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Finite Element Analysis and Static Loading in Dental Implant with Innovative Crown Design (IN VITRO STUDY)

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Abstract

Objective: *The purpose of this study is to examine how different crown materials affect stress transformation and distribution around both dental implants. To do this, 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 by to evaluate the effect of the different type of material (E max, zirconia, composite) on the short implant. 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 softer 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 design and manufacturing the 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:*** *by using stiff 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

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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 in the first ready-made dental arch is used which have all the teeth and in full occlusion, the teeth are attached to the base by the screw, first lower molar is choice and replaced by the implant.

After the teeth is removed the socket of the teeth is grinded to become wider for the fixation, for the parallelism of the implant dental surveyor is used (dental farm S.r.I. Via Susa, 9/A-10138 torino-italy). 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.

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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.

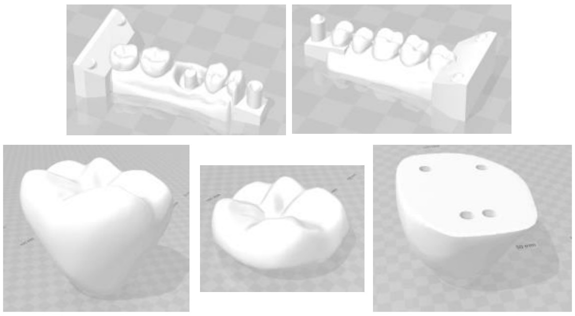

Figure 2: Samples of the scanned parts in STL format

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 implants were 4.5mm and their lengths were 6mm, respectively. Figure 3 show the details of the aforementioned models.

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5. Development of the FE models

The geometrical models were imported to ABAQUS package (SIMULIA, Providence, RI, USA) to simulate the effect of material properties of the crown and implant size on biomechanical response. For this purpose, 18 FE models were developed as following scenario:

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

Mechanical properties of the model were considered as isotropic elastic theory, which was extracted from the available data in literature (Table 1)

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Table 1: Mechanical properties of different components in FE models

Components	Elastic modulus (GPa)	Poisson's ratio
Implant	110 [1]	0.3 [1]
Abutment	110 [1]	0.3 [1]
Cancellous Bone	1.37 [2, 3]	0.3 [2, 3]
Cortical Bone	12.6 [2, 3]	0.3 [2, 3]
E-Max	95 [3, 4]	0.2 [3, 4]
Zirconia	210 [5]	0.33 [5]
Composite resin	21 [6]	0.24 [6]

The analyses were classified as static and the solution examined the governing equation system using the element diagonal mass matrix and the law of explicit integration. The applied boundary condition between different components were considered using the discretization method of surface to surface with tie contact property to simulate perfect connection to constrain equal degrees of freedom (i.e., equal translational and rotational motions). The static compressive load equal to 200 N [7] was vertically applied on the upper surface of the crown for comparative analysis using the reference point positioning technique as shown in Figure 4.

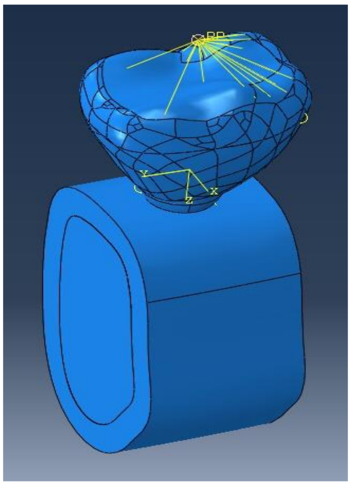

Figure 4: The applied axial compressive concentrated force to FE model

10-node quadratic tetrahedron elements were used to generate the meshed models (Figure 5 to 6) and sensitivity analyses to assess the independency of the results from meshing were performed. The finalized number of elements after mesh sensitivity analyses were considered as Table 2 and 3.

Table 2: Number of elements for finalized FE model after convergence analyses for integrated crown models with short implants

Components	Number of Elements
Short Implant	13810
Crown	25955
Cancellous Bone	38381
Cortical Bone	33134

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Table 3: Number of elements for finalized FE model after convergence analyses for combined crown models with short implants

Components	Number of Elements
Short Implant	13810
Crown (Upper Part)	28398
Crown (Lower Part)	25063
Cancellous Bone	38381
Cortical Bone	33134

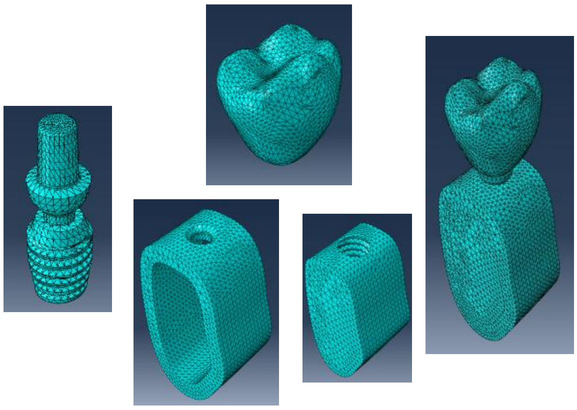

Figure 5: Meshing the FE models based on sensitivity analyses

(Integrated crown with short implant)

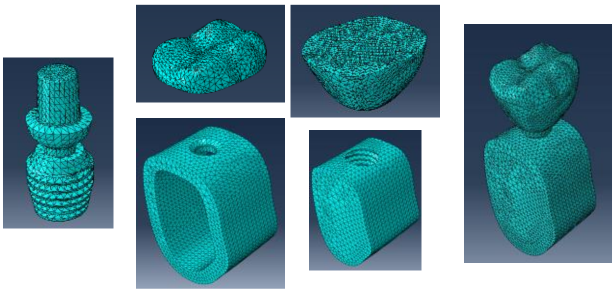

Figure 6: Meshing the FE models based on sensitivity analyses

(Combined crown with short implant)

The simulations were performed as described previously by comparing the results for 18 different models (i.e., Based on combination of (1) integrated and (2) combined crown implanted using short implants.) subjected to vertical static force equal to 200N. The values of Von-Mises stress were calculated in critical nodes in different components of the models (i.e., cortical bone, cancellous bone, implants, and crown) for comparative study.

RESULT

The results of sensitivity analyses verified the accuracy of the FE models for investigation of the main objective of this study. The calculated values of Von-Mises stress in different FE models subjected to static loading (i.e., vertical compressive force equal to 200N) over the upper surface of the crown were extracted. The maximum equivalent stress in critical regions achieved results were calculated in different components of different models (i.e., cortical bone, cancellous bone, implants, abutments, and crown) and the calculated results were compared.

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The comparative results are summarized in figures 9 to 16 in which the values of Von-Mises stress were shown for different implant configurations with different materials for the crowns. The result from the static loading appears that the stress formation inside the crown for the short implant with zircon crown has higher value while followed by the E-max and the last one composite crown. The details are show in figure (7). The most highly statistically significant one is composite VS zirconia and the least one which is non statically significant is E-Max VS. Composite and other are between them as shown in table (3):

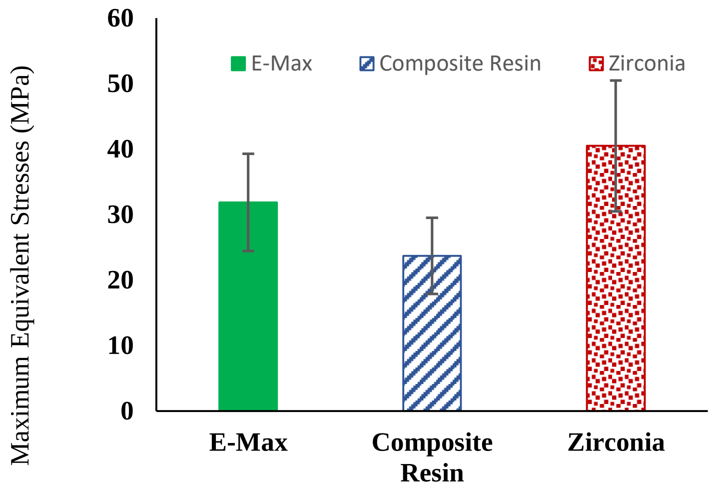

Figure 7: Comparative results for values of maximum Von-Mises stress in crown for the models with integrated crown using short implant.

The result from the static loading appears that the stress formation inside crown while using zirconia as the superior part of the combined crown in both Z/E, Z/C crown while followed by the E/Z and E/C and the last one C/E and C/Z. The details are show in figure (8). The most statistically significant one is Composite/Zirconia vs. Zirconia/Composite and last non statically significant one is Composite/E-max vs. Composite/Zirconia and other are between them as shown in table (4):

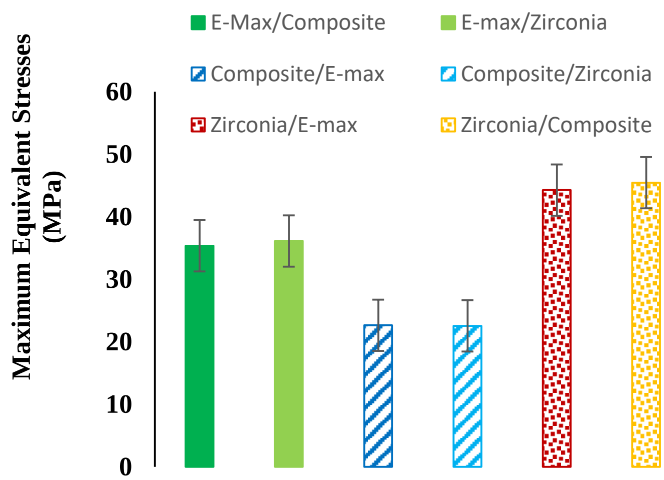

Figure 8: Comparative results for values of maximum Von-Mises stress in crown for the models with combined crown using short implant.

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Table 4: statistical analysis of crown

Pair (Short Implant) Crown	P- value	Statistical analysis
E-Max vs. Composite Resin	0.07329	
E-Max vs. Zirconia	0.0447	*
Composite Resin vs. Zirconia	0.0001785	*
E-Max/Composite vs. E-max/Zirconia	0.9998	
E-Max/Composite vs. Composite/E-max	0.001219	*
E-Max/Composite vs. Composite/Zirconia	0.00111	*
E-Max/Composite vs. Zirconia/E-max	0.04841	*
E-Max/Composite vs. Zirconia/Composite	0.01694	*
E-max/Zirconia vs. Composite/E-max	0.0005098	*
E-max/Zirconia vs. Composite/Zirconia	0.0004629	*
E-max/Zirconia vs. Zirconia/E-max	0.09124	
E-max/Zirconia vs. Zirconia/Composite	0.03459	*
Composite/E-max vs. Composite/Zirconia	1	
Composite/E-max vs. Zirconia/E-max	2.91E-08	*
Composite/E-max vs. Zirconia/Composite	6.65E-09	*
Composite/Zirconia vs. Zirconia/E-max	2.61E-08	*
Composite/Zirconia vs. Zirconia/Composite	5.98E-09	*
Zirconia/E-max vs. Zirconia/Composite	0.9987	

Pair (Short Implant) Crown	Mean	SD
Zirconia	40.496	9.980093743
E-Max	31.853	7.423834065
Composite Resin	23.706	5.821193463
E-Max/Composite	35.348	7.160511776
E-max/Zirconia	36.143	6.533477975
Composite/E-max	22.6344	4.3443233
Composite/Zirconia	22.5478	4.069622363
Zirconia/E-max	44.265	8.556589728
Zirconia/Composite	45.455	8.26326711

The result forms the static loading appear that the stress formation in implant itself for the short implant more for the full anatomical zirconia crown while followed by the E-max and the least stress formation is composite crown. The details are show in figure (9). The most statistically significant one is Composite Resin vs. Zirconia and the least one which is non statically significant is E-Max vs. Zirconia and other are between them as shown in table (5):

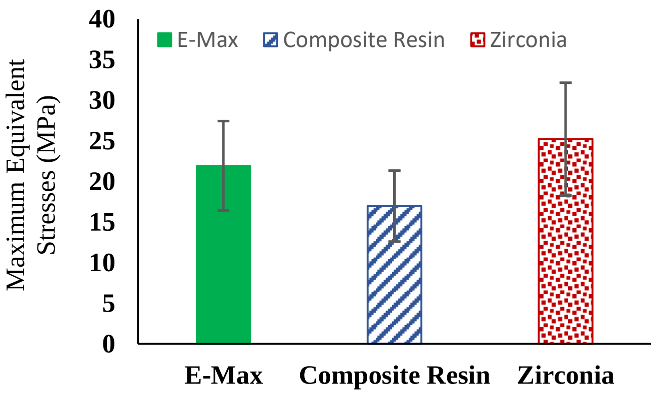

Figure 9: Comparative results for values of maximum Von-Mises stress in implants for the models with integrated crown using short implant.

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The result from the static loading appears that the stress formation in implant itself for the short implant the result show more stress formation while using zirconia crown as superior part in both Z/E, Z/C while followed by the E/Z and E/C then C/E and C/Z. The details are show in figure (12). The most highly statistically significant one is Composite/E-max vs. Zirconia/E-max and the least one which is non statically significant is E-Max/Composite vs. E-max/Zirconia and other are between them as shown in table (10):

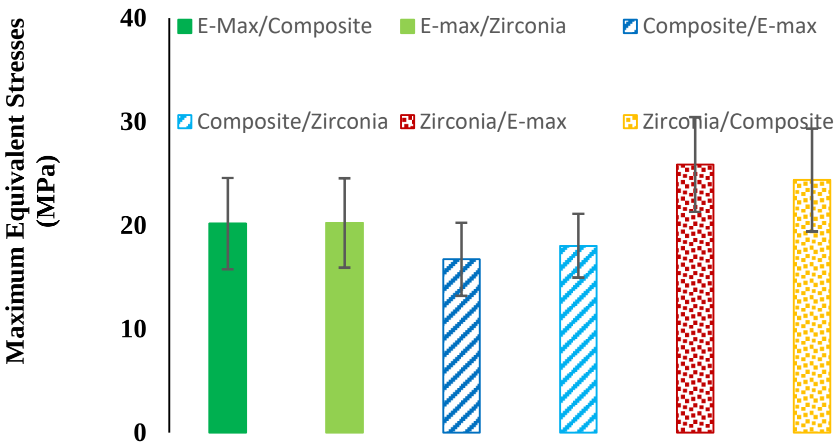

Figure 10: Comparative results for values of maximum Von-Mises stress in implants for the models with combined crown using short implant.

Table 5: statistical analysis of implant

Pair (Short Implant) implant	P- value	Statistical analysis
E-Max vs. Composite Resin	0.1475	
E-Max vs. Zirconia	0.4093	
Composite Resin vs. Zirconia	0.008718	*
E-Max/Composite vs. E-max/Zirconia	1	
E-Max/Composite vs. Composite/E-max	0.4445	
E-Max/Composite vs. Composite/Zirconia	0.8594	
E-Max/Composite vs. Zirconia/E-max	0.03974	*
E-Max/Composite vs. Zirconia/Composite	0.2354	
E-max/Zirconia vs. Composite/E-max	0.4254	
E-max/Zirconia vs. Composite/Zirconia	0.8451	
E-max/Zirconia vs. Zirconia/E-max	0.04306	*
E-max/Zirconia vs. Zirconia/Composite	0.2493	
Composite/E-max vs. Composite/Zirconia	0.981	
Composite/E-max vs. Zirconia/E-max	0.0001312	*
Composite/E-max vs. Zirconia/Composite	0.001906	*
Composite/Zirconia vs. Zirconia/E-max	0.001382	*
Composite/Zirconia vs. Zirconia/Composite	0.01571	*
Zirconia/E-max vs. Zirconia/Composite	0.966	

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Pair (Short Implant) Implant	Mean	SD
Zirconia	25.231	6.94377331
E-Max	21.924	5.506868842
Composite Resin	16.981	4.363598031
E-Max/Composite	20.174	4.414886937
E-max/Zirconia	20.233	4.309258895
Composite/E-max	16.709	3.525354041
Composite/Zirconia	18.024	3.074111254
Zirconia/E-max	25.883	4.574829809
Zirconia/Composite	24.38	4.956457068

DISCUSSION

The result of the study show that the stress formation on parts of crown of the two part crown in short implant consist of zirconia base 2/3 gingival crown and 1/3 composite or e max occlusal part are more than the other types of the crown formed by other hybrid crowns this because of the high modulus of elasticity, stress induced toughening mechanism and high fracture resistance this lead to more stress formation inside zirconia part of crown, this finding is similar with Güngör et al, 2018 where compared the fracture strength of all-ceramic crowns fabricated from zirconia and different other materials and found that the highest fracture strength and stress formation inside the crown mean value was recorded by crowns fabricated from zirconia.

When the base 2/3 of the crown made form the composite for short implant the stress formation on the implant is less and more in zirconia base because material has law modulus of elasticity (less stiffer) so lead to more absorption of the force coming from the mastication and less stress formation, Inconsistent with our results, Duan and Griggs (Duan and Griggs, 2015) compared the stress distribution in lithium disilicate ceramic and resin nanoceramic CAD-CAM crowns and reported that resin nanoceramic crowns showed lower stress values under vertical loading on the implant. The polymer-infiltrated hybrid ceramic crown exhibited low stress values in the cervical region. The resin content (Gracis et al, 2015), (Duarte et al, 2016) of these materials is thought to provide a favorable stress distribution in restorative crowns. Opposite to our result (Skalak, 1983) found that resin-based restorative materials may reduce the stress on implants and peripheral bone.

For the all position of stress formation on (crown, implant and bone), full anatomical zirconia crown form the greatest stress formation among all the types of the prosthetic part because material is hard and have no property of elasticity so they did not absorb any stress, when the stress formed either fracture or failure of the material occur or transmitted to the other part of the structure, then followed by E max material and the last one is resin composite which absorb most of the stress because of the spongy properties related to filler particle of material which provide more space inside structure so only transmitted little of the stress to the other part of implant structure.

This founding is similar to study done by De kok P et al 2012 concluded that monolithic implant supported crowns have a higher initial load to failure than conventional veneered ceramic crowns and are expected to show clinically fewer fractures. Monolithic ceramic restorations perform better than composite resin crowns in force standing but composite is better in stress absorption. Composite resins with a low modulus of elasticity show promising results in withstanding the force absorption, in other way opposite to Jassim and Majeed (2018) which concluded that the highest fracture strength mean value was recorded by monolithic crowns fabricated from zirconia (CEREC Zirconia) followed by crowns fabricated from reinforced composite (BRILLIANT Crios), zirconia-reinforced lithium silicate (CELTRA DUO), and lithium disilicate (IPS e.max CAD), while the lowest fracture strength mean value was recorded by crowns fabricated from hybrid dental ceramic (VITA ENAMIC).

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CONCLUSION

In summary, the comparative results showed that manufacturing the crown using softer 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 design and manufacturing the 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.

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