Finite Element Analysis of Occlusal Veneer Restorations: Effect of Material Type and Bonded Substrate

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Abstract:

Objective: To evaluatestress distribution within and around lithium disilicate, zirconia and hybrid ceramic occlusal veneers bonded to dentin, dentin with prepared cavity and dentin with composite filling.

Materials and Methods Nine fresh extracted individual mandibular first molar were distributed into three equal groups (n=3) according to bonded substrate ,where group I lithium disilicate (L): LD, LC and LF subgroups, group II zirconia (Z): ZD, ZC and ZF subgroups, group III hybrid ceramic (H): HD, HC and HF subgroups, a computer aided design/manufacturing system was used. A dual cure, adhesive resin cement was used to bond all occlusal veneers to corresponding prepared teeth. FEA was carried out as well to evaluate the distribution of stresses.

Results: Different occlusal veneers preparation designs showed minor differences appeared by changing restoration materials in each model. Under vertical loading zirconia occlusal veneer showed the lowest deformation followed by lithium disilicateocclusal veneer and hybrid ceramics occlusal veneer showed the highest deformations. LF, ZF and HF subgroups and LD, ZD and HD subgroups occlusal veneer can be conservative and safe to use as a restoration to worn posterior teeth. Cement under zirconia restoration showed the lowest deformation followed by lithium disilicate and hybrid ceramics showed the highest deformations. The dentin for the model of LF, ZF and HF subgroup showed the lowest stresses then the model of LD, ZD and HD subgroup and the highest values appeared on model of LC, ZC and HC subgroup

Conclusions: Both models of the occlusal veneers displayed maximum stress within the safety factor when the designs were subjected to the standard biting force.

Key words: Occlusaal veneers, CAD/CAM, Finate Element Analysis.

Introduction

Occlusalveneer (thin onlay/overlay with non-retentive desing) are posterior extra cornal restoration requrinig a simpler and more intuitive perparation driven by inter-occlusal clearance and anatomical consideratio.Suchminmalistic restoration can be machine-milled from various restorative material to match the occlusalcontoure for extended, stable restablishment of the posterior occlusion. Minimally invasive, CAD/CAM posterior occlusal restoration are recommended alternative to traditional means of restoringn posterior occlusion. Overlays are extracoronal restorations that require easier and more intuitive planning, motivated by interocclusal clearing and morphological aspects. 1 Ultra-small back bonded overlays have been shown to be a conservative alternative to conventional onlays and full coverage of crowns for the management of chronic corrosive lesions. The main advantage of The occlusal veneers are the recovery of the masticatory feature, the full protection of the dental structure being a conservative choice for conventional onlays and the complete coverage of crowns.[2] Such benefits are the probability of predicting the final outcome of temporary restorations and ease of cementation.[3] It is very restrictive in planning as an enamel decrease of 0.5 mm less than is appropriate. 4 Although the occlusal veneer is weak, it is solid when bound to the tooth. 5 When the structure is loaded, the stress is produced within the substance. These stresses, their intensity, distribution and orientation depend not only on the geometry of the structure, but also on the design of the loading and the property of the materials.**[6]** The FEA arose from the need to solve complex problems of elasticity and structural analysis in civil and aeronautical engineering.[7] In dentistry; the special techniques of mathematical stress analysis are extremely restricted in scope and inadequate for dental structures of abnormal structural shape and complex loading.[8]

molecules including: CD31, CD34 and CD105 (endoglin) [(20,21)]. CD105 (endoglein) is a homodimeric cell membrane glycoprotein and is a component of TGF-β receptor complex. This marker is an indicator of endothelial cell proliferation and is up-regulated during angiogenesis [(22,23)]. Moreover, the expression of CD105 is one of the most conspicuous characteristics of newly formed blood vessels; Hence, it is more appropriate to determine MVD [(24)]. Several types of cells are associated with the development of cysts and tumors [(16)]. Among inflammatory cells, mast cells have been considered in growth and expansion of cysts. Mast cells are one of the defense cells of immune system with metachromatic cytoplasmic granules [(25,26)].

Recently,mast cells were recognized in the pathogenesis of more aggressive pathologic lesions [(27)]. Mast cells have an inhibitory role on the development of pathological lesions. However, stimulatory role of mast cells in the growth of pathological lesions is more prevalent and obvious than their inhibitory effect [(28)]. With respect to several roles of mast cells such as participation in inflammation, degradation of extracellular matrix and bone resorption[29], previous studies have identified mast cells in odontogenic cysts, but there were limited studies about the role of mast cells in the pathogenesis of odontogenic cysts [30]. There is a hypothesis that the more aggressive behavior of odontogenickeratocysts is related at least, partly, to distribution of mast cells. However, their pathogenesis and mechanism of expansion and enlargement have not been evaluated [31].

The aim of this study was to determine the density of microvessels and MCs in odontogenic cysts. Correlate the microvessel density with their corresponding mast cells density in the three types of cysts, in order to detect their possible role in the variable behavior of these odontogenic cysts.

Material and method :

A total of nine freshly extracted human mandibular first molar teeth with the average similarity in size, shape and root morphology (Figure 1). To standardize the size of the teeth chosen, a digital caliper has been used to determine the size of each tooth. Standard teeth dimension were in buccolingually width (10 ±1 mm), mesiodistally width (11 ±0.5 mm) and from cementoenamel junction to proximal cusp was (5 ±0.5 mm) Every teeth were examined during proper lighting to ensure the presence of caries, cracks or fractures. The root of each tooth was vertically enclosed in transparent epoxy resin blocks to facilitate handling the teeth during preparation, impression taking, bonding and cementation procedures. Before tooth preparation putty index was generated using impression product, the indices for all nine teeth undergoing preparation was incised buccolignually into equal halves by using scalable blades to guide preparation steps and evaluate the consistency of teeth reduction. A special milling machine (Marathon-103 SURVEYOR MARATHON 103,China) was used for standardized teeth preparation and a low speed motor (Ultimate 500, NSK, Japan) The assembly includes a traditional low-speed straight handpiece. (FX 65 Straghthandpice, NSK, Japan) (Figure 2) perpendicular to the surveyor platform.

Subgroups LD, ZD and HD preparation, Subgroups LC, ZC and HC Preparation and Bonded to dentin with filling composite all preparation were done by the same operator and performed as groups bonded to dentin with prepared cavity. Then the cavity was etched 9% hydrofluoric acid etching gel (N-ETCH IVoclarVivadent, Schaan, Liechtenstein) For 20 seconds as instructed by the manufacturer. The engraved surfaces were rinsed with water spray for 60 seconds and dried with oil-free compressed air for 30 seconds. (Figure 1-3) The milling machine (IMES-ICORE Coritec 250i touch, CAD/CAM Milling Germany) which has a computer controlled 5 axis simultaneous milling unit was used. The scanned prepared teeth were correlated to a virtual occlusal veneer restoration from lithium disilicate, hybrid ceramic blocks and zirconia blank with standardized cement space with 50 µm. To start the milling procedure, the type of lithumdisilicate, hybrid ceramic blocks and zirconia blank as well as the size were selected and confirmed with "OK" button. The selected hybrid ceramic and lithumdisilicate block size (14 mm). and zirconia (20mm).Cementation of ceramic occlusal veneer [illegible]hium disilicate and hybrid ceramic) were treated by 9.5% hydrofluoric acid (porcelain etchant,Bisco, USA) on the intaglio surface of ceramic occlusal veneers for 60 sec according to manufacturer's instruction. The fitting surface of the occlusal veneer should appear chalky white, without the presence of debris, white or glossy spots. The fitting surfaces of zirconia occlusal veneer of all groups were sandblasted according to manufacturer instruction with 50 µm alumina at a pressure of 60 psi (0.4 MPa) from 10 mm distance. All the occlusal veneer covered by one coat by porcelain silanized (Z-PRIME PLUS,Bisco,USA). Then dried with air syringe for 3-5 seconds following to the manufacture recommendation. The occlusal veneer was seated on corresponding tooth and held in place with light pressure. A customized loading device was used to apply a constant load of 1/2 kg parallel to the long axis of each tooth during cementation

Finite Element Analysis Test 3D digital models of mandibular first molars were constructed, one model for each group, the first model LD, ZD and HD, the second model LC, ZC and HC. and the third model LF, ZF and HF. Boolean and assembly of models' components took place on the finite element package (ANSYS version 16 ANSYS Inc, Canonsburg, PA, USA). Set of Boolean operations was used to generate cement layer of 40µm around the coping, in addition to create roots cavity inside bone on each restoration case model, The Final tooth geometry and models' parts from ANSYS screen (Figure 4). Three models were designed to simulate restoration of the occlusal veneer in clinical cases in order to recover the occlusal vertical dimension of patients with high occlusal wear associated with parafunctional habit or physiological processes such as erosion. Both substances used in this study were presumed to be homogeneous, isotropic and to possess linear elasticity, and their characteristics were indicated in Table 1. Each of the model components (bone, cement, restoration) was assigned to a material properties on the finite element package (ANSYS Workbench version 16 ANSYS Inc, Canonsburg, PA, USA).The parabolic tetrahedral element was used for meshing the model, that adequate mesh density was selected to insure results accuracy for the discrete model. Mesh density of all model components is presented in Table 2. illustrate cut sections on the three final models after meshing, final models components on ANSYS screen after meshing (Figure 5).

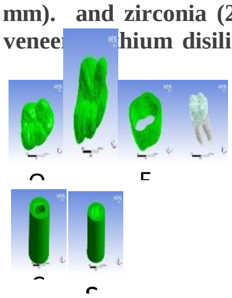

Figure 4. 3D

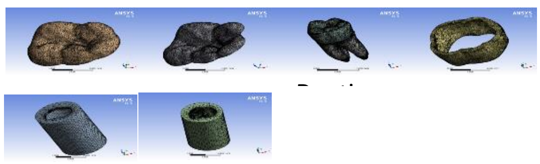

Figure 5. Meshing of the 3D digital models of

	Model #1		Model #2		Model #3	
Component	No of nodes	No of elements	No of nodes	No of elements	No of nodes	No of elements
Cortical bone	25.137	13.000	25.137	13.000	25.137	13.000
Spongy bone	89.372	53.632	89.372	53.632	89.372	53.632
Enamil	67.657	3.727	67.801	37.373	67.801	37.373
Dentine	177.813	104.402	174.802	102.171	174.802	102.171
Composite	-----	-----	439	60	-----	-----
Cement	72.923	36.255	67.792	33.820	60.034	29.787
Restoration	57.588	32.867	57.588	32.867	60.960	35.544

Table 2 Materials properties used in the analysis [8,7]

Material	Young's modules [GPa]	Poisson's ratio
Restoration (Hybrid ceramic)	34.5	0.24
Restoration (Lithium disilicate ceramic)	102.7	0.25
Restoration (Zirconia)	210.0	0.24
Cement (RESIN type, of 40µm)	8.3	0.35
Composite filling	21.0	0.25
Enamel	84.1	0.33
Dentin	18.6	0.31
Cortical bone	13.7	0.30
Cancellaus bone	1.37	0.30

Table 3 Mesh density

	Model #1		*Model #2*		*Model #3*	
Component	*No of nodes*	*No of elements*	*No of nodes*	*No of elements*	*No of nodes*	*No of elements*
Cortical bone	*25.137*	*13.000*	*25.137*	*13.000*	*25.137*	*13.000*
Spongy bone	*89.372*	*53.632*	*89.372*	*53.632*	*89.372*	*53.632*
Enamil	*67.657*	*3.727*	*67.801*	*37.373*	*67.801*	*37.373*
Dentine	*177.813*	*104.402*	*174.802*	*102.171*	*174.802*	*102.171*
Composite	*-----*	*-----*	*439*	*60*	*-----*	*-----*
Cement	*72.923*	*36.255*	*67.792*	*33.820*	*60.034*	*29.787*
Restoration	*57.588*	*32.867*	*57.588*	*32.867*	*60.960*	*35.544*

Results:

Comparison between finite element Results The finite element analyses on all models restored by the three tested materials and under both loading conditions showed stresses within physiological limits on bone with all tested models. compare maximum values total deformation and Von Mises stress on all parts of the studied models.

Restoration results comparisonoblique loading exert higher stresses on restoration than vertical one. On the other hand, total deformations showed opposite behavior that vertical loading caused less deformation than oblique ones. Minor differences appeared by changing restoration materials among the three restorations' designs. Whatever the restoration material, for the model LF, ZF and HF subgroup showed the lowest stresses then the model LD, ZD and HD subgroup and the highest values appeared on the model LC, ZC and HC subgroup. Under oblique loading and for the same restoration design, no significant was recorded. While, under vertical loading zircon restoration showed the lowest deformation followed by lithumdisilicate and hybrid ceramic showed the highest deformations.

Cement resultsoblique loading exert higher stresses on restoration than vertical one. On the other hand, total deformations showed opposite behavior that vertical loading caused less deformation than oblique ones. Minor differences appeared by changing restoration materials among the three restorations' designs. Whatever the restoration material, the cement for the model of LF, ZF and HF subgroup showed the lowest stresses then the model of LC, ZC and HC subgroup and the highest values appeared on the model of LD, ZD and HD subgroup. Under oblique loading and for the same restoration design, no significant was recorded. While, under vertical loading zirconia restoration showed the lowest deformation followed by lithium disilicateand hybrid ceramics showed the highest deformations..

Dentin results comparison oblique loading exert higher stresses on restoration than vertical one. On the other hand, total deformations showed opposite behavior that vertical loading caused less deformation than oblique ones. Minor differences appeared by changing restoration materials among the three restorations' designs. Whatever the dentin, for the model of LF, ZF and HF subgroup showed the lowest stresses then the model of LD, ZD and HD subgroup and the highest values appeared on model of LC, ZC and HC subgroup. Under oblique loading and for the same restoration design, no significant was recorded. While, under vertical loading zirconia restoration showed the lowest deformation followed by lithium disilicateand Hybrid ceramics showed the highest deformations**.**

Discussion*:*

Treatment of advanced wear patients is difficult. Big complications include potential damage to the teeth due to a tooth eruption (preserving dimension) and further reduction of the sound tooth structure to repair worn teeth, where there is a wide difference in the amount of reduction required for various restorations.[10] Conventional complete crowns may be produced in the case of worn dentures. However, in order to achieve a viable and aesthetic reconstruction, the application of such full-length crowns normally involves removing the additional tooth structure. In patients already experiencing significant loss of dental tissue, further destruction can compromise the long-term viability of the teeth[10]. A total of nine freshly extracted human mandibular first molar teeth with average similarity in size, shape and root morphology,standardize the size of the selected teeth to minimize possible variation and errors. Furthermore, the dentine and enamel surface for bonding are more accurate than on artificial teeth.[11] The prosthetic reconstruction depends not only on the resistance of the material to fracture, but also on the preparation of an appropriate template with a sufficient thickness of the material. Each phase in the dental preparation process requires careful attention to ensure the effectiveness of subsequent procedures.[12] Both samples were built using CAD/CAM technology that uses the ability to monitor the density and morphology of the restoration during the production process. It also made it possible to standardise the internal fit of the reconstruction, as well as the dimensions and physical characteristics of the restorative materials.[13] Occlusal veneers lured to dentin or composite substrates, increased fracture resistance. Recent study suggests a more prudent occlusal thickness for partial lithium-disilicate restorations of 1–1,2 mm[22]. Due to its excellent material properties, lithium disilicate glass ceramics have been the materials of choice for all-ceramic posterior restorations. [14] Zirconia the minimal forces which are required to form cracks within the material were 1100 N. This, it is assumed that these material are supposed to withstand high masticatory forces.[15] Also, zirconia have become the materials of choice for posterior restorations due to their superior mechanical properties.[14] The CAD/CAM composite is constructed from a restorative polymer under optimised process conditions to achieve a high level of cross-linking.[3] The occlusal veneer in hybrid ceramic shows an elastic modulus that resembles the dentin structure. The lowest chance of failure for the crown and the cement axis.[3] The minimal forces of hybrid ceramic were 800 N, which is in accordance to another study revealing failures in hybrid ceramic -crowns only at very high loads, thus it is assumed that these materials are supposed to withstand high masticatory forces.[15] In the current study all values of deformations and stresses appeared on all model components (cortical, spongy bone, dentin, enamel, composite and restoration materials) were within physiological limits under all cases of load application. The results in this study are in agreement with the finding in a study done by **Kotb et al2019**[16]Full chew strengths in the posterior molar area range from 200 to 540 N. In bruxers, these values rise dramatically to a maximum of 800 N. As shown in our current study, minor differences appeared by changing restoration materials in each model. Whatever the model is the used restoration materials showed equivalent (very close to each other) values of deformations and stresses under similar conditions The results in this study are in agreement with the finding in a study done by**Sasse et al 2015**[10],**Al-khali et al 2017**[17]Data on the performance of thinner CAD/CAM among all ceramic occlusal veneers and the effect of the new design on the performance of these restorations is still scarce in the literature, especially with regard to the analysis of finite elements and the distribution of stress.As shown in our current study whatever the loading condition, negligible differences were recorded on cement deformations by changing restoration materials. Such differences may be referred to restoration material stiffness (related to modulus of elasticity). As the restoration material stiffness increased the cement showed less deformations due to better load distribution. The results in this study are in agreement with the finding in a study done by **Ma et al 2013**[14] the load-bearing potential approaching monolithic zirconia was investigated as a result of a smaller elastic modulus mismatch here between lithium disilicate and its support permanent teeth relative to zirconia. It has been shown that cement has a much weaker modulus compared to enamel, the addition of any cement layer can have a detrimental effect on ceramic load bearing capability..

Conclusion: Within the limitations of this in vitro study, the following conclusions could be drawn:

- The bonded to dentin with filling composite preparation design can be conservative and safe to use as a restoration to worn posterior teeth.
- All three occlusal veneers preparation designs showed stress values within the safety factor when subjecting the models to the average biting force, throughout the models.

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