MATERIAL AND METHODS

Two models representing the right mandibular molar bone section with different amounts of marginal bone loss were created geometrically using a computer software (VRMesh Studio; VirtualGrid Inc. Bellevue City, WA, USA). The specifications were 2 mm cortical and 25.067, 58.300, and 35.636-mm thicknesses on the x-, y, and z-axes, respectively. The two models were converted to the Standard Tessellation Language (STL) format to make them eligible for analysis. Rhinoceros (Version 4.0SR8; McNeel North America, Seattle, WA, USA) CAD software was used to model the 3D structures. Three regular titanium implants (Bone Level CrossFit SLA Implant; 4.1 × 12 mm, Institute Straumann® AG, Basel, Switzerland), titanium abutments (RC Variobase for Crown; Straumann) 4.5 mm in diameter and 5.5 mm in height, and their inner screws were scanned with Activity 880 (Smart Optics Sensortechnik GmbH, Sinterstrasse 8, D-44795 Bochum, Germany) to analyze stress on the crown, implant, and peripheral bone. Computer-generated data from the lower and upper structural parts of the prosthesis, implant screws, and bone tissues were harmonized using Boolean operations. The results for the cortical and cancellous bone were recorded separately [18].

The bone structure of the model was fixed in all directions. A static load was applied vertically (90°) and obliquely (30°). A vertical load was applied to the central fossa and buccal cusps, whereas an oblique load was applied only to the buccal cusps. The vertical load was 500 N and the oblique load was 250 N [6]. In each direction of force (vertical and oblique), the total load was divided such that the force at each point of application was equal (*e.g.*, a total load of 500 N was divided such that five loading points [buccal cusps, central fossa, and three others] each received 100 N force). The loading points were determined according to the implant-supported prosthesis occlusal scheme [5]. One model simulated 0 mm marginal bone loss with a splinted crown design, and the second simulated 3 mm marginal bone loss with a non-splinted crown design [19]. In both models, the implants were located in the second premolar, first molar, and second molar areas. The three-dimensional components of the crowns were modeled as monolithic. The gingiva was ignored in both models, and a cement layer was generated between the abutment and crown to mimic clinical conditions [7,20]. The resin cement thickness was assumed to be 0.3 mm [20]. Four different materials were used for the prosthetic structures: hybrid ceramic (HC), resin-nano ceramic (RNC), lithium disilicate (LiSi), and zirconia (Zr). The elastic modulus values and Poisson's ratios (*i.e.*, physical property measures) for the investigated material types and structures were derived from the literature (Table I).

The mesh was created with 71.302 nodes and 307.522 finite elements for the first model and with 62.239 nodes and 297.626 finite elements for the second model after the (10%) convergence test for both models [22]. The materials were considered to be homogeneous, isotropic, and linearly elastic. Because this study did not evaluate the torque failure, the contacts were assumed to be bonded. The implants were assumed to be 100% osseointegrated. Stress distribution in the peripheral bone was evaluated using Maximum and Minimum Principal Analyses, and stress values in implants and prosthetic structures were evaluated using von Mises analysis.

Table I - Mechanical properties of materials tested in the study

Material	Elastic modulus (GPa)	Poisson ratio
Resin cement	7.5 [20]	0.25 [20]
Hybrid ceramic	30 [7]	0.23 [7]
Resin-nano ceramic	10.3 [21]	0.3 [22]
Lithium disilicate	63.9 [23]	0.22 [23]
Zirconia	220 [24]	0.33 [24]
Cortical bone	13.7 [19]	0.3 [19]
Spongy bone	1.37 [19]	0.3 [19]
Titanium	110 [10]	0.35 [10]

RESULTS

Figure 1 shows the vertical (A) and oblique (B) loading conditions for Model 1, and the vertical (C) and oblique (D) loading conditions for Model 2.

Figure 2 shows the Maximum and Minimum Principal stresses on the cancellous and cortical bones for vertical and oblique force applications using each of the four materials in the two models.

Figures 3A and 3B show the results of the von Mises analysis for stresses around the restorative crowns and implants under different loading scenarios.

Table II summarizes the findings for the maximum and minimum principal stresses on the cortical and cancellous bone and von Mises stress on the crowns and implants.

Oblique loading resulted in higher stress values than vertical loading for the implants, crowns, and cortical and cancellous bones (Table II). In the cortical bone, the minimum principal stress values were higher than the maximum principal stress values, whereas the opposite was observed in the cancellous bone (Table II and Figure 2). The maximum and minimum principal stress values under vertical loading in Model 1 were higher than those in Model 2 (Figure 2A). The maximum and minimum principal stress values under oblique loading in Model 2 were higher than those in Model 1 (Figure 2B).

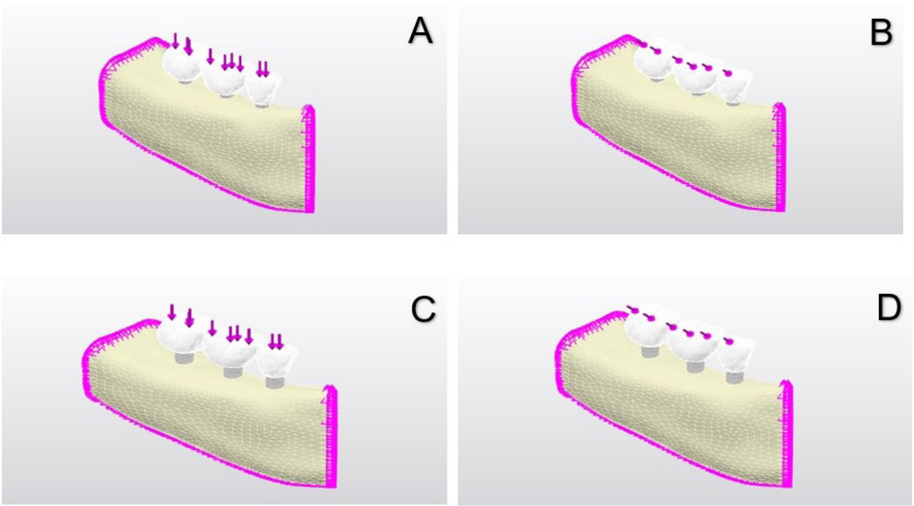

Figure 1 - Vertical (A) and oblique (B) loading conditions of Model 1, vertical (C) and oblique (D) loading conditions of Model 2.

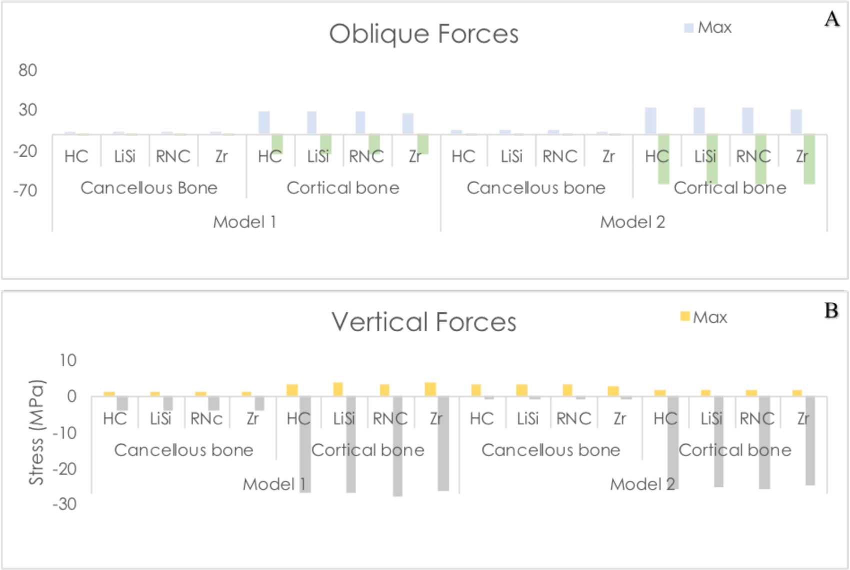

Figure 2 - Maximum and minimum stress values under oblique (A) and vertical (B) forces in the cancellous and cortical bone in Model 1 and Model 2.

Table II - Maximum and minimum principal stresses for cortical and cancellous bone, and the von Mises stress values recorded for crowns and implants in the two models

			Crown material			
			HC	LiSi	RNS	Zr
Model 1	Vertical load (MPa)	Cortical bone	27.06-3.47	26.71-3.57	27.70-3.22	26.37-3.66
		Cancellous bone	4.17-1.13	4.14-1.12	4.23-1.16	4.12-1.11
		Implants	175.88	172.27	182.30	168.76
		Crowns	37.8	52.12	20.6	65.89
	Oblique load (MPa)	Cortical bone	26.33-28.19	26.29-27.89	26.55-28.27	26.43-27.26
		Cancellous bone	2.45-2.16	2.45-2.13	2.46-2.36	2.44-2.11
		Implants	344.3	341.51	349.34	339.81
		Crowns	51.19	55.71	35.07	61.35
Model 2	Vertical load (MPa)	Cortical bone	25.54-1.59	25.39-1.54	25.79-1.69	25.01-1.5
		Cancellous bone	0.93-3.11	0.94-3.01	0.92-3.25	0.94-2.87
		Implants	91.83	89.89	94.19	85.75
		Crowns	35.49	38.69	25.46	56.70
	Oblique load (MPa)	Cortical bone	62.71-32.59	62.87-34.42	62.56-33.49	63.02-31.78
		Cancellous bone	1.91-4.18	1.9-4.01	1.93-4.46	1.87-3.79
		Implants	184.44	183.03	185.99	178.77
		Crowns	139.68	174.98	80.42	178.61

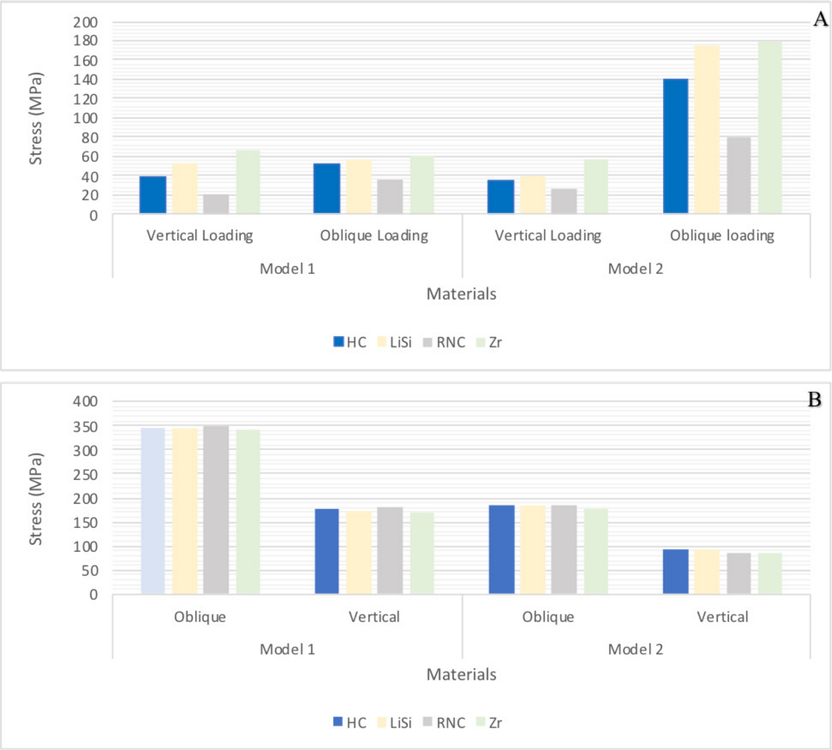

Figure 3 - Von Mises stress values observed in restorative crowns (A) and implants (B) under oblique and vertical loading.

Under oblique loading, various restorative materials generated different maximum and minimum principal stress values in cortical and cancellous bones. LiSi exhibited the highest maximum principal stress value in Model 1 (34.42 MPa), and Zr exhibited the lowest maximum principal stress value in Model 2 (1.5 MPa). The highest and lowest minimum principal stress values (-63.02 MPa and -25.01 MPa, respectively) were observed with Zr in Model 2, with the highest being under oblique loading and the lowest under vertical loading.

The maximum and minimum physiological stress limits of the cortical bone (173 MPa and 100 MPa, respectively) were not exceeded in either model under any of the scenarios tested. When each restorative material was analyzed individually, the total stress values for the cortical bone were identical (Table II). Regarding the cancellous bone, HC under oblique loading in Model 2 exhibited the highest maximum principal stress (4.46 MPa), and Zr under vertical loading in Model 1 exhibited the lowest maximum principal stress (1.11 MPa). The highest and the lowest minimum principal stress values (-4.23 MPa and -0.92 MPa, respectively) were observed with RNS under vertical loading. The RNS values in Model 1 were higher than those in Model 2.

Under vertical loading, the effects of the two different prosthesis designs on cortical and cancellous bones were similar. However, the splinted prosthesis design under oblique loading resulted in a more favorable stress distribution than the non-splinted prosthesis design. In each scenario, the stress concentration and pattern were the same. In Model 1 (Figure 4), the maximum and minimum stresses occur in the distobuccal region of the cortical bone under vertical loading.

In the cancellous bone, the maximum and minimum principal stresses were concentrated in the buccal region of the bone. Under oblique loading in Model 1, the maximum principal stresses occurred around the implants. In contrast, the minimum principal stresses were more widely spread, but more concentrated in the distobuccal region of the bone. In Model 2 (Figure 5), the maximum and minimum stresses were concentrated in the distal region of the cortical bone under vertical loading.

In the cancellous bone, the maximum and minimum principal stresses were concentrated in the palatal and buccal regions of the bone. Under oblique loading in Model 2, the maximum principal stresses were concentrated around the implants but more concentrated in the palatal region, and the minimum principal stresses were concentrated in the distobuccal region of the bone.

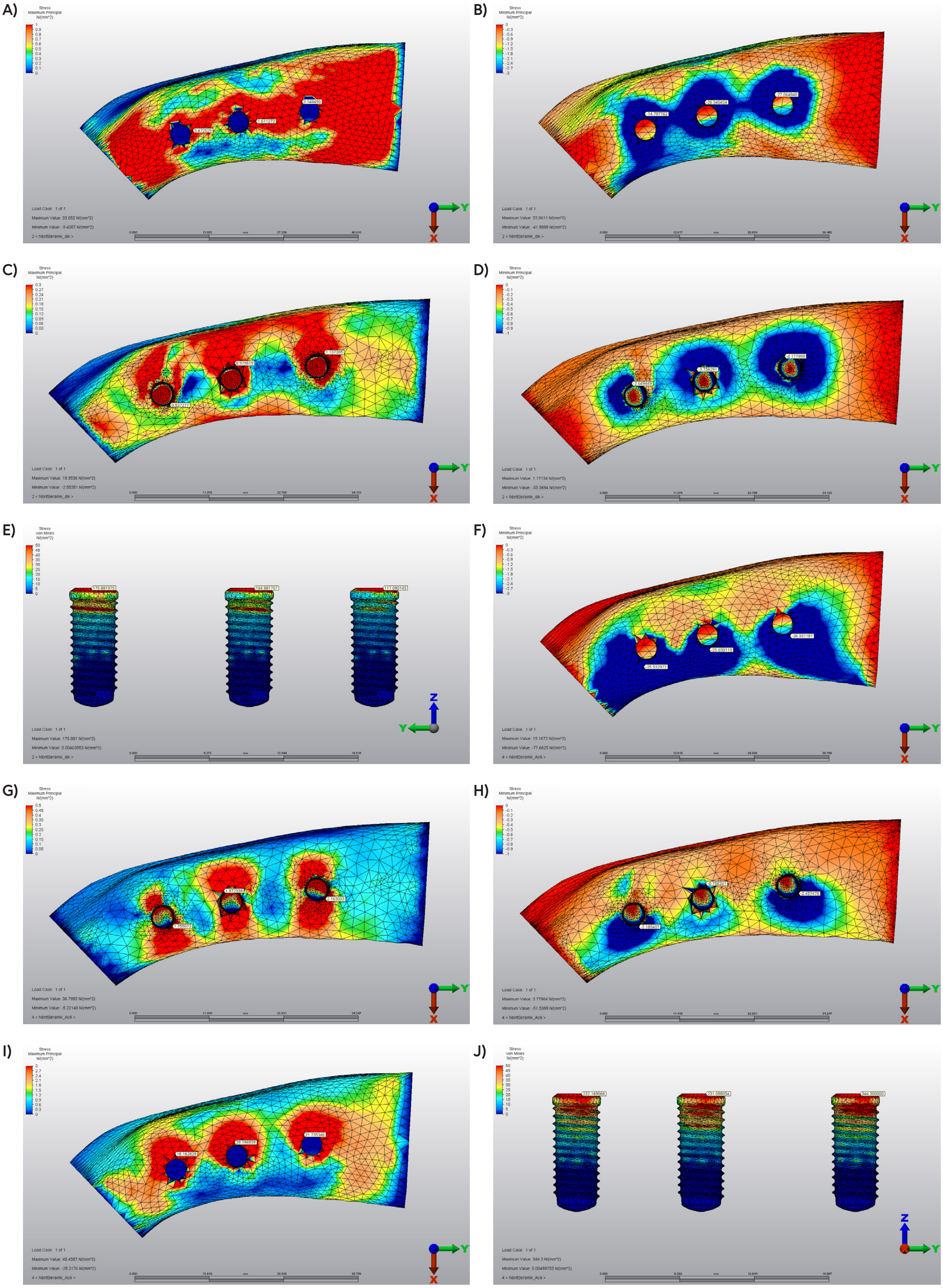

Figure 4 - All scenarios that were applied for Model 1 under vertical loading: maximum principal stress in cortical bone (A); minimum principal stress in cortical bone (B); maximum principal stress in cancellous bone (C); minimum principal stress in cancellous bone (D); von Mises analysis in implants (E). All scenarios that were applied for Model 1 under oblique loading: maximum principal stress in cortical bone (I); minimum principal stress in cortical bone (F); maximum principal stress in cancellous bone (G); minimum principal stress in cancellous bone (H); von Mises analysis in implants (J).

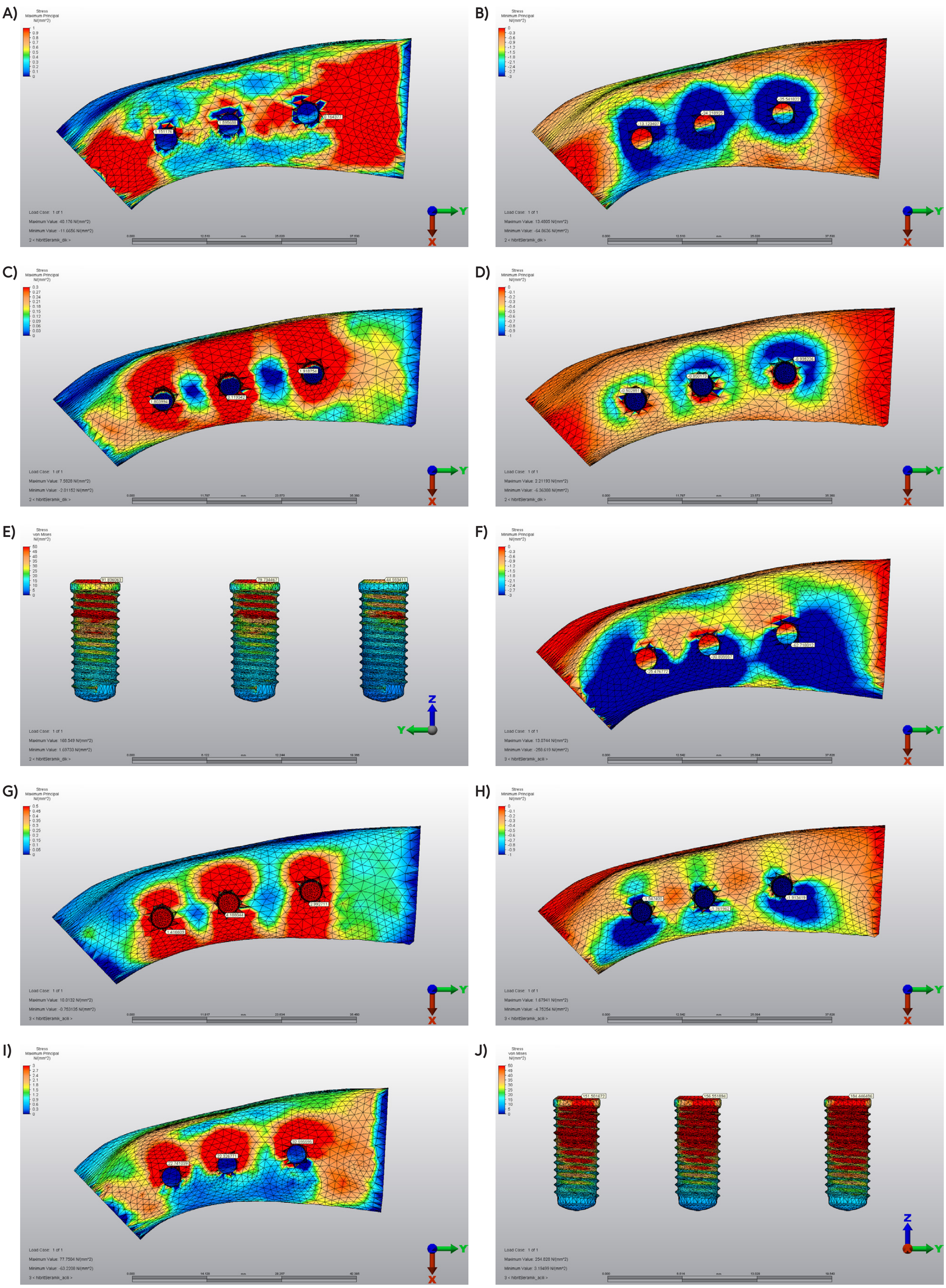

Figure 5 - All scenarios that were applied for Model 2 under vertical loading: maximum principal stress in cortical bone (A); minimum principal stress in cortical bone (B); maximum principal stress in cancellous bone (C); minimum principal stress in cancellous bone (D); von Mises analysis in implants (E). All scenarios that were applied for Model 2 under oblique loading: maximum principal stress in cortical bone (I); minimum principal stress in cortical bone (F); maximum principal stress in cancellous bone (G); and minimum principal stress in cancellous bone (H); von Mises stress analysis in implants (J).

All the restorative materials generated comparable implant stress values. The highest von Mises stress values were observed for RNS under oblique loading in Model 1 (349.34 MPa), and the lowest values were observed for Zr under vertical loading in Model 2 (85.75 MPa). Under vertical loading, stresses were concentrated in the neck region of the implant and decreased toward the apex, whereas under oblique loading, stresses were more widespread through one-third of the middle portion of the implant (Figures 4 and 5). The splinted prosthesis design generated more stress around the implants than the non-splinted design. In both models, the highest stress values were concentrated at the buccal tubercles, force application sites, central fossa, contact areas, and marginal finishing line (Figure 6).

In Model 1, the stresses that occurred at the occlusal surface were more widespread than those observed in Model 2. The highest von Mises values were recorded for Zr in Model 2 (178.61 MPa) and the lowest von Mises values were observed for RNS in Model 1 (20.6 MPa). The splinted prosthesis design generated favorable stress values for the restorative crowns.

DISCUSSION

The results of this study indicate that none of the restorative materials tested have significant effects on the peri-implant bone; however, the load angle and prosthesis design may have a significant impact on stress generation. Although this is a theoretical study that assumes ideal bonding conditions for each scenario, the findings for material mechanics are of scientific significance [20].

According to this study and previous literature, the force applied to a dental implant primarily loads the neck area and near the threads of the abutment [7,10,18,23]. This can be explained by an engineering principle: stresses at the point of application are greatest when a load is applied between two materials that have different moduli of elasticity [24]. Teeth and cortical bone have similar moduli of elasticity, whereas titanium implants have a modulus of elasticity 5 or 10 times greater. Thus, the load on the tooth does not create much stress at the crest interface, whereas the load on the implant may cause significant stress on the bone even if it is partially transmitted [5].

To analyze stress on the crown, implant, and peripheral bone, we used two models for simulating a 0 mm and a 3 mm marginal bone loss with different prosthesis designs. Studies by Manzoor et al. [19] and Kitamura et al. [25] showed that bone loss of more than 2.6 mm could lead to biomechanical failure. In our study, biomechanical failure was not observed under either of the loading conditions. In Model 2, however, less stress was generated on the implants, more stress was generated on the restorative crowns, and equal stress was generated on the peri-implant bone than in Model 1.

As the oral environment is dynamic, occlusal forces are applied in multiple directions, resulting in a leverage effect on the oral bone. As in the present study, investigations conducted using FEA should combine different angulated forces to mimic oral conditions [26]. In line with several previous studies, the present study demonstrated that oblique loading causes more significant stress on cortical and cancellous bone tissue than vertical loading [6,7,10,12,14].

Cortical bone has a higher elastic modulus than cancellous bone making it more resistant to occlusal forces and deformation. Thus, cortical bone tissue is more resistant to stress than cancellous bone tissue and forms a stronger bond with implants [27]. The current study demonstrated that stresses in peri-implant cortical bone tissue are higher than those in cancellous bone and that stresses decrease towards the apex. Previous FEA investigations have shown that forces are concentrated in the cortical bone, as observed in the current study [7,10,14,22,23,28]. It has also been stated that the cortical bone near the neck of an implant sustains the highest stress [7,20,29].

The yield strength is the point at which elastic deformation transitions to plastic deformation. Titanium implants have a maximum yield strength of 550 MPa. An implant may fail if the maximum von Mises value exceeds the yield strength [30]. None of the von Mises values recorded in the present study exceeded the maximum yield strength.

The different restorative materials did not significantly affect the loads transferred to the peri-implant bone (Table II). Khazaei et al. [10] modeled implant-supported bridges using materials with four different elastic moduli: polymethyl methacrylate, full metal, metal-based ceramics,

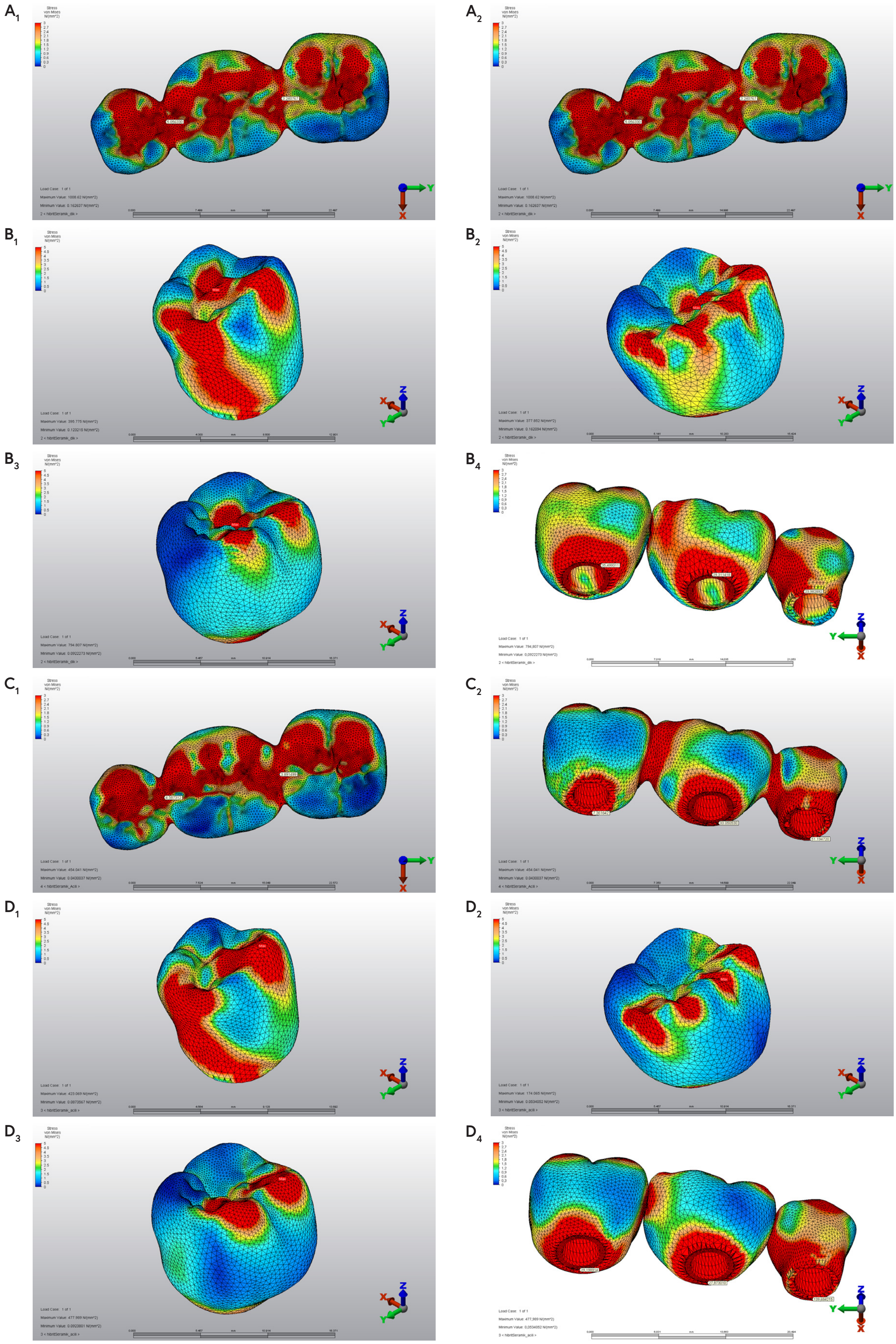

Figure 6 - Results for the study scenarios in the restorative crowns. All scenarios that were applied under vertical loading: von Mises stress analysis in Model 1 (A_1-occlusal view, A_2-gingival view); von Mises stress analysis in Model 2 (B_1-occlusal view of the second premolar, B_2-occlusal view of the first molar, B_3- occlusal view of the second molar, B_4-gingival view). All scenarios that were applied under oblique loading: von Mises stress analysis in Model 1 (C_1-occlusal view, C_2-gingival view); von Mises stress analysis in Model 2 (D_1-occlusal view of the second premolar, D_2-occlusal view of the first molar, D_3- occlusal view of the second molar, D_4-gingival view).

and all ceramics. Finite element analysis showed that the restorative materials did not affect the bone tissue. In addition, Papavasiliou et al. [12] found that different restorative materials did not significantly affect the stresses around the bone-implant interface. Kaleli et al. [7] used FEA to model implant-supported second molar crown prostheses and tested monolithic zirconia, lithium disilicate, and hybrid ceramic. The analyses revealed that the different materials evaluated did not affect the implant or the bone. Furthermore, Sevimay et al. [29] showed that different restorative materials made of porcelain and all-ceramic with two different metal substructures did not affect the stresses on the bone or implant. In another FEA study, Stegaroiu et al. [11] investigated the stresses around implant-supported fixed prostheses made from gold alloys, composite resins, and porcelains. They found that the stress formation in gold alloy and porcelain restorations was similar. In agreement with the literature, different restorative materials generated comparable stress values at the implant-bone interface in this study. Several components transmit forces to the implant-bone interface, including crowns, screws, abutments, and cement. In particular, the abutment-implant interface transfers energy to the implant-bone interface, and the structures in between absorb some of the energy [13]. This theory explains the similar biomechanical responses to different restorative materials.

A possible advantage of splinted implant-supported restorations is that the loads are distributed across implants. Theoretically, this may reduce the stresses between the implant and bone tissue, especially in areas where occlusal forces are high [14]. When a single crown is loaded in a splinted prosthesis design, the unloaded components may redistribute forces through the implant [16]. This was avoided by applying force to the functional tubercles and central fossa of each crown in the present study.

Wang et al. [13] and Lemos et al. [14] reported that splinted prostheses were more suitable for patients with poor bone quality, and also provides uniform stress distribution [15]. The results of the current study showed that the splinted prosthesis design resulted in favorable stress formation on the bone and restorations under oblique loading. In a retrospective clinical study, Naert et al. [17] observed increased implant loss with a splinted prosthesis design. This may be explained by Jemt and Book's [31] hypothesis that biological complications may occur if prostheses do not have a passive fit. In the current study, the splinted prosthesis design generated greater stress on the implants. Although various prosthesis designs lead to different stress distributions on the bone and implant, both prosthesis designs are suitable for clinical use because the stresses are within physiological limits [12]. Adhesive cementation is recommended for all-ceramic restorations to increase the fracture strength. The present study, as well as previous studies [7,13,28], considered the elastomeric properties and thickness of the resin cement.

Several limitations are inherent in this study that warrant consideration. Firstly, the stress distribution findings may not fully capture the nuanced variations associated with different bone densities, as the jaw models utilized in this investigation were of standard density. Secondly, the study adopted a uniform occlusal geometry, potentially overlooking diverse stress patterns that could arise from variations in occlusal configurations. Moreover, finite element analysis (FEA) assumes linear, homogeneous, and isotropic properties in models, yet the real clinical environment is notably heterogeneous. Despite assuming 100% osseointegration for all implants, the clinical reality of varied osseointegration levels remains unaccounted for in the models and calculations. Additionally, the study applied forces vertically and obliquely, while recognizing that incorporating horizontal forces would be more representative of the complex oral environment. Therefore, the outcomes of this investigation should be interpreted with caution, acknowledging the inherent limitations associated with in vitro experiments.

CONCLUSIONS

This study provides crucial insights the occurrence of stresses implant-supported prostheses. In every investigated scenario, the oblique loading generated more stress. The type of restorative material did not significantly affect the stress distribution in the supporting bone and implant. Resin-infiltrated restorative materials generate favorable stresses in prosthesis limitations, particularly in marginal finish areas. The splinted prosthesis design resulted in less stress on bone support. a splinted design may be preferable in the presence of parafunctional habits. Overall, the results for the splinted and non-splinted prosthesis designs were comparable.

Author's Contributions

SDI: Conceptualization, Methodology, Software, Validation, Formal Analysis, Investigation, Resources, Data Curation, Writing – Original Draft Preparation, Writing – Review & Editing, Visualization, Supervision, Project Administration. VT: Supervision, Project Administration. FBT: Conceptualization, Methodology, Software, Validation, Formal Analysis, Investigation, Visualization, Supervision, Project Administration.

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of: Clinical Research Ethics Committee of Istanbul University.

The approval code for this study is 2019/40.

REFERENCES

1. Thome G, Caldas W, Vianna CP, Cartelli CA, Trojan LC. Surgical and prosthetic outcomes of 967 implants under immediate or delayed loading in full-arch rehabilitation: a retrospective study with up to 5 years of follow-up. Braz Dent Sci. 2021;24(3):1-7. http://dx.doi.org/10.14295/bds.2021.v24i3.2403.
2. Andrade GS, Kalman L, Giudice RL, Adolfi D, Feilzer AJ, Tribst JP. Biomechanics of implant-supported restorations. Braz Dent Sci. 2023;26(1):e3637. http://dx.doi.org/10.4322/bds.2023.e3637.
3. Ahmed MAMH, Hamdy AM, Fattah GA, Elfadl AKA. Effect of prosthetic design and restorative material on the stress distribution of implant-supported 3-unit fixed partial dentures: 3D-FEA. Braz Dent Sci. 2022;25(4):e3523. http://dx.doi.org/10.4322/bds.2022.e3523.
4. Ahmed MA, Hamdy AM, Fattah GA, Effadl AK. Prosthetic design and restorative material effect on the biomechanical behavior of dental implants: strain gauge analysis. Braz Dent Sci. 2022;25(3):e3380. http://dx.doi.org/10.4322/bds.2022.e3380.
5. Sheridan RA, Decker AM, Plonka AB, Wang HL. The role of occlusion in implant therapy: a comprehensive updated review. Implant Dent. 2016;25(6):829-38. http://dx.doi.org/10.1097/ID.0000000000000488. PMid:27749518.
6. Almeida DAF, Pellizzer EP, Verri FR, Santiago JF Jr, Carvalho PS. Influence of tapered and external hexagon connections on bone stresses around tilted dental implants: three-dimensional finite element method with statistical analysis. J Periodontol. 2014;85(2):261-9. http://dx.doi.org/10.1902/jop.2013.120713. PMid:23688104.
7. Kaleli N, Sarac D, Kulunk S, Ozturk O. Effect of different restorative crown and customized abutment materials on stress distribution in single implants and peripheral bone: a three-dimensional finite element analysis study. J Prosthet Dent. 2018;119(3):437-45. http://dx.doi.org/10.1016/j.prosdent.2017.03.008. PMid:28645667.
8. Paes TJA Jr, Tribst JP, Piva AM, Figueiredo VM, Borges AL, Inagati CM. Influence of fibromucosa height and loading on the stress distribution of a total prosthesis: a finite element analysis. Braz Dent Sci. 2021;24(2):1-7. http://dx.doi.org/10.14295/bds.2021.v24i2.2144.
9. Ganesan L, Murugaian J, Shankar MSS, Annapoorni H. A comparative evaluation of stress distribution between an All-on-Four implant-supported prosthesis and the Trefoil implant-supported prosthesis: a three-dimensional finite element analysis study. J Indian Prosthodont Soc. 2022;22(1):56-64. http://dx.doi.org/10.4103/jips.jips_203_21. PMid:36510948.
10. Khazaei S, Iranmanesh P, Abedian A, Nasri N, Ghasemi E. Stress analysis of different prosthesis materials in implant-supported fixed dental prosthesis using 3D finite element method. Dent Hypotheses. 2014;5(3):109-14. http://dx.doi.org/10.4103/2155-8213.136757.
11. Stegaroiu R, Kusakari H, Nishiyama S, Miyakawa O. Influence of prosthesis material on stress distribution in bone and implant: a 3-dimensional finite element analysis. Int J Oral Maxillofac Implants. 1998;13(6):781-90. PMid:9857588.
12. Papavasiliou G, Kamposiora P, Bayne SC, Felton DA. Three-dimensional finite element analysis of stress-distribution around single tooth implants as a function of bony support, prosthesis type, and loading during function. J Prosthet Dent. 1996;76(6):633-40. http://dx.doi.org/10.1016/S0022-3913(96)90442-4. PMid:8957790.
13. Wang TM, Leu LJ, Wang J, Lin LD. Effects of prosthesis materials and prosthesis splinting on peri-implant bone stress around implants in poor-quality bone: a numeric analysis. Int J Oral Maxillofac Implants. 2002;17(2):231-7. PMid:11958406.
14. Lemos CAA, Verri FR, Santiago JF Jr, Batista VES, Kemmoku DT, Noritomi PY, et al. Splinted and nonsplinted crowns with different implant lengths in the posterior maxilla by three-dimensional finite element analysis. J Healthc Eng. 2018;2018:3163096. http://dx.doi.org/10.1155/2018/3163096. PMid:30254726.
15. Clelland NL, Seidt JD, Daroz LG, McGlumphy EA. Comparison of strains for splinted and nonsplinted implant prostheses using three-dimensional image correlation. Int J Oral Maxillofac Implants. 2010;25(5):953-9. PMid:20862409.
16. Guichet DL, Yoshinobu D, Caputo AA. Effect of splinting and interproximal contact tightness on load transfer by implant restorations. J Prosthet Dent. 2002;87(5):528-35. http://dx.doi.org/10.1067/mpr.2002.124589. PMid:12070516.
17. Naert I, Koutsikakis G, Duyck J, Quirynen M, Jacobs R, van Steenberghe D. Biologic outcome of implant-supported restorations in the treatment of partial edentulism. Part I: a longitudinal clinical evaluation. Clin Oral Implants

Res. 2002;13(4):381-9. http://dx.doi.org/10.1034/j.1600-0501.2002.130406.x. PMid:12175375.

18. Singh P, Wang C, Ajmera DH, Xiao SS, Song J, Lin Z. Biomechanical effects of novel osteotomy approaches on mandibular expansion: a three-dimensional finite element analysis. J Oral Maxillofac Surg. 2016;74(8):1658.e1. http://dx.doi.org/10.1016/j.joms.2016.04.006. PMid:27182974.
19. Manzoor B, Suleiman M, Palmer RM. The effects of simulated bone loss on the implant-abutment assembly and likelihood of fracture: an in vitro study. Int J Oral Maxillofac Implants. 2013;28(3):729-38. http://dx.doi.org/10.11607/jomi.2819. PMid:23748303.
20. Tribst JPM, Dal Piva AMO, Ozcan M, Borges ALS, Bottino MA. Influence of ceramic materials on biomechanical behavior of implant supported fixed prosthesis with hybrid abutment. Eur J Prosthodont Restor Dent. 2019;27(2):76-82. http://dx.doi.org/10.1922/EJPRD_01829Tribst07. PMid:31046208.
21. Alamoush RA, Silikas N, Salim NA, Al-Nasrawi S, Satterthwaite JD. Effect of the composition of cad/cam composite blocks on mechanical properties. BioMed Res Int. 2018;2018:4893143. http://dx.doi.org/10.1155/2018/4893143. PMid:30426009.
22. 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(3):507-12.
23. Zhong J, Guazzato M, Chen J, Zhang Z, Sun G, Huo X, et al. Effect of different implant configurations on biomechanical behavior of full-arch implant-supported mandibular monolithic zirconia fixed prostheses. J Mech Behav Biomed Mater. 2020;102:103490. http://dx.doi.org/10.1016/j.jmbbm.2019.103490. PMid:31877512.
24. Borie E, Orsi IA, de Araujo CP. The influence of the connection, length and diameter of an implant on bone biomechanics. Acta Odontol Scand. 2015;73(5):321-9. http://dx.doi.org/10.3109/00016357.2014.961957. PMid:25598357.
25. Kitamura E, Stegaroiu R, Nomura S, Miyakawa O. Biomechanical aspects of marginal bone resorption around osseointegrated implants: considerations based on a three-dimensional finite element analysis. Clin Oral Implants Res. 2004;15(4):401-12. http://dx.doi.org/10.1111/j.1600-0501.2004.01022.x. PMid:15248874.
26. Smedberg JI, Nilner K, Rangert B, Svensson SA, Glantz SA. On the influence of superstructure connection on implant preload: a methodological and clinical study. Clin Oral Implants Res. 1996;7(1):55-63. http://dx.doi.org/10.1034/j.1600-0501.1996.070107.x. PMid:9002823.
27. Eskitascioglu G, Usumez A, Sevimay M, Soykan E, Unsal E. The influence of occlusal loading location on stresses transferred to implant-supported prostheses and supporting bone: a three-dimensional finite element study. J Prosthet Dent. 2004;91(2):144-50. http://dx.doi.org/10.1016/j.prosdent.2003.10.018. PMid:14970760.
28. Ding X, Liao SH, Zhu XH, Zhang XH, Zhang L. Effect of diameter and length on stress distribution of the alveolar crest around immediate loading implants. Clin Implant Dent Relat Res. 2009;11(4):279-87. http://dx.doi.org/10.1111/j.1708-8208.2008.00124.x. PMid:18783411.
29. Sevimay M, Usumez A, Eskitascioglu G. The influence of various occlusal materials on stresses transferred to implant-supported prostheses and supporting bone: a three-dimensional finite-element study. J Biomed Mater Res B Appl Biomater. 2005;73(1):140-7. http://dx.doi.org/10.1002/jbm.b.30191. PMid:15742379.
30. Akça K, Iplikcioglu H. Finite element stress analysis of the effect of short implant usage in place of cantilever extensions in mandibular posterior edentulism. J Oral Rehabil. 2002;29(4):350-6. http://dx.doi.org/10.1046/j.1365-2842.2002.00872.x. PMid:11966968.
31. Jemt T, Book K. Prosthesis misfit and marginal bone loss in edentulous implant patients. Int J Oral Maxillofac Implants. 1996;11(5):620-5. PMid:8908860.

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