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Evaluation of Innovative Crown Design on Dental Implant in Dynamic Loading (In Vitro Study)

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Abstract

Objective: *The purpose of this study is to examine how different crown materials affect the manner of stress transformation and distribution around short dental implants. To achieve this objective, integrated and combined crowns were built, modelled, and tested under static axial loads using various material combinations. The biomechanical response was then examined.* ***Methods****: A validated three-dimensional finite element (FE) models of crown supported by implant was developed to evaluate the effect of the different type of materials (E max, zirconia, composite) on short implants in stress distribution. After the FE models had been validated, simulations utilizing various configurations of various crowns fixed to two distinct types of implants were run and subjected to static loading to ascertain the distribution of stresses inside the bone around the implants.* ***Result:*** *The comparative results showed that manufacturing the crown using more elastic material (i.e., materials with lower elastic modulus) reduced the stress distribution in crown, implant and cancellous bone. It may refer to this phenomenon that softer material can absorb more energy from the applied compressive load, and result in transferring less energy to the implant and jaw bone. However, this effect was not significant on cortical bone compared to the cancellous bone. Combination of different materials for making a new designed crown can alter the biomechanical response and could be beneficial for decreasing the stress distribution in implant and spongy region of jaw bone when stiffer material is needed to be covered in upper surface of the crown. In addition, the results suggests that shorter implant can increase the stress distribution in both cortical and cancellous bone.* ***Conclusion:*** *using stiff crown material the stress will increase on the parts of implant and the surrounding bone which may led to failure of implant or bone resorption around of the implant, in other way by using less stiffer material the possibility of success will be increased and also the success rate of the implant is increased, also before deciding which implant size and length are used you select which type of the prosthetic will be used.*

Keywords: *Dental Biomechanics, Dental Implant, Innovative Crown, Zirconia, E-Max, Composite, Implant Length, Finite Element Modeling*

INTRODUCTION

In order to regain complete, pleasant masticatory function and face esthetic, humans have tried using a variety of methods to restore lost teeth throughout history. Before to the osseointegration period, there were several designs of dental implants and frameworks that were used to support dentures and partial dentures with varying degrees of effectiveness. Among the various materials used in implants are porcelain, cobalt chromium, and radioplatinum, but the discovery of titanium changed the course of implant history. There are several techniques for comprehending the force distribution, including analytical mathematical models that include strain gauges, the photo elastic model, and studies like the finite element analysis (vandana and kartik, 2004).

FEA has been extensively used in implant dentistry to foresee the biomechanical behavior of various dental implant designs as well as the influence of clinical factors on clinical success. There has been a great deal of study done on the stress patterns in implant components and the surrounding bone. The accuracy of the used simulating structures influences the outcome of every FE investigation. These are the material properties of the implant and bone, the surface features and shapes of the implant and its parts, the force applied, and the biomechanical behavior of the implant-bone relationship. (Trivedi S, 2014)

In FEA, a specific physical system's behavior is mathematically modelled. The FEA separated the structure of the model into several distinct parts, each of which retains the structure's original features. Each component requires a unique equation that must be solved using mathematical models chosen in accordance with the facts being examined. (Boccaccio et al, 2011, Dejak and Mlotkowski, 2011).

By altering the parameters of those geometries, FEA makes it possible to apply a force or a system of forces to any point and/or in any direction, providing knowledge of the movement, amount of tension, and compression force on each area. It also converts natural or artificial tissue into complex structures that accurately represent the original one. (Vasudeva G, 2009)

In addition to providing a forecast of a desirable outcome with the lowest chance of failure, FEA assists in the study of stress direction and distribution between natural teeth and the kind of material used to reconstruct the original tooth or dental structure if they are lost. Zarone et al, 2005 researchers looked at how stress surrounding teeth from everyday load on the maxillary central incisor was affected by finishing line preparation with an alumina porcelain veneer in 2005. They advised utilizing a chamfer with palatal overlap design when repairing with porcelain veneers because it achieves the advised stress distribution more effectively than the window approach. (Srirekha and Bashetty, 2010)

MATERIAL METHODS

1. Model preparation

For the model preparation, a ready-made full dentated dental arch is used in full occlusion, the teeth are attached to the base by the screw, first lower molar is replaced by the implant.

After the tooth is removed the socket is prepared for the implant by using a dental surveyor (dental farm S.r.I. Via Susa, 9/A-10138 torino-italy) to perpendicular alignment. Table of dental surveyor is balanced until become parallel with floor by the bubble level, then the dental arch is locked on the table by model clamp lock nut of the device laterally like each corner of the triangular. Implant fixed to the tool adapter holder and perpendicular to the table. The head of the surveyor pushed implant to the socket and placed in the center without touching any border and the level of the implant neck below the level of the gum about 2-3 mm then fixed the tool holder in the place, Cold cure acrylic (vertex type, Vertex Dental ByV, 872.3760 EBI, ISO020795) is choice for fixation the implant which is mixed according to the manufacture instruction and used before reach to dough stage, in flow stage. Cold cure acrylic is putted to the socket and waited until the material become set then the tool holder is opened and the cast removed for the table and watched for any problem present. Then the surface of the acrylic around the implant is grinded with low-speed engine to provide smooth surface of the acrylic and free of projection and irregularities. After that the length of the implant adjusted and shortened until provide good space for occlusal surface of the crown.

2. Scanning the model

After the model is prepared TRIOS, scanner is used (3Shape TRIOS® 3, Copenhagen, Denmark) to scan the model, scanning is done for all the lower arch and opposite arch in respect to occlusion and making STL file, then the design of the samples is made which consist of full crown and two-part crown of Emax, zircon and composite. Figure 1

Figure 1: TRIOS3 intraoral scanner

3. Design of samples

Crown are made in two forms first form is made in full anatomical crown without any changing and second form made in to two parts which is first part 1/3 occlusal part and second part 2/3 gingivally which are connect to each other by resin in between the two parts there is 4 projection in the first part and 4 holes in the second part which orient the two parts to each other and prevent movement of two parts, the projection are orient in square shape each corner has one projection, Length of the projection is about 2mm.

4. Development of the geometrical models

The STL input data which was received based on scanned parts (Figure 2) were evaluated. To develop fine geometrical models which can be used in finite element (FE) analyses, the STL files were imported to Solid works (Dassault Système©, Vélizy-Villacoublay, France) and the surfaces were trimmed and smoothed to achieve acceptable geometries for exporting to FE package. To simplify the simulation, a sliced part of the jaw bone was mimicked in simulations.

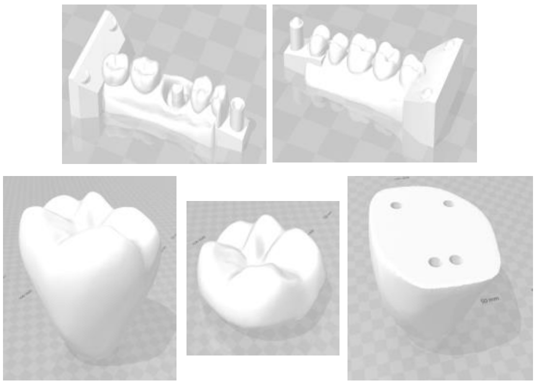
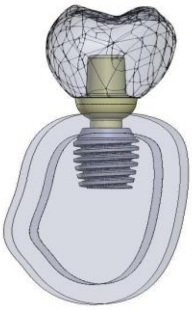


Figure 2: Samples of the scanned parts in STL format

Based on objective of this study, four general geometrical models were developed based on combination of (1) integrated and (2) combined crown implanted using short implants. The diameters for short and implants were 4.5mm and their lengths were 6mm, respectively. Figure 3 show the details of the aforementioned models.

5. Development of the FE models

The geometrical models were loaded into the widely used ABAQUS package, created by SIMULIA in Providence, RI, USA, to examine the impact of crown and implant qualities on the biomechanical response. A thorough research of material qualities and implant sizes was made possible because to this potent software's facilitation of scenario simulation and analysis. A total of 18 finite element (FE) models were created based on specific scenarios in order to cover a variety of eventualities (Figure 3). These models were painstakingly made, taking into account various arrangements of implant sizes and crown materials. The study's objective was to learn more about how the dimensions of the implant and the material's qualities affect the overall biomechanical response. The FE models allowed for the simulation of accurate loading conditions using the ABAQUS program, simulating the dynamic forces encountered during functional operations. The performance and behavior of the crown-implant system could be better understood thanks to this method, which enabled a thorough analysis of stress and strain patterns. The study aimed to understand the complex link between material qualities, implant sizes, and the consequent biomechanical response by running these models across several scenarios.



Model 1: E-Max

Model 2: Composite Resin

Model 3: Zirconia

Model 4: E-Max / Composite Resin

Model 5: E-Max / Zirconia

Model 6: Composite Resin / E-Max

Model 7: Composite Resin / Zirconia

Model 8: Zirconia / E-max

Model 9: Zirconia / Composite Resin

Figure 3: The arrangement of different FE models

The isotropic elastic theory was used in this study to calculate the mechanical properties of the models. Specific values were retrieved from the literature that already existed and used for the analysis in order to achieve these features. To assure the correctness and dependability of the simulations, the available data, including material parameters like Young's modulus, Poisson's ratio, density, and yield strength, were thoroughly evaluated and referred to (Table 1). presents the compiled information from the literature, providing a comprehensive overview of the selected elastic response for the various components of the models.

Table 1: Mechanical properties of different components in FE models

Components	Elastic modulus (GPa)	Poisson's ratio	Density (g/cm3)	Yield strength (MPa)
Implant (Ti–6Al–4V)	110 [1]	0.3 [1]	4.5 [2]	800 [3]
Abutment (Ti–6Al–4V)	110 [1]	0.3 [1]	4.5 [2]	800 [3]
Cancellous Bone	1.37 [4, 5]	0.3 [4, 5]	3 [2]	10 [2]
Cortical Bone	12.6 [4, 5]	0.3 [4, 5]	3 [2]	190 [2]
E-Max	95 [5, 6]	0.2 [5, 6]	2.6 [7]	130 [8]
Zirconia	210 [9]	0.33 [9]	6.05 [10]	900 [11]
Composite resin	21 [12]	0.24 [12]	2.28 [13]	87.75 [14]

The constitutive model used in this work has been integrated into the finite element (FE) models together with the experimental data given in the literature Ilie N, (2021). By using a user-defined material subroutine (UMAT) created expressly for this task, this integration was made possible. The study's findings under cyclic loading were made more reliable and accurate by using the UMAT to enable the FE models to precisely reproduce the behavior of the materials based on the established constitutive model. Explicit dynamic simulations were used in this study's research to look at the set of governing equations. The law of explicit integration and the element diagonal mass matrix were both used to analyze the answer. Surface-to-surface with tie contact feature, a discretization technique, was used to create flawless connections between various components, ensuring adequate connectivity and enforcing equal degrees of freedom.

The loading condition was created under the presumption that a person chews for three periods of 15 minutes each, three times per day, at a rate of 60 cycles per minute (1 Hz). This translates to about 2700 chewing cycles daily.

The aforementioned loading condition was applied vertically on the crown's upper surface utilizing the reference point placement approach for comparison investigation, as shown in Figure 4. This method guarantees the reference point's consistent and exact location, enabling proper analysis and result interpretation. The goal of the study was to obtain understanding of the behavior and functionality of the investigated system by using detailed dynamic analysis and taking into account the particular loading circumstances. Explicit integration, the surface-to-surface with tie contact property, and the element diagonal mass matrix allowed for a thorough analysis of the system's reaction to dynamic cyclic stress.

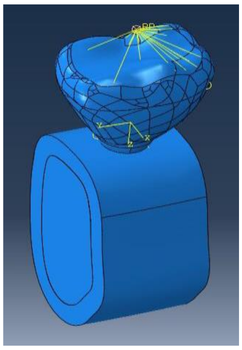


Figure 4: The applied axial cyclic force to FE model using reference point technique

Ten-node quadratic tetrahedron components were used to create the mesh models shown in Figures 5. Sensitivity tests were carried out to assess the independence of the findings from the meshing process in order to guarantee the robustness and reliability of the findings. The final mesh's element count, as determined via sensitivity assessments for each element

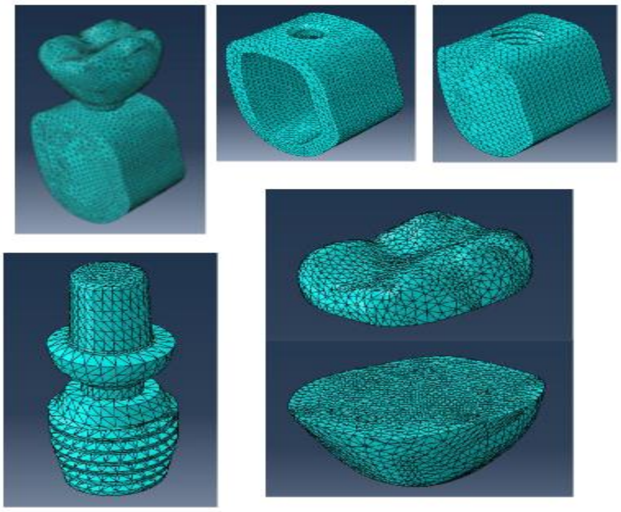


Figure 5: Meshing the FE models based on sensitivity analyses

As previously mentioned, the simulations involved the comparison of outcomes for a total of 18 alternative models. These models were built using different combinations of elements, such as the usage of integrated or combined crowns and short or lengthy implants. To assess their performance under such stress circumstances, all models underwent a vertical cyclic loading regime. At crucial nodes positioned inside various model components, the values of Von-Mises stress were computed in order to conduct a comparison research. Cortical and cancellous bones, implants, and crowns were all included in this. The study aims to investigate the stress distribution and analyze the performance of each component under the given loading circumstances by measuring the Von-Mises stress in these specified areas. A thorough investigation of the effects of the various parameters on the stress distribution within the system was possible thanks to the comparison of stress levels between the various models.

This method made it possible to thoroughly examine the stress levels that important nodes inside each model's component encountered. The study attempted to derive relevant conclusions on the relative performance and behavior of the various model configurations by examining and contrasting the computed Von-Mises stress values. This comparative research shed light on how the use of short implants and integrated or combined crown designs affect the stress distribution within the system, enabling a thorough knowledge of the investigated parameters and their ramifications. Physical testing or fatigue analysis can be used to determine if an ideal dental implant design has a maximum or infinite fatigue life. In this specific study, we also investigated the fatigue life of the implant and crown by doing stress analysis with FE-SAFE (SIMULIA). We performed fatigue study on the models indicated previously, taking into account different material combinations, using the Goodman mean-stress theory. To facilitate a comprehensive comparison of the outcomes obtained from different materials, we analyzed the fatigue factor of safety using the following equation (Pekedis and Yildiz, 2011).

$$Factor\ of\ safety = \frac{1}{\frac{\sigma_a}{S_e} + \frac{\sigma_m}{S_{ut}}}$$

Where σ_a and σ_m stand for the maximum endurance and ultimate strength, respectively, while a and m stand for the alternating and mean stresses. The simulations carried out to compare and assess the outcomes of the computed factor of safety over 5 million cycles involved a total of 18 distinct models.

RESULT

The major goal of the research has been accomplished as a result of the results of the sensitivity analyses that were carried out in this study, which effectively validated the correctness of the FE models. The computed values of Von-Mises stress were taken from multiple FE models in order to assess the impact of cyclic loading on the models. As shown in Figure 4, the cyclic loading was carried out at a frequency of 1Hz for 2700 cycles with a maximum amplitude of 200N applied across the crown's top surface.

The highest equivalent stress measured in important areas of several model components, such as cortical bone, cancellous bone, implants, abutments, and crowns, was included in the retrieved data. A thorough investigation of the stress distribution and changes among the various components was accomplished by contrasting these computed findings. Figure 6 is an example of a contour plot that illustrates the findings of the investigation. The acquired results support the dependability and sturdiness of the FE models used in the research since they faithfully represented the impacts of cyclic stress on the system.

By comparing the computed stress values, it was possible to evaluate the stress distribution in crucial areas in detail and get insight into how different components behaved under the loading circumstances that were used. Making educated decisions is made easier with the use of this knowledge, which also helps us gain a thorough grasp of the behavior and integrity of the examined models.

Figure 6: A sample of achieved results from FE models at the end of cyclic loading condition

In the other hand when we use zircon crown the stress formed inside the implant will be more than other type of crown and followed by the E max and the last one is composite crown but in all three types of material there is no statistically significant between materials as shown in table (2). And also, in combined crown the occlusal surface formed from the zirconia material with two other crown material will form more stress in the implant than other two hybrid crown which the occlusal surface formed from E max or composite crown as shown in figure 7. The most statistically significant one is composite/ E max VS zirconia/E max and the last one which is non statically significant is E-Max/Composite vs. E-max/Zirconia and other are between them as shown in table (2):

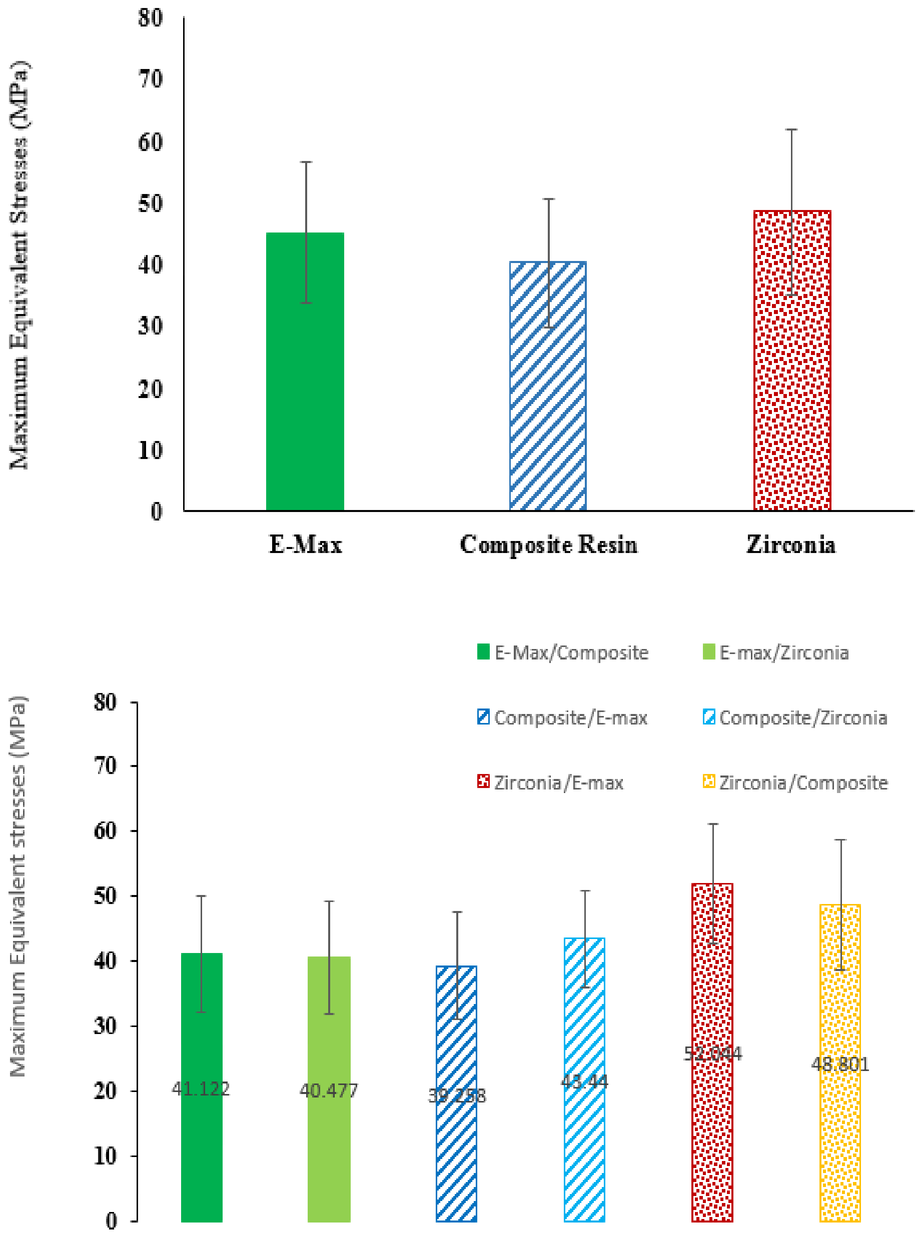


Figure 7: Comparative results for values of maximum Von-Mises stress in implants for the models with combined and integrated crown

Table 2: statistical analysis of implant

Pair (Short Implant) implant	P- value	Statistical analysis
E-Max vs. Composite Resin	0.6438	
E-Max vs. Zirconia	0.7825	
Composite Resin vs. Zirconia	0.2747	
E-Max/Composite vs. E-max/Zirconia	1	
E-Max/Composite vs. Composite/E-max	0.9969	
E-Max/Composite vs. Composite/Zirconia	0.9914	
E-Max/Composite vs. Zirconia/E-max	0.0478	*
E-Max/Composite vs. Zirconia/Composite	0.3852	
E-max/Zirconia vs. Composite/E-max	0.9996	
E-max/Zirconia vs. Composite/Zirconia	0.9742	
E-max/Zirconia vs. Zirconia/E-max	0.0436	*
E-max/Zirconia vs. Zirconia/Composite	0.2969	
Composite/E-max vs. Composite/Zirconia	0.8945	
Composite/E-max vs. Zirconia/E-max	0.02354	*
Composite/E-max vs. Zirconia/Composite	0.1674	
Composite/Zirconia vs. Zirconia/E-max	0.2626	
Composite/Zirconia vs. Zirconia/Composite	0.7502	
Zirconia/E-max vs. Zirconia/Composite	0.962	

Pair (Short Implant) implant	Mean	SD
Zirconia	48.708	13.4213
E-Max	45.173	11.3594
Composite Resin	40.417	10.3908
E-Max/Composite	41.122	9.027881258
E-max/Zirconia	40.477	8.636570886
Composite/E-max	39.258	8.273498252
Composite/Zirconia	43.44	7.414485822
Zirconia/E-max	52.044	9.235345388
Zirconia/Composite	48.801	10.06635259

Also the result show when using short implant and different material of the crown and applying dynamic force on the crown the stress formation inside the cancellous bone are more in zirconia material than other material and followed by Emax and in the last is composite material, when compared composite to the zirconia there is highly statistically significant between them and followed by the statistically significant between E max and zirconia material and no statistically significant between E max vs composite resin as shown in table (3).

Also, when using the two-part crown over implant show that when using zirconia for 1/3 occlusal part the stress formation in the cancellous bone will be more than other hybrid crowns and followed by crowns which occlusal surface formed by the Emax material and the last one which form less stress inside the cancellous bone is the crown formed the occlusal part form the composite and other 2/3 gingivally form the zirconia and E max crown as shown in fig 8. The only statically significant present when compared composite/E max VS zirconia/E-max and the other comparison are non-statistically significant as shown in table (3):

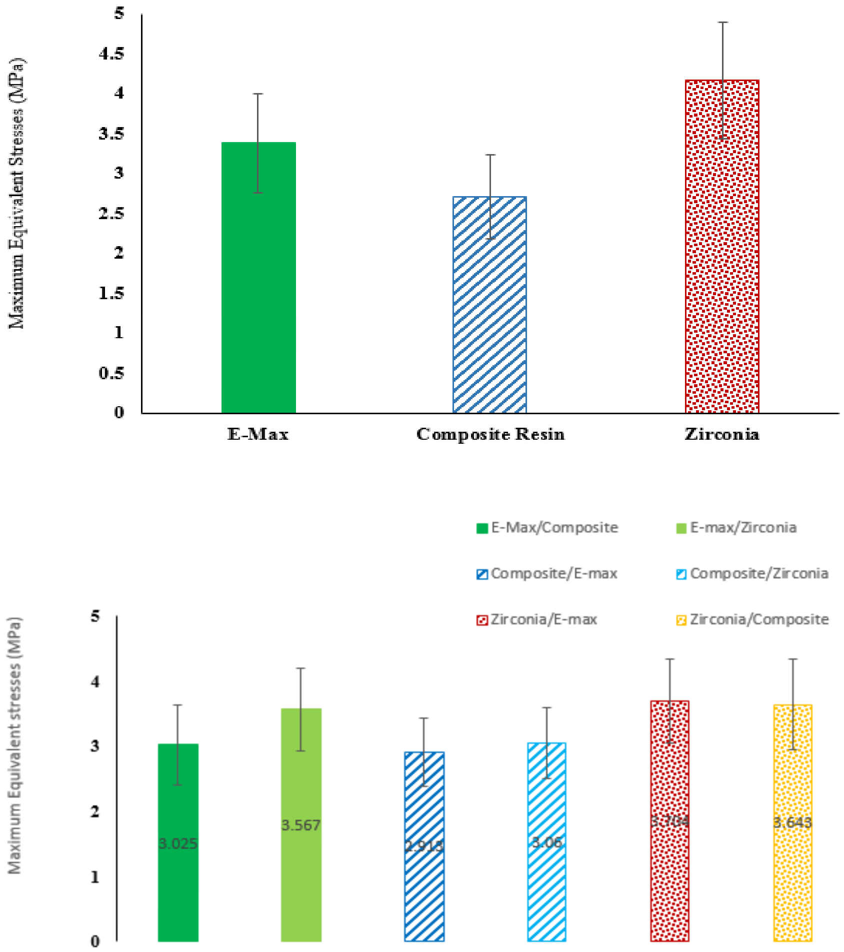


Figure 8: Comparative results for values of maximum Von-Mises stress in cancellous bone for the models with integrated and combined crown using short implant.

Table 3: statistical analysis of cancellous bone

Pair (Short Implant) cancellous bone	P- value	Statistical analysis
E-Max vs. Composite Resin	0.05884	
E-Max vs. Zirconia	0.02493	*
Composite Resin vs. Zirconia	0.0000522	*
E-Max/Composite vs. E-max/Zirconia	0.3729	
E-Max/Composite vs. Composite/E-max	0.9985	
E-Max/Composite vs. Composite/Zirconia	1	
E-Max/Composite vs. Zirconia/E-max	0.1523	
E-Max/Composite vs. Zirconia/Composite	0.2345	
E-max/Zirconia vs. Composite/E-max	0.1829	
E-max/Zirconia vs. Composite/Zirconia	0.4482	
E-max/Zirconia vs. Zirconia/E-max	0.9961	
E-max/Zirconia vs. Zirconia/Composite	0.9998	
Composite/E-max vs. Composite/Zirconia	0.9945	
Composite/E-max vs. Zirconia/E-max	0.0497	*
Composite/E-max vs. Zirconia/Composite	0.1022	
Composite/Zirconia vs. Zirconia/E-max	0.1963	
Composite/Zirconia vs Zirconia/Composite	0.2935	
Zirconia/E-max vs. Zirconia/Composite	0.9999	

Pair (Short Implant) cancellous bone	Mean	SD
Zirconia	4.166	0.732002
E-Max	3.377	0.621308
Composite Resin	2.698	0.525099
E-Max/Composite	3.025	0.613192
E-max/Zirconia	3.567	0.643256
Composite/E-max	2.913	0.531748
Composite/Zirconia	3.06	0.541643
Zirconia/E-max	3.704	0.647339
Zirconia/Composite	3.643	0.697870

DISCUSSION

Recent developments in CAD/CAM technology have given physicians the ability to utilize a variety of material combinations. There is a large body of research demonstrating the impact of various prosthetic materials on the stress distribution in implant-supported full arch prostheses; however, there are almost no studies examining the impact of the opposing arch material. In this investigation, finite element analysis (FEA) has been used to mechanically assess the reaction of several prosthetic designs with various material combinations for fabricating an implant-supported dental prosthesis (tooth/implant).

Result of the present study revealed that, changing in the restorative material have different stress formation under dynamic force which may led to decrease force on the short implant and increase durability of the implant and more success, stress formation in depend on the elastic modulus which is different from one material to another and one of the most important factors for determine the behavior of the material, in the present study stress formed inside the crown is more in zircon crown than other, followed by the Emax and the end is resin composite which form less stress formation. These is referred to the modulus of elasticity of the material which is more in the zircon and less in the composite material and these make composite material more shock absorption and decrease the dynamic force coming from occlusion (Duan and Griggs, 2015). This is in same direction with the result of the Duan and Griggs, 2015 evaluated the stress distribution in CAD-CAM crowns made of resin nanoceramic and lithium disilicate ceramic, reporting that the latter displayed reduced stress levels under dynamic loading.

Also the study showed that the superstructure restorative material over the implant when formed from the composite material it will lead to transfer less stress to the underline implant may result in the less implant movement which decrease the chance for the implant failure and in opposite the zircon material form more stress on the implant and Emax material between them, this may be due to modulus of elasticity of different material as the more rigid material which is zircon transmit more force to the underline implant and make stress formation on the implant and Emax material make less stress formation than zircon material and more than composite material and composite material which is not stiff material transfer less force to the underline implant and make less stress formation inside the implant. In agreement with to Reyes et al (2021), who demonstrated that high stiffness of the material superstructure had a greater impact on micromovement, this was in contrast with Holst et al 2008 and Benzing et al 1995. Who claimed that the elastic modulus of the material used for superstructure has an important role in stresses distribution.

In general, the stress formation is less on the spongy bone in all three different prosthetic material, this related to the formation and the characteristic of the spongy bone which is trabecular bone and has elastic modulus with 1/10 when compared with elastic modulus of the cortical bone. In the present study when use different type of the material appear that the there are no statistical different between all types of material this is in one line with the study of the Geng et al, 2001 which compared the acrylic resin, porcelain fused to metal and veneered gold and show that there is no difference between them. Also, Bassit et al, 2002 concluded that there is no difference in stress formation when use different occlusal material for the crown over the implant. Cibrika et al, 2002 found that there is no statistical difference between gold, resin ceramic when used as a superstructure of the implant.

From the result appear that the resin composite form less stress on the cortical bone when used as restorative crown over implant, also in the hybrid type of the crown when the composite used as the super structure with E max material has less stress formation in the same place this may related to the structure of the composite such as resin matrix and filler particle which can be formed in such manner that with stand force of the mastication also the ratio of between matrix and fillers and the filler nanoparticle size and shape (Mokhtar et al, 2022). This finding of this research is not in the same line with the result of the Gomes et al, 2011 which they came to the conclusion that the stress distribution in the supporting bone was unaffected by the using of various materials to create a superstructure for a single implant-supported prosthesis, moreover Sevimay et al (2005). looked at how different occlusal surface materials affected stress production when subjected to functional stresses. They came to the conclusion that choosing a more stiff or robust material for the superstructure of an implant-supported prosthesis had no impact on the stress levels and distribution at the bone tissue around the implant while utilizing dynamic loading at two places.

CONCLUSION

In conclusion, the comparative results demonstrated that the stress distribution in the crown, implant, and cancellous bone was lessened when the crown was manufactured using softer material (i.e., materials with lower elastic modulus). It could be a reference to the fact that softer materials can absorb more force from a compressive load, delivering less force to the implant and jaw bone in the process. When a stronger material is required to cover the upper surface of the crown, combining various materials during design and manufacturing can change the biomechanical response, which may be advantageous for reducing the stress distribution in the implant and spongy region of the jaw bone. Additionally, the findings imply that shorter implants may improve the distribution of stress in both cortical and cancellous bone.

References

1) Ueda N, Takayama Y, Yokoyama A. Minimization of dental implant diameter and length according to bone quality determined by finite element analysis and optimized calculation. Journal of prosthodontic research. 2017;61(3):324-32.

2) Kitagawa T, Tanimoto Y, Nemoto K, Aida M. Influence of cortical bone quality on stress distribution in bone around dental implant. Dental materials journal. 2005;24(2):219-24.

3) Kaleli N, Sarac D, Külünk S, Öztürk Ö. 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. The Journal of prosthetic dentistry. 2018;119(3):437-45.

4) Alqahtani M. Mechanical properties enhancement of self-cured PMMA reinforced with zirconia and boron nitride nanopowders for high-performance dental materials. Journal of the Mechanical Behavior of Biomedical Materials. 2020; 110:103937.

5) Kaleli N, Saraç D and Kulunk S (2017). Effect of different restorative crown and customized abutment materials on stress distribution in single implants and peripheral bone: A three-dimensional finite element analysis. The Journal of prosthetic dentistry; 17:17-23.

6) Kátia R, Paula Benetti, Álvaro D, Pedro H, Juliana A. Medeiros D, Ediléia L and Márcia B (2018). How does the piston material affect the in vitro mechanical behavior of dental ceramics. The Journal of prosthetic dentistry; 20:862-72.

7) Ozkir SE (2018). Effect of restoration material on stress distribution on partial crowns: A 3D finite element analysis. Journal of dental science; 13, 311-317

8) Himmlova L, Dostalova T, Kacovsky A and Konvickova S (2004). Influence of implant length and diameter on stress distribution: a finite element analysis. Journal Prosthet Dent; 91: 20-25

9) Bijjargi S, Chowdhary R (2013). Stress dissipation in the bone through various crown materials of dental implant a 2-D finite element analysis. J Investig Clin Dent; 4:172-7.

10) Güngör, Merve B and Secil KN (2018). "Fracture resistance of CAD-CAM monolithic ceramic and veneered zirconia molar crowns after aging in a mastication simulator." Journal of Prosthetic Dentistry; 119(3):473-480.

11) Duan Y & Griggs JA (2015). Effect of elasticity on stress distribution in CAD/CAM dental crowns: Glass ceramic vs. polymer–matrix composite. Journal of Dentistry; 43: 742-749.

12) Duarte S, Sartori N & Phark J-H (2016). Ceramic-reinforced polymers: CAD/CAM hybrid restorative materials. Current Oral Health Reports; 3: 198-202.

13) Gracis S, Thompson VP, Ferencz JL, Silva NR & Bonfante EA (2015). A new classification system for all-ceramic and ceramic-like restorative materials. International Journal of prosthodontics; 28.

14) Renouard F & Nisand D (2006). Impact of implant length and diameter on survival rates. Clinical oral implants research; 17, 35-51.

15) De Kok p, Kleverlaan CJ, de Jager N, Kuijs R and Feilzer AJ (2012). Mechanical performance of implant-supported posterior crowns. *The journal of prosthetic dentistry;* V (114): 59-66

16) Jassim ZM and Majeed MA (2018). Comparative Evaluation of the Fracture Strength of Monolithic Crowns Fabricated from Different all-ceramic CAD/CAM Materials (an in vitro study). *Biomedical & Pharmacology Journal*; Vol. 11(3); 1689-1697

17) Ilie N, (2021). 'Frequency-related viscoelastic properties in high translucent CAD-CAM resin-based composites', J Mech Behav Biomed Mater; 118: pp. 104427

18) Pekedis M and Yildiz, H (2011). Comparison of fatigue behaviour of eight different hip stems: a numerical and experimental study', Journal of Biomedical Science and Engineering; 04: (10)pp. 643-650

19) Duan Y, Griggs JA (2015). Effect of elasticity on stress distribution in CAD/CAM dental crowns: Glass ceramic vs. polymer-matrix composite. *J Dent*: 742-9.

20) Reyes et al (2021). Micromotion analysis of immediately loaded implants with Titanium and Cobalt-Chrome superstructures. 3D finite element analysis: 234-244.

21) Benzing UR, Gall H, Weber H (1996). Biomechanical aspects of two different implant-prosthetic concepts for edentulous maxillae. *Int J Oral Maxillo facial Implants*; 10:188–198

22) Holst S, Geiselhoeeringer H, Wichmann M and Hoslst A (2008). the effect of provisional restoration type on micromovment of implants. *J prosthet Dent*: 100:173-182.

23) Cibirka RM, Nelson SK, Lang BR and Rueggeberg FA 2001.Examination of the implant-abutment interface after fatigue testing. *J Prosthet Dent*; 85: 268-75.

24) Geng JP, Tan KB, Liu GR 2001. Application of finite element analysis in implant dentistry: a review of the literature. *J Prosthet Dent*; 85: 585-98.

25) Bassit R, Lindstrom H, Rangert B 2002. In vivo registration of force development with ceramic and acrylic resin occlusal materials on implant supported prostheses. *Int J Oral Maxillofac Implants*;17: 17-23.

26) Mokhtar MM, Farahat DS, Eldars W, Osman MF (2022). Physico- mechanical properties and bacterial adhesion of resin composite CAD/CAM blocks: an in-vitro study. *J Clin Exp Dent*; 14: 413–9.

27) Gomes ÉA, Barão VA, Rocha EP, de Almeida ÉO, Assunção WG (2011). Effect of metal-ceramic or all-ceramic superstructure materials on stress distribution in a single implant supported prosthesis: three- dimensional finite element analysis‖, Int J Oral Maxillofac Implants;26:1202-9.

28) Sevimay, Usumez, and Eskitascioglu (2005). 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; 73B:140–7.