ORIGINAL RESEARCH

Influence of Different Cements and Cement Thickness on the Stress Distribution under Occlusal Surfaces of Porcelain-fused-to-metal and Porcelain-fused-to-zirconium Crowns: A Finite Element Analysis

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Abstract

Aim: The purpose of this study is to compare and evaluate the influence of two different cement space settings and two different cement types on the stress distribution under occlusal surfaces of tooth restored with two different types of crowns and studied by using three-dimensional (3D) finite element analysis (FEA).

Materials and methods : Eight 3D finite element models (FEMs) representing a mandibular first molar tooth restored with crowns of, porcelain-fused-to-metal (PFM) and porcelain-fused-to-zirconia (PFZ) crowns with two cement space settings (50 and 80 µm) and with two different types of cement were constructed, using an FEA software (ANSYS, version 10). Each model was subjected to a distributed load simulating normal masticatory bite force of 225 N and was applied axial direction. Also, von Mises stress of each individual part in the system of models was calculated.

Results: The PFM crowns undergo less stress distribution than the PFZ crowns. The PFM crowns are more compatible with self-adhesive cements, and the PFZ crowns are more compatible with resin-modified glass ionomer cements.

Conclusion: The PFM crowns with G-Cem Link Ace with 50 µm and PFZ crowns with RelyX Luting Plus with 80 µm combinations displayed less amount of stress distribution under normal masticatory bite force.

Clinical significance: Self-adhesive resin cements with PFM crowns and PFZ with resin-modified glass ionomer cements show more benefits in stress distribution under occlusal surfaces under normal masticatory bite force.

Keywords: Cement thickness, Finite element analysis, Porcelain-fused-to-metal crowns, Porcelain-fused-to-zirconia crowns, Stress distribution.

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Introduction

Porcelain-fused-to-metal (PFM) crowns have long been regarded as the gold standard for restoring damaged teeth. Metal ceramic restorations have a high degree of success because of their excellent mechanical properties. However, metal ceramics have a disadvantage from an esthetic standpoint, hence there has been a steady shift from traditional systems made of PFM to all ceramic crowns.[1,2] Because of their excellent mechanical properties, biocompatibility, and aesthetic results, all-ceramic restorations have become more popular.[3,4] Porcelain-fused-to-zirconium (PFZ) crowns are created by combining porcelain with zirconium oxide. The zirconia base has a white shade and is layered with porcelain to match the final restoration. Ironically, this addition causes the most common failures of zirconium crown restorations, they are fractures and chipping of porcelain veneers due to their fragility.[5]

The failure of restorations is influenced by a wide variety of variables such as preparation design, cement type, cement space setting, marginal fit, bond strength, and alternatives created in the oral environment. These variables have different effects on the stress distribution. A certain width of the cement space provides space for the sealant and facilitates its distribution in the axial area. The width of the cement space and the choice of the appropriate cement affect the exact seating and final marginal and internal irregularities of the restoration. A large cement space can increase the risk of the highest stresses encountered in the veneer layer and lead to a higher risk of crown failure, indicating the important role of the cement layer in the fracture resistance of ceramic crowns. Inadequate cement space adjustment can impede crown seating and cause higher marginal leakage. An important factor that can predict their clinical success is how stress is dissipated on the ceramic restoration.[6]

Finite element analysis (FEA) is the analysis of any given physical phenomenon using a numerical technique called the finite element method (FEM). Finite element analysis principles assume that structures can be mechanically modeled as a series of points (nodes) that are connected by elastic springs (represented

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by the local elastic modulus) to form deformable local volumes (elements) whose behavior is described by the Poisson's ratio of the material. If a structure is carefully modeled, contains enough elements, and is appropriately loaded, it can reveal stresses and strains throughout the structure in response to a particular load. In dentistry, FEA is used to study the stress distribution in teeth and restorative materials. Kamposiora et al. reported a minimal effect of cementum thickness on stress distribution in the first premolar.[7] In addition, Proos et al. reported the little effect of cement thickness and type on the maximum tensile stress distribution in glass-infiltrated gold–alumina substructures. These studies determined cementum thicknesses to be between 25–100 and 50–100 µm.[8] On the other hand, May et al. demonstrated a significant effect of cement thickness on the failure load of feldspar ceramic crowns, indicating that the thickness of the cement layer can be directly related to gap formation, which increases the tensile stresses on the crown surface and reduces the failure load of feldspar ceramic crowns.[9,10]

The aim of this study was to analyze the effect of types of cement (self-adhesive and resin-modified glass ionomer) and cement space settings (50 µm and 80 µm) on the stress distribution under occlusal surfaces of the molars restored with PFM and PFZ crowns.

Materials and Methods

This study was conducted in the Department of Prosthodontics – Crown and Bridge, Sree Sai Dental College and Research Institute, Srikakulam. The duration of this study was 18 months. The FEA of this study was done at Tejvi Techno Solutions, Bengaluru.

Preprocessing Stage

The D2 (mandibular molar region) bone model was obtained from a CT scan. Then the geometric models were imported into Hyper mesh software for meshing. The FEM consists of nodes and elements. Assembled finite element mandibular molar model of the enamel, dentin, pulp, cortical and cancellous bone and was then imported into Ansys software for analysis (Fig. 1). This model was then modified accordingly to incorporate the approximate dimensions of different crown systems. The crown systems involved in this study are listed as follows:

- Group I: PFM crown tooth preparation (dimensions are occlusal reduction, 2 mm; overall circumferential reduction, 1.5 mm; 6° taper; buccal shoulder finish line 1-mm width; lingual chamfer finish line, 0.5-mm width).[11]
  Subdivisions
  - Group Ia – PFM with G-Cem Link Ace, 50 µm
  - Group Ib – PFM with G -Cem Link Ace, 80 µm
  - Group Ic – PFM with RelyX Luting Plus, 50 µm
  - Group Id – PFM with RelyX Luting Plus, 80 µm
- Group II: PFZ crown tooth preparation (dimensions are occlusal reduction, 2 mm; overall circumferential reduction, 1.5 mm; 6° taper; buccal and lingual shoulder finish line, 1-mm width).[11]
  Subdivisions
  - Group IIa – PFZ with G-Cem Link Ace, 50 µm
  - Group IIb – PFZ with G-Cem Link Ace, 80 µm
  - Group IIc – PFZ with RelyX Luting plus, 50 µm
  - Group IId – PFZ with RelyX Luting plus, 80 µm

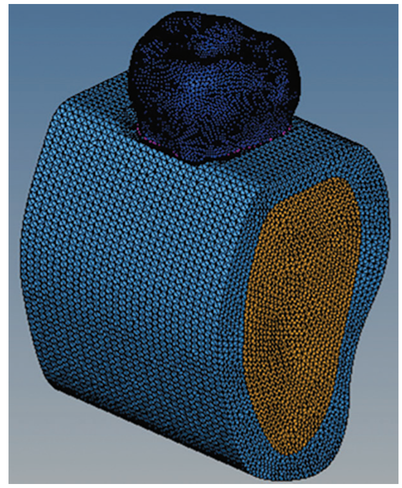

Fig. 1: Three-dimensional model parts assembled together

Table 1: Material properties

S.No.	*Material*	*Young's modulus of elasticity*	*Poisson's ratio*
1	Dentin[10]	18.6 GPa	0.31
2	Pulp[10]	0.002GPa	0.45
3	Periodontium[10]	0.069 GPa	0.45
4	Cortical bone[10]	13.7 GPa	0.3
5	Cancellous bone[10]	13.7 GPa	0.3
6	PFM[10] Porcelian metal base material	82,800 MPa 2,06,000 MPa	0.35 0.33
7	Zirconia[10]	250 GPa	0.3
8	RelyX Luting Plus[18]	4 GPa	0.35
9	G-Cem Link Ace[19]	1.8 GPa	0.25

The shape and dimensions used to model the tooth and the different crown tooth preparations were obtained from Wheeler's dental anatomy and from Contemporary fixed prosthodontics. The material properties (Young's modulus and Poisson's ratio) of Dentin, Pulp, Periodontium, Cortical bone, Cancellous bone, PFM crown, PFZ crown, G-Cem Link Ace, and RelyX Luting Plus cement were assigned to the created models (Table 1).

Solving Stage

All models' loads and boundary conditions were applied at the solution step. All 8 models created were replicated 7 times then a distributed load that simulated a normal masticatory biting force of 225 N was delivered in an axial direction to each model. Eight different loading points were selected as follows: Three points on the outer inclines of the buccal cusps, three points on the inner inclines of the buccal cusps, and two points on the inner inclines of the lingual cusps, as shown in (Fig. 2). After the application of the above boundary conditions, the stresses were measured at the following nodes of each model.

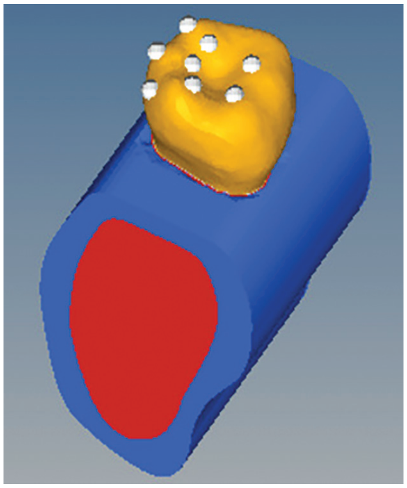

Fig. 2: Normal masticatory bite 225-N load application

- Group Ia and IIa models with 571.906 nodes and 807,914 elements, respectively.
- Group Ib and IIb models with 562.724 nodes and 801,823 elements, respectively.
- Group Ic and IIc models with 581.423 nodes and 846,629 elements, respectively
- Group Id and IId models with 578,273 nodes and 844,284 element, respectively.

Postprocessing Stage

The von Mises stress of each individual part in the system of models was calculated.

Statistical Analysis

In this study two groups were taken, group I PFM crowns and group II PFZ crowns. Each group was subdivided into 4 and each was replicated 7 times. The obtained data were analyzed using statistical package for the social sciences (SPSS), version 20, software (IBM SPSS, IBM Corp, Armonk, NY, USA). One-way analysis of variance (ANOVA) with Tukey's *post hoc* tests and independent samples *t*-tests were done to analyze the study data.

Results

When the differences in study parameters between different combinations of cement and cement space settings under occlusal surfaces of group I, (Table 2) were done overall deformation (0.18545 µm) and cancellous stress (8.38755 µm) were observed to be significantly lesser for RelyX Luting Plus cement with the cement space setting of 80 µm (group Id). All the other parameters namely overall stress (74.52723 µm), (5.85584 µm), periodontium stress (0.47433 µm), dentin stress (36.25810 µm), cement stress (12.53706 µm), and crown stress (74.51747 µm) were observed to be significantly lower for G-CEM Link Ace cement with 50-µm cement space setting (group Ia).

When the differences in study parameters between different combinations of cement and cement space settings under occlusal surfaces of group II (Table 3) were done. The mean overall deformation (0.18542 µm), cancellous stress (8.38755 µm), and dentin stress (46.38407 µm) were found to be significantly lower for RelyX Luting Plus cement with 80-µm cement space setting (group IId). The mean overall stress (78.65350 µm) was observed to be significantly lesser for RelyX Luting Plus cement with a 50-µm cement space setting (group IIc). The parameters of cortical stress (6.19105 µm) and cement stress (12.58820 µm) were significantly lesser for the G-CEM Link Ace cement with 50-µm cement space setting (group IIa), while cancellous stress (6.28051 µm) and periodontium stress (0.47517 µm) were significantly lesser for the G-CEM Link Ace cement with 80-µm cement space setting (group IIb).

When comparing study variables between PFM and zirconia crowns using G-CEM Link Ace cement and RelyX Luting Plus with both 50 and 80 µm, respectively, was done. The PFM crowns with G-CEM Link Ace 50 µm showed much less overall stress distribution compared to the PFZ crowns with both cements and cement space settings, respectively.

Discussion

Porcelain-fused-to-metal crowns have long been regarded as the gold standard for the restoration of damaged teeth.[12] One of its key drawbacks was its inability to transmit light.[13] All-ceramic crowns have been used for the past four decades as an alternativeto PFM crowns to overcome their esthetic limitations. The increased demand for metal-free restorations in the posterior region has increased due to their advantages in patient comfort and acceptability and superior mechanical properties.[14,15]

The RelyX Luting Plus cement is a resin-modified glass ionomer luting cement that releases fluoride and is radiopaque. It is used to cement metal, PFM, all-alumina, and all-zirconia restorations to implant abutments. The setting reactions for RelyX Luting and RelyX Luting Plus cement are remarkably comparable. For each system, two setting reactions to take place: A free radical polymerization of the pendant methacrylate groups of the polymer and HEMA, which is the true glass ionomer setting reaction, and an acid-base reaction between the fluoroaluminosilicate glass and the methacrylate functionalized polycarboxylic acid. Free radical polymerization is self-curing since it occurs without the requirement for light activation. An additional methacrylate reaction results in higher strength and lower limiting solubility without sacrificing adhesion or fluoride release. Because of this chemical property, the cement can be called resin-modified glass ionomer cement.[16,17]

For the luting of restorations, simplified self-adhesive resin types of cement have been created that can decrease the clinical steps needed for the luting process, minimize method sensitivity, and lessen postoperative sensitivity.[18] Furthermore, G-CEM Link Ace is a dual-curing, self-adhesive resin cement supplied in a two-barrel auto-mix syringe. It is intended for cementing all-ceramic, resin, and metal crowns and bridges, inlays, onlays, and posts. Also, G-CEM Link Ace offers the highest polymerization in self-setting mode and provides reliable results regardless of the type of prosthetic material being cemented.[19,20]

The width of the cement space affects both the internal gap dimension and the marginal gap and concluded that zirconia copings with a cement space set to 60 µm showed better marginal adaptation than copings with a cement space set to 10 and 30 µm[21]. May et al., studied the effect of cement thickness and bonding status on a feldspathic porcelain crown using 2D Multiphysics FEA and physical test and found that a well-fitted, bonded feldspar crown can withstand higher loads than an unbonded crown, but the bonding effect disappears under a large cement layer.[9]

According to the results from this study when comparisons were done between the two different restorative materials (PFM and PFZ

Table 2: Differences in study parameters between different combinations of cement and cement space settings under occlusal surfaces of PFM crowns

Parameter	*Group*	*N*	*Mean*	*Standard deviation*	*Standard error*	*95% Confidence interval*		*F-value*	*p-value*
						Lower	*Upper*		
Overall deformation	G-CEM 50 µm	7	0.18576	0.000426	0.000161	0.18537	0.18616	3.87	0.022*
	G-CEM 80 µm	7	0.18580	0.000002	0.000001	0.18580	0.18580		
	RelyX	7	0.18569	0.000003	0.000001	0.18568	0.18569		
	RelyX 80 µm	7	0.18545	0.000021	0.000008	0.18543	0.18547		
Overall stress	G-CEM 50 µm	7	74.52723	0.037441	0.014151	74.49260	74.56186	84722.5	<0.001*
	G-CEM 80 µm	7	78.65629	0.000227	0.000086	78.65608	78.65650		
	RelyX 50 µm	7	78.65261	0.001892	0.000715	78.65086	78.65436		
	RelyX 80 µm	7	78.65271	0.001251	0.000473	78.65156	78.65387		
Cortical stress	G-CEM 50 µm	7	5.85584	0.014984	0.005663	5.84198	5.86970	5440.47	<0.001*
	G-CEM 80 µm	7	6.28041	0.000393	0.000149	6.28005	6.28078		
	RelyX 50 µm	7	6.25932	0.000226	0.000085	6.25911	6.25952		
	RelyX 80 µm	7	6.28012	0.000016	0.000006	6.28010	6.28013		
Cancellous stress	G-CEM 50 µm	7	8.57299	0.037889	0.014321	8.53794	8.60803	162.71	<0.001*
	G-CEM 80 µm	7	8.38922	0.000162	0.000061	8.38907	8.38937		
	RelyX 50 µm	7	8.39432	0.000152	0.000057	8.39418	8.39446		
	RelyX 80 µm	7	8.38764	0.000076	0.000029	8.38757	8.38771		
Periodontium stress	G-CEM 50 µm	7	0.47433	0.003837	0.001450	0.47079	0.47788	0.435	0.73
	G-CEM 80 µm	7	0.47514	0.000003	0.000001	0.47513	0.47514		
	RelyX 50 µm	7	0.47547	0.000004	0.000001	0.47546	0.47547		
	RelyX 80 µm	7	0.47508	0.000011	0.000004	0.47507	0.47509		
Dentin stress	G-CEM 50 µm	7	36.25810	0.004582	0.001732	36.25386	36.26234	17118.11	<0.001*
	G-CEM 80 µm	7	46.84057	0.294919	0.111469	46.56782	47.11333		
	RelyX 50 µm	7	53.99176	0.000509	0.000193	53.99129	53.99223		
	RelyXx 80 µm	7	46.40261	0.002882	0.001089	46.39995	46.40528		
Cement stress	G-CEM 50 µm	7	12.53706	0.005910	0.002234	12.53159	12.54252	161527.5	<0.001*
	G-CEM 80 µm	7	13.47221	0.000248	0.000094	13.47199	13.47244		
	RelyX 50 µm	7	12.79009	0.000204	0.000077	12.78990	12.79027		
	RelyX 80 µm	7	13.62586	0.003579	0.001353	13.62255	13.62917		
Crown stress	G-CEM 50 µm	7	74.51747	0.004834	0.001827	74.51300	74.52194	1386919.8	<0.001*
	G-CEM 80 µm	7	78.65633	0.000269	0.000102	78.65608	78.65658		
	RelyX 50 µm	7	78.65064	0.007742	0.002926	78.64348	78.65780		
	RelyX 80 µm	7	78.63219	0.001633	0.000617	78.63068	78.63370		

*Significance; One-way ANOVA; $p \leq 0.05$ considered statistically significant

crowns) regardless of the cement thickness. The loading protocol followed in this study was according to previously conducted studies by Nakamura et al.[22]

After evaluating the obtained data about the different virtual spacer settings of 50 and 80 µm with PFZ crowns. The results indicate that overall deformation, cancellous stress, and dentin stress were found to be significantly lower for RelyX Luting Plus cement with an 80-µm cement space setting compared to 50 µm. Sulaiman et al.[18] noticed in their study that the clicker-hand mix version of RelyX RMGI (RelyX Luting Plus) and the automix version of GC Fuji RMGI types of cement have film thicknesses well over 100 µm. Liu et al. stated that the results of the numerical simulations also showed that there is an ideal thickness (roughly 90 µm) that can lower the stress level in all-ceramic crowns.[23] Finite element

Table 3: Differences in study parameters between different combinations of cement and cement space settings under occlusal surfaces of PFZ crowns

Parameter	*Group*	*N*	*Mean*	*Standard deviation*	*Standard error*	*95% Confidence interval*		*F-value*	*p-value*
						Lower	*Upper*		
Overall deformation	G-CEM 50 μm	7	0.18587	0.000082	0.000031	0.1858	0.18595	104.04	<0.001*
	G-CEM 80 μm	7	0.18577	0.000039	0.000015	0.18573	0.1858		
	RelyX 50 μm	7	0.18565	0.000036	0.000013	0.18562	0.18568		
	RelyX 80 μm	7	0.18542	0.00002	0.000008	0.18541	0.18544		
Overall stress	G-CEM 50 μm	7	78.65797	0.003941	0.001489	78.65433	78.66162	8.69	<0.001*
	G-CEM 80 μm	7	78.65701	0.000254	0.000096	78.65678	78.65725		
	RelyX 50 μm	7	78.6535	0.000465	0.000176	78.65307	78.65393		
	RelyX 80 μm	7	78.65379	0.000801	0.000303	78.65305	78.65453		
Cortical stress	G-CEM 50 μm	7	6.19105	0.113492	0.042896	6.08609	6.29602	3.87	<0.001*
	G-CEM 80 μm	7	6.28051	0.000223	0.000084	6.2803	6.28071		
	RelyX 50 μm	7	6.25914	0.000036	0.000014	6.2591	6.25917		
	RelyX 80 μm	7	6.27971	0.000316	0.00012	6.27941	6.28		
Cancellous stress	G-CEM 50 μm	7	8.39309	0.00454	0.001716	8.38889	8.39728	14.19	<0.001*
	G-CEM 80 μm	7	8.38892	0.00049	0.000185	8.38847	8.38937		
	RelyX 50 μm	7	8.39434	0.000049	0.000019	8.39429	8.39438		
	RelyX 80 μm	7	8.38755	0.000046	0.000017	8.38751	8.38759		
Periodontium stress	G-CEM 50 μm	7	0.47551	0.000058	0.000022	0.47545	0.47556	0.57	<0.001*
	G-CEM 80 μm	7	0.47512	0.000041	0.000015	0.47508	0.47516		
	RelyX 50 μm	7	0.47547	0.000004	0.000001	0.47546	0.47547		
	RelyX 80 μm	7	0.47576	0.00183	0.000692	0.47407	0.47745		
Dentin stress	G-CEM 50 μm	7	54.42253	0.005419	0.002048	54.41752	54.42754	175786.4	<0.001*
	G-CEM 80 μm	7	46.9509	0.000245	0.000093	46.95067	46.95113		
	RelyX 50 μm	7	53.97031	0.000867	0.000328	53.96951	53.97112		
	RelyX 80 μm	7	46.38407	0.00025	0.000094	46.38384	46.3843		
Cement stress	G-CEM 50 μm	7	12.5882	0.000458	0.000173	12.58778	12.58862	429341.6	<0.001*
	G-CEM 80 μm	7	13.41473	0.00017	0.000064	13.41457	13.41489		
	RelyX 50 μm	7	12.69101	0.001107	0.000418	12.68999	12.69204		
	RelyX 80 μm	7	13.53316	0.000276	0.000104	13.5329	13.53341		
Crown stress	G-CEM 50 μm	7	78.65483	0.002575	0.000973	78.65245	78.65721	1.002	0.409
	G-CEM 80 μm	7	78.65704	0.000162	0.000061	78.65689	78.65719		
	RelyX 50 μm	7	77.22453	3.781453	1.429255	73.72727	80.72179		
	RelyX 80 μm	7	78.65406	0.002281	0.000862	78.65195	78.65617		

*Significance; One-way ANOVA; $p \leq 0.05$ considered statistically significant

analysis study conducted by Rezende et al. results showed that a thicker cement space leads to higher stress concentrations in bilayer Y-TZP-based ceramic crowns. This study agrees and relates with the study conducted by Sulaiman et al. and Liu et al. that using the RelyX Luting Plus cement with the thicker cement space is more favorable with all ceramic crowns and this contradicts the results of the study by Rezende et al.[24]

After the analysis of the obtained data from this study, it was noticed that under different virtual spacer settings of 50 and 80 μm when PFM crowns with G-CEM Link Ace cement with 50 μm preferred to reduce stress in all the parameters while the cancellous stress was found to be significantly higher. It was observed that the stresses rise as cement thickness increases. While the studies done by Sangeetha et al. stated that there will be 2–4 times more stresses were found in the prosthesis and cement layer with an increase in cement thickness (100 μm). Thus, thinner film thickness favors the success of the prosthesis in withstanding stress as well as in preventing microleakage.[25]

This study had the following limitations. This study constructed 3D FEMs using standard anatomical data in the literature. However, the complex geometrical features of the teeth were simplified during the manual construction of the FEMs. In addition, several assumptions were made when designing the models. Since the stress distribution directly depends on the model design and the material properties assigned to each layer of the model, any inaccuracy can be directly reflected in the results.

In this study, influence of types of cement and cement thickness on stress distribution was analyzed. Further studies are required to evaluate the influence of porosities in the cement space settings and various structural modifications in the prosthesis on the stress distribution.

Conclusion

Within the limitations of this study, the following conclusions are drawn, that is, both the resin-modified glass ionomer cements and self-adhesive cements are used for both PFM and PFZ crowns. However, irrespective of the cement type PFM crowns are more favorable with the stress distribution to that of PFZ crowns and regardless of the cement thickness, PFM with G-CEM Link Ace and PFZ with RelyX Luting Plus showed significantly lower stress in all parameters.

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