Research Article

FEM: Mono-implant cement-retained crown with two-different adhesive materials

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Received date: 09-05-2023
Accepted date: 10-06-2023
Published date: 15-09-2023

https://doi.org/10.26477/jbcd.v35i3.3450

Abstract: Background: The finite element method (FEM) is expected to be one of the most effective computational tools for measuring the stress on implant-supported restorations. This study was designed using the 3D-FEM to evaluate the effect of two adhesive luting types of cement on the occlusal stress and deformation of a hybrid crown cemented to a mono-implant. Materials and Method: The mono-screw STL file was imported into the CAD/CAM system library from a database supported by De-Tech Implant Technology. This was to assist in the accurate reproduction of details and design of a simulated implant abutment. Virtually, a digital crown was designed to be cemented on an abutment screw. A minimum occlusal thickness of 1mm and marginal fitting of 1.2mm was intended. An 80µm cement interface thickness for this study's purposes was applied using U-Cem Premium and 3M RelyXTm adhesives. The FEA software meshed into tetrahedral elements. Two three-dimensional finite element models were simulated under different loads of 200N, 400N, 600N, 800N, 1000N, 1200N, and 1400N. Results: The results showed that the hybrid ceramic crown attached to a mono-implant with each adhesive cement exhibited comparable stress and strain. However, the amount of distortion was less when RelyX cement was used. Conclusion: Overall, it was advisable to use 3M RelyXTm adhesive cement up to 1400N load.

Keywords: FEA, mono-Implant, cement, adhesive, all-ceramic, stress, deformation

Introduction

Considering hybrid ceramics, doubts about the appropriate combination of ceramics and adhesive cement retained mono-implant were common. Patients tended to accept dental implants for the repair of partly edentulous arches due to cosmetic conformity, functional competence, and a high percentage of survival[1,2]. Fixed prostheses supported by implants could be screwed or retained to implant abutments[3]. The selection of these retention approaches has been primarily influenced by irretrievability[4,5], passivity, occlusion, and esthetics[6]. Researchers have focused on the optimistic and adverse effects of the screw and cement-retained prostheses in terms of many criteria such as retention, restoration of internal and marginal fit, occlusal stability, reversibility, gingival health, and survival[7]. Numerous techniques have been used to investigate the biomechanical behavior of screw- and cement-retained prostheses in terms of stress generation on tissues and prosthetic components, but the results have been inconsistent[8].

However, the association between cement type and its influence on the stress, strain, and deformation of a hybrid crown cemented to a single implant was poorly understood. Nonetheless, many studies have demonstrated that cement-retained prostheses were successfully operated[9,10]. Cement-retained prostheses have risen in favor, especially for single and fixed partial prosthetic treatments. As a result, In single-unit restorations or prostheses with a small span, cementation may be preferred[11,12,13].

Clinically, Rohr *et al*., (2015) investigated the fractography central occlusal contact point through the application of stress to the occlusal surface. They applied an adhesive and self-adhesive cement which appears to have reduced some tensile stress at the interface, causing several potential fissures up to fracture started at the loading point [14]. In addition, Rohr *et al*., (2018) demonstrated how the compressive strength of the cement affects the progress in fracture load for ceramics made of feldspar, polymer-infiltrated ceramic, and lithium disilicate[15]. According to Kelly's research, clinical failure origins were found in the bonded interface region. However, this research showed that the fracture of cemented crowns began at the occlusal contact points[16]. Tensile stress concentration at the ceramic crown's cementation surface appears to have a higher potential to damage restorations in clinical practice than the load at the loading point. Since the 1960s, the FEA was functionalized to address structural issues in the aviation engineering industry and adapted to be widely used as a prediction tool in dentistry and was primarily applied for biomechanics in dental implants by Weinstein *et al*., accordingly, the failure stress of a specific material was estimated using the material's known properties. Therefore, many researchers used von Mises stress as a measure of failure stress in dentistry research[17,18].

The FEA approach may be applied efficiently to analyze the biomechanical behavior of the crown at the cement-implant interface and to verify the areas of elevated stress concentration in clinical and in vitro analyses[19]. Over 2D axially symmetric models, FEA models have offered a more precise three-dimensional understanding of the events happening at the interface of the crown implant[20,21,22]. In addition, statistical analysis has been proven to be a useful tool for determining the factors that significantly affect stress and strain concentrations[23]. This stress was either represented as von-mises stress, which was an equivalent mixing of compression, tension, and shear stresses, or a maximum principal stress that may be considered tension stress and a minimum principal stress that can be considered compressive stress.

This technique was also based on the idea that each complex engineering production may be approximated by subdividing the structure or component into smaller, more manageable (limited) portions[24,25].

Finite element analysis (FEA) was considered one of the techniques available for measuring the force dissipation of dental prostheses (FEA). FEA based on three-dimensional virtual restoration models enables the visualization of high-stress areas by simulating the forces applied to the restoration. Some studies have demonstrated the efficacy of this technique in determining the dissipation of stresses and anticipated longevity of all-ceramic crowns and prostheses [26,27].

In the field of biomedical engineering, the finite element method (FEM) is anticipated to be one of the most effective computational techniques for assessing the stress on implant-supported restoration under definite settings. A study by Duan and Griggs (2015) demonstrated the stress on the CAD crown occlusal surface surrounding the area of loading and the cemented surface underneath the loading area[28].

CAD/CAM technology may enable the more efficient replacement of a lost tooth by an implant abutment. When combined with the rapid loading of a dental implant, this therapy can provide a patient with a permanent tooth replacement in a single visit[29].

Manufacturers have developed many novel chairside CAD/CAM materials that combine the strengths of composite resins with the advantages of ceramics, such as improved flexural characteristics and low abrasiveness. This was to create materials that have the durability and colour stability of ceramics and the low abrasiveness of composite resins. Enamic was a ceramic network material with copolymer infiltration that has an 86% (by weight) porous feldspathic ceramic matrix (urethane dimethacrylate and triethylene glycol dimethacrylate) and 14% (urethane dimethacrylate and triethylene glycol dimethacrylate)[30].

To investigate the biomechanical factors, researchers have focused on the effects of different luting agents on the long-term efficacy of ceramic crown cement-implant repairs. The luting materials might contribute to defining the implant's longevity and primary stability under immediate loading circumstances[31,32,33].

Most dental restorative materials, especially ceramics, were brittle, and tensile stress was considered the main cause of dental material failure. To assess dental material failure, it may be preferred to analyze the different types of stress as Principal Stress reveals both the maximum and minimum values for normal stress. To what extent a component can withstand a force was indicated by its maximum normal stress[34].

A study by Dauti *et al.*, 2020 concluded that the different virtual spacer settings using FEA software of 80μm including RelyX Unicem resin-based cement materials may have no influence on the marginal and internal fit of cemented hybrid material crowns with less deformity[35]. Another study by Syed *et al.* (2021) concluded that due to the thick cement layer the occlusal load distribution with greater stress was created in the occlusal surface of the cement layer than it was elsewhere surrounding the defect. Additionally, a lower elastic modulus might be crucial for the absorption of stresses, but not when the cement was distributed unevenly[36]. In this virtual study, three-dimensional (3D) finite element analysis (FEA) was operated to assess the effects of cement material types on stress distribution across a crown made of a hybrid ceramic-loaded mono-implant (one-piece implant having a condensing thread, machined straight rigid collar and abutment).

Materials and Methods

The ANSYS software System was used for Finite Element Modeling/Finite Element Analysis when the study crown specimen was modeled and analyzed. The force was applied at 200N, 400N, 600N, 800N, 1000N, and 1400N on the occlusal surface of a hypothetical vita crown that virtually cemented to mono-implant using two different types of cement parameters. The analytical data were displayed as a contour. The results of the stress distribution were displayed in color graphics with their corresponding scales in megapascals (MPa).

The study investigation included material property assumptions, model design, and FE model development. The implant-screw STL file was imported from De-Tech Implant Technology Company; (De-tech single screw implant, 101221/M5, Turkey) with a diameter of 5mm and a length of 10mm (Figure 1). One model was designed for a maxillary right first molar of monolithic polymer-infiltrated ceramic crowns using a CAD system (dental DB ver. 3.0, Galway 2021) which was virtually cemented with 80um interface gap over the abutment of mono-implant (Figure 2).

The FEM software imported the solid model values (Ansys® software, version, 2018 R1, America), resulting in tetrahedral elements from the meshing of those models. The implant-hybrid crown restoration was represented in the finite element model (FE) as a homogeneous, isotropic, and linearly elastic material with a titanium mono-implant system. Direct assumptions affect how accurately the values from the FE analysis were calculated[20,37]. Table 1 demonstrates the material characteristics employed in the current study. Data on Self-adhesive universal resin cement (U-Cem) depended on a pilot study that commenced earlier for this study's purposes.

The current investigation assumed a vertical load over the hybrid crown with mono-implant, with no relative deformation. Except for the vertical direction, all degrees of freedom were entirely constrained in the models. Two different types of cement parameters were applied (U-Cem, VER14755, Korea) and (3M RelyX™, U200: USA) with interface spacing of 80μm. Four points that were ideal for static contact of occlusion were applied vertically to the occlusal surface of the virtual hybrid molar crown (Figure 3). The following loads were applied, 200N, 400N, 600N, 800N, 1000N, 1200N, and 1400N. In the current study, three-dimensional FE models were constructed according to the grouping and analyzed using the modeling software tool (Ansys® software (V-2018 R1), America). Mesh independency with 448,331 tetrahedral elements test was performed to ensure mesh quality and to determine the lowest mesh density needed for valid results.

The cemented molar crown on mono-implant was analyzed qualitatively in three dimensions using the von Mises stress distribution and deformation for U-Cem and RelyX cement materials.

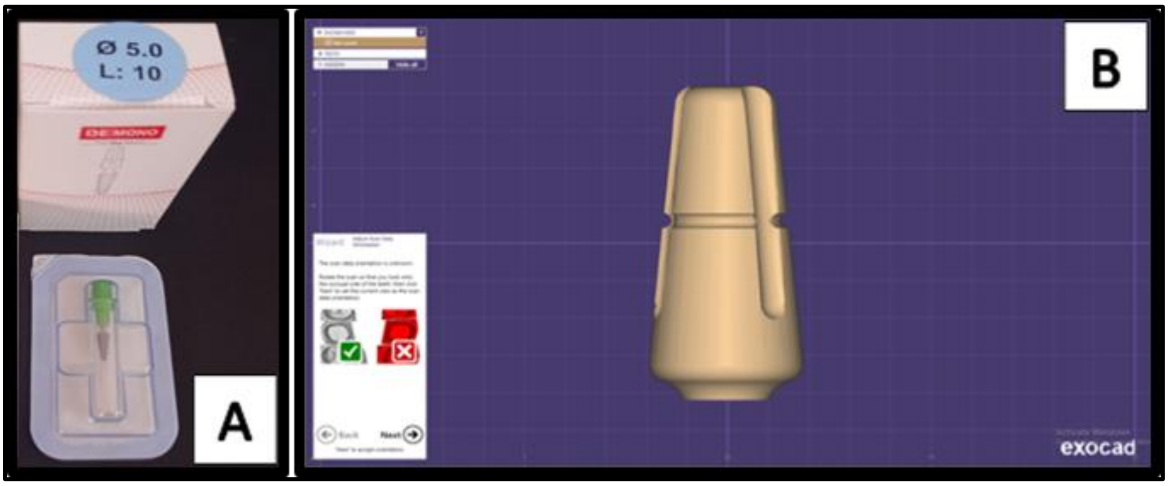

Figure 1: A) Mono-implant screw; B) Mono-implant imported STL file design

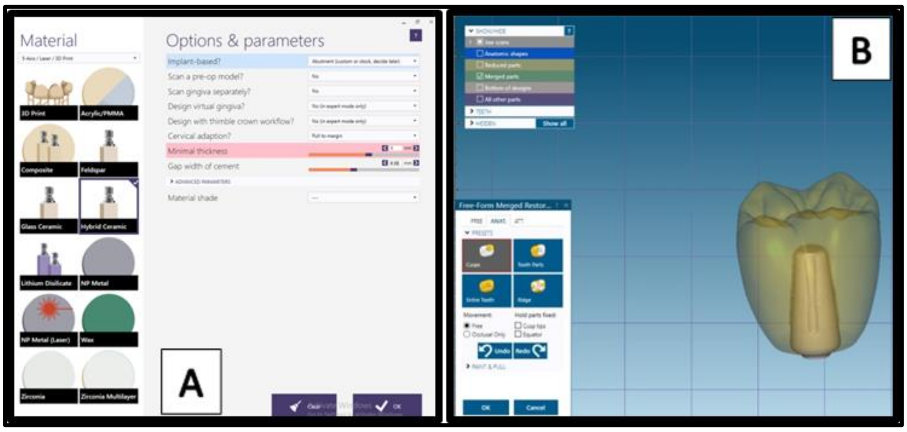

Figure 2: A) Selected interface space of 80(±10µm); B) Digital design of a hybrid ceramic crown

Table 1: The characteristics of the mechanical study components' materials

Components	Young's Modulus (MPa)	Poisson Ratio
U-Cem	2333	0.3
3M^{Tm} (RelyX^{Tm})	7700	0.3
Hybrid Ceramic (Vita Enamic)	30.000	0.23
Titanium	110000	0.3

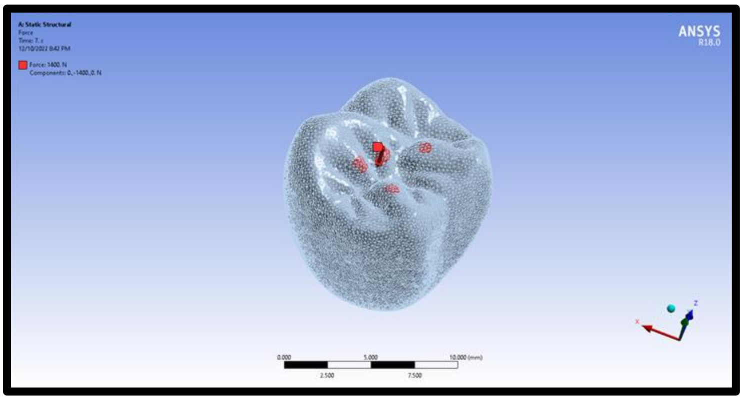

Figure 3: FEM, four loaded points on the occlusal surface of the hybrid crown

Statistical Analysis

To compare the two groups, the Mann-Whitney U-test was used to meet the requirement for non-parametric testing. Therefore, the data were assessed and compared using valid statistics. This was to establish the significance of their contribution to stress concentration over mono-implant.

Results

The FE modeling analysis was performed to evaluate the stress and deformation of the hybrid crown occlusal surface cemented to mono-implant using two luting agents. The loads were applied at four loading points under variant forces.

Generally, the scale color indicates a similar range of stress and elastic strain distributed level. (Figure 4) illustrates the von Mises stress, strain, and deformation, while (Figure 5), the maximum and minimum deformation of the hybrid crown restoration at a static vertical load of 200N, 400N, 600N, 800N, 1000N, 1200N, and 1400N.

To determine the statistical difference in stress distribution, strain, and deformation between the groups, Tables 2 and 3 displayed the Mann-Whitney analysis for hybrid crowns cemented using two different adhesives.

In general, the application of static loads on the hybrid crown occlusal surface using a non-destructive von Mises test shows a non-significant stress distribution, but deformation. There was a non-statistical difference ($p>0.05$) in stress ($p=0.775$), even though the difference was significant ($p\leq0.05$) in deformation ($p=0.019$).

The analytical results of the present study material from the von Mises point of view at static loads might not be acknowledged properly because of the brittle properties of hybrid zirconia material, accordingly, further virtual tests like the maximum principal stress were conducted (Figure 6). Nevertheless, the maximum principles when performed highlighted the non-significant distribution in elastic strain compared to von Mises. The stress distributions in the maximum principal might slightly change between the two types of cement materials, this reflects the positive relationship between the force and the tension stress.

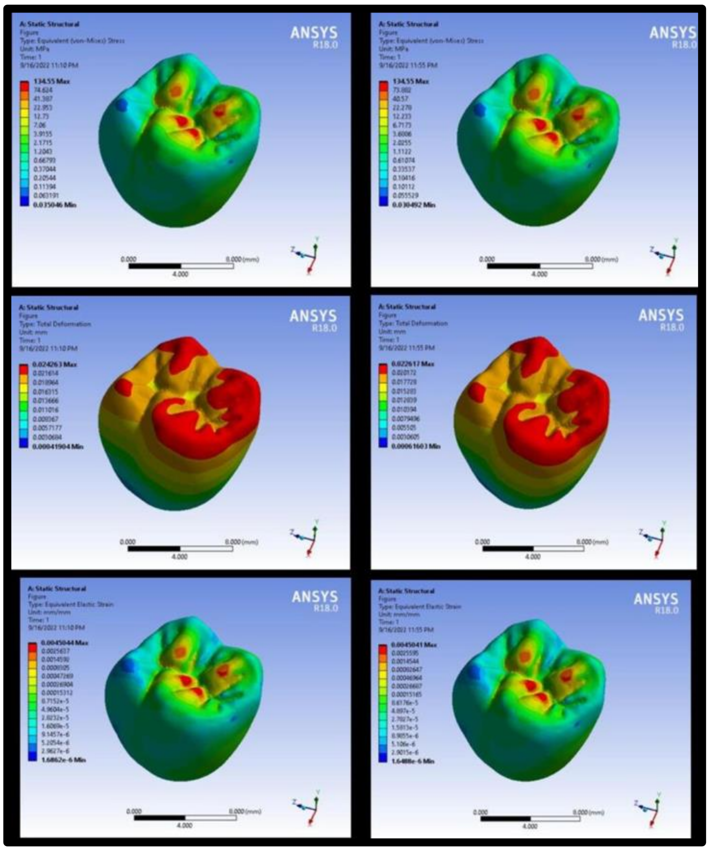

Figure 4: FEA of the hybrid crown under the load of 200N for two adhesives, U-Cem (left) and 3M RelyX (right)

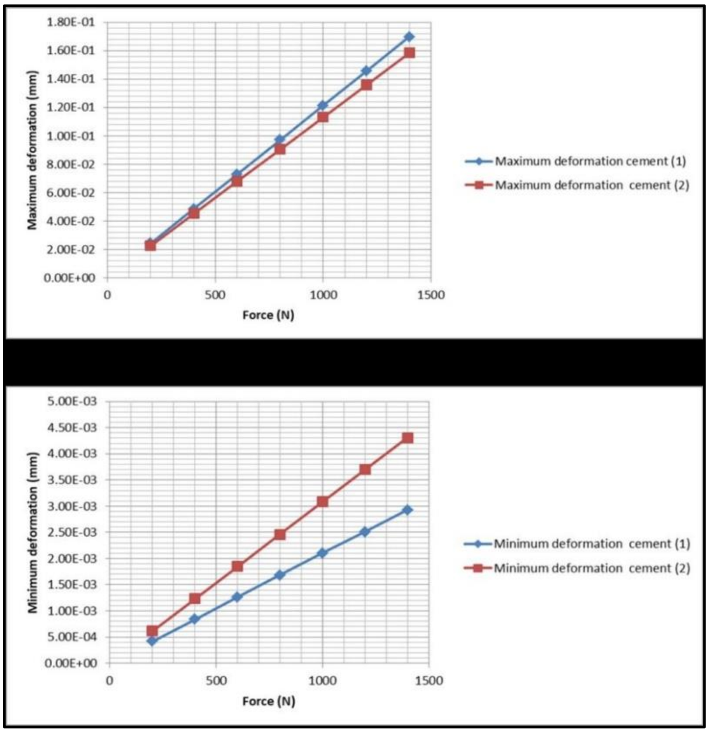

Figure 5: Plot chart showing the deformation of the hybrid crown under the load of 200N up to 1400N with (1) U-Cem and (2) 3M RelyX adhesives

Table 2: Mann-Whitney analysis for hybrid crown cemented to mono-implant with two different adhesives

	Cement		Force at hybrid ceramic crown cemented to mono-implant						
			200N	400N	600N	800N	1000N	1200N	1400N
Stress (MPa)	U-Cem	Min	0.035046	0.070082	0.10513	0.14019	0.17525	0.21033	0.24542
		Max	134.55	269.11	403.66	538.22	672.77	807.33	941.88
	3M	Min	0.030492	0.060984	0.091476	0.12197	0.15246	0.18295	0.21344
	Relyx	Max	134.55	269.09	403.64	538.18	672.73	807.28	941.82
	P-Value		0.775	0.775	0.775	0.775	0.775	0.775	0.775
Strain (mm)	U-Cem	Min	1.6862E-06	3.3727E-06	5.0591E-06	6.7452E-06	8.4312E-06	0.0000101	0.000011
		Max	0.0045044	0.0090088	0.013513	0.018018	0.022522	0.027026	0.031531
	3M	Min	1.6488E-06	0.00000329	4.9446E-06	6.9516E-06	0.00000823	9.8838E-06	0.000011
	Relyx	Max	0.0045041	0.0090082	0.013512	0.018016	0.022521	0.027025	0.031529
	P-Value		0.775	0.775	0.775	0.775	0.806	0.775	0.775
Defor-mation	U-Cem	Min	0.00041904	0.00083804	0.001257	0.001676	0.002095	0.002514	0.002932
		Max	0.024263	0.048526	0.07279	0.097053	0.12132	0.14558	0.16984
	3M	Min	0.00061603	0.0012321	0.0018481	0.0024641	0.0030801	0.0036962	0.004312
	Relyx	Max	0.022617	0.045233	0.06785	0.090466	0.11308	0.1357	0.15832
	P-Value		0.019	0.019	0.019	0.019	0.019	0.019	0.019

Table 3: Maximum principal stress for hybrid crown cemented to mono-implant with two different adhesives

Force (N)	Maximum Principal using U-Cem		Maximum Principal using 3M RelyX	
	Stress (MPa)	Elastic Strain (mm)	Stress (MPa)	Elastic Strain (mm)
200	66.01	2.4118e-003	65.978	2.4107e-003
400	132.02	4.8237e-003	131.96	4.8215e-003
600	198.03	7.2355e-003	197.93	7.2322e-003
800	264.04	9.6473e-003	263.91	9.643e-003
1000	330.05	1.2059e-002	329.89	1.2054e-002
1200	396.06	1.4471e-002	395.87	1.4464e-002
1400	462.07	1.6883e-002	461.85	1.6875e-002

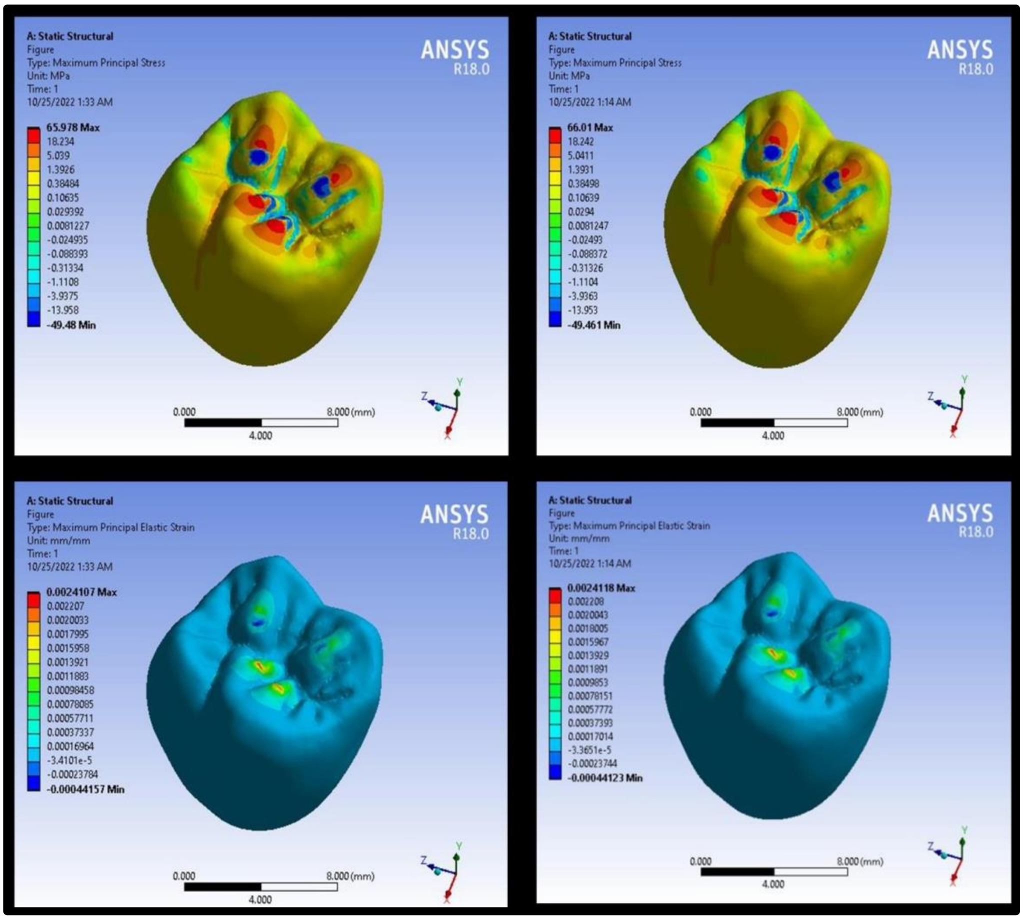

Figure 6: Maximum principal stress and maximum elastic strain of hybrid crown under static loads for two adhesives, U-Cem (left) and 3M RelyX (right)

Discussion

The stress distribution, concentration, and deformity of the crown restoration are frequently modified by the prosthesis, implant, and luting materials[35]. Analysing and finding reasonable solutions to problems involving complex geometrical features, such as bone and implant surfaces, proved difficult. In such cases, computational technologies such as finite element modelling (FEM) and analysis (FEA) may be used. Von Mises stress indicates the entire effect of three basic equivalent stresses (compression, tension, and shear) compared to the yield stress of the material. It was previously unknown how the cement type influences stress deformation in hybrid crowns. The effects of stress deformation of hybrid crowns using cementation with mono-implant are yet to be understood. The distribution of stresses and deformations was investigated in this study.

In a mono-implant system, occlusal loads seem to be directly transferred to the implant. Nonetheless, this was different from natural teeth, which are supported by fibers of the periodontal ligament. This observation may be in agreement with Ghasemi *et al.*, 2015 as they stated that the periodontal ligament was lacking in implant-supported Fixed Dental Prosthesis (FDP), resulting in stress caused by functional forces that were directly passed to the supporting tissue through the implant body[12].

The fracture load values of crown materials with low internal strength are increased by cementing them with total-etch and self-etch composite resin cement. The stability of the restorative system might be increased by the homogenous stress distribution caused by the high compressive strength of the cement. The cement closes the space between the crown and the implant, preventing first interactions that could lead to stress peaks and the emergence of cracks early[14].

Theoretically, the loaded crown restoration with luting material of the highest elastic modulus may take most of the stress due to uneven stress distribution to the cement underneath the hybrid crown. Deformation-like cracks may spread through the structure of the ceramic causing its failure in the form of chips or complete breaks which catastrophically fail ceramics.

It seems that some cement properties potentially affect materials with low inherent strength fracture load[15]. Therefore as in Table (2), the RelyX luting material results show less deformity than the U-Cem. Such findings may be in agreement with Kelly (1999) who reported that the higher stiffness luting agent with low modulus may allow the restoration to suffer a lesser deformation, and increase the concentration of stress in the ceramic crown, primarily, in the occlusal region[16]. This agreement may be due to U-cem cement's lower elastic modulus property that fills such space with a hybrid crown. Additionally, the material with a higher modulus of resilience like RelyX may have a larger energy absorption capacity before irreversibly deforming and failing a restoration[30]. In contrast, Weyhrauch *et al*. investigated the use of various types of and different monolithic ceramic crown materials milled using a CAD/CAM system to determine the amount of stress concentration and lifetime of a monolithic all-ceramic crown cemented on a titanium implant abutment concluded in negative effect by luting types[29].

Yet, a clinical and virtual study by Dauit *et al*. (2020) assumed that the differences in cement material characteristics such as particle size might contribute to the formation of porosities which in turn allow the material to deform under loading conditions[35]. The RelyX result seems to have less distinctive porosity evenly spread under crown restoration. Therefore, the results of the present study for the U-Cem luting agent with more deformity might agree with such a study as it could have higher porosity than that of the RelyX luting agent. Furthermore, Syed *et al.* in 2021 stated in their study using the 3D FEA that the mismatch between the materials of crown restoration and luting agent may affect the hybrid dental ceramic crown that was machined in terms of anatomic design and elastic modulus[36].

Conclusions

Within the limits of this study, 3MTm RelyXTm cement with high elastic moduli properties might reduce the deformation compared to the U-cem cement agent on a hybrid ceramic crown when bonded to a mono-implant. Based on this study data, there were no significant differences in stress and strain between the U-Cem and 3M RelyXTm cement; yet, a RelyX cement can be recommended for clinical application.

Conflict of interest: None.

Author contributions

SMS; study conception and design. SMS; data collection. SMS and RSAM; Methodology. SMS and SAM; statistical analysis and interpretation of results. SMS; original draft manuscript preparation. SMS, SAM and RSAM; Writing - review & editing. Supervision; SAM and RSAM. All authors reviewed the results and approved the final version of the manuscript to be published.

Acknowledgement and funding

No grant or financial support was received from any governmental or private sector for this study

Informed consent

Informed consent was obtained from all individuals or their guardians included in this study.

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نمذجة العناصر المحدودة:التاج المثبت اسمنتيا بالزرعة الأحادية باختلاف مادتين لاصقتين

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المستخلص:

الخلفية:تم تصميم هذه الدراسة باستخدام نمذجة العناصرالمحدودة ثلاثية الأبعاد لتقييم تأثير اثنين من الإسمنت اللاصق على إجهاد الإطباق وتشوه التاج الهجين المثبت بالغرسة الأحادية. تم استيراد ملف **STL** للزرعة الأحادية إلى نظام التصميم والتصنيع الرقمي من قاعدة بيانات مدعومة بتقنية **De-Tech Implant Technology** للمساعدة في الاستنساخ الدقيق للتفاصيل وتصميم الدعامة لمحاكاة الغرسة. عمليًا ، تم تصميم التاج الرقمي ليتم تثبيته على الزرعه. تم تصميم الحد الأدنى لسماكة الإطباق 1 ملم والتركيب الهامشي 1.2 ملم. كما تم تطبيق سمك واجهة أسمنتية 80 ميكرومتر لأغراض هذه الدراسة باستخدام مواد لاصقة **U-Cem Premium** و **3M RelyX** وتم دمج برنامج تحليل نمذجة العناصر. تمت محاكاة نموذجين من العناصر المحدودة ثلاثية الأبعاد تحت أحمال مختلفة تبلغ 200 نيوتن و 400 نيوتن و 600 نيوتن و 800 نيوتن و 1000 نيوتن و 1200 نيوتن و 1400 نيوتن. أظهرت نتيجة التاج الخزفي الهجين المرتبط بالغرسة الأحادية مع كل مادة لاصقة ضغطًا وإجهادًا مشابهين. ومع ذلك ، كانت كمية التشوه أقل عند استخدام مادة الأسمنت **3M RelyX**. بشكل عام ، يُنصح باستخدام الأسمنت اللاصق **3M RelyX** حتى حمولة 1400 نيوتن.