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Stress and fatigue analysis of fracture in dental veneers fabricated from different materials using finite element analysis

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Abstract
Introduction: Ceramic veneers are a conservative and highly aesthetic restorative option widely used in anterior dentistry. Despite their clinical popularity, long-term success depends on the mechanical behavior of the restorative material under functional and parafunctional loads.
Objective: To evaluate stress distribution and fatigue resistance of dental veneers fabricated from monolithic zirconia, lithium disilicate, and feldspathic ceramic using three-dimensional finite element analysis.
Materials and Methods: A maxillary central incisor prepared for a veneer was digitally modeled and restored with veneers of identical geometry fabricated from the three materials. Static oblique loading and cyclic fatigue loading were applied to simulate clinical conditions. Von Mises stress, total displacement, and fatigue life were assessed.
Results: Monolithic zirconia demonstrated the lowest stress concentration, minimal displacement, and the longest fatigue life. Lithium disilicate exhibited intermediate performance, while feldspathic ceramic showed the highest stress values and the lowest fatigue resistance.
Conclusion: Material selection significantly influences the biomechanical performance of veneers. Monolithic zirconia showed superior resistance under static and cyclic loads, suggesting its indication for patients with high functional demand.

Keywords: Dental veneers, finite element analysis, dental ceramics, fatigue resistance, biomechanics, aesthetic restorations

Introduction
Dental veneers represent a cornerstone of contemporary restorative and aesthetic dentistry. Their minimally invasive nature allows modification of tooth color, shape, and alignment while preserving enamel structure, which is essential for reliable adhesive bonding. Advances in ceramic materials and adhesive techniques have significantly expanded the clinical indications of veneers, making them suitable for both aesthetic enhancement and functional rehabilitation.
Despite favorable long-term survival rates, veneer failures such as fracture, chipping, and debonding continue to be reported. These failures are frequently associated with mechanical overload, parafunctional habits, unfavorable occlusal schemes, and intrinsic limitations of restorative materials. Anterior teeth are subjected to complex biomechanical forces during mastication, protrusion, and lateral movements, generating oblique stresses that concentrate at the incisal edge and cervical margin of veneers.
Ceramic materials commonly used for veneers differ significantly in elastic modulus, flexural strength, and fracture toughness. Feldspathic ceramic offers superior translucency but limited mechanical resistance. Lithium disilicate provides a balance between aesthetic quality and mechanical strength, whereas monolithic zirconia exhibits outstanding mechanical properties with improving translucency. Understanding how these materials behave under static and cyclic loading is essential for optimizing material selection and enhancing clinical longevity. Finite element analysis (FEA) is a computational method that enables detailed assessment of stress distribution and deformation in complex structures. In dental research, FEA has been extensively used to evaluate restorations and dental tissues under simulated clinical conditions. The aim of this study was to compare the stress distribution and fatigue resistance of veneers fabricated from monolithic zirconia, lithium disilicate, and feldspathic ceramic using three-dimensional finite element analysis.

Materials and Methods
This in silico experimental study was conducted using three-dimensional finite element analysis. A digital model of a maxillary central incisor was generated from a high-resolution intraoral scan of a healthy adult subject. The tooth was prepared virtually following a conservative veneer preparation with a chamfer finish line and a uniform facial reduction of 0.5 mm.
A veneer restoration with identical geometry was designed and duplicated for each evaluated material: monolithic zirconia, lithium disilicate, and feldspathic ceramic. All materials were assumed to be homogeneous, isotropic, and linearly elastic. Material properties were obtained from validated literature sources.
The finite element mesh consisted of second-order tetrahedral elements, with refinement applied to the incisal and cervical regions. Mesh convergence analysis was performed to ensure numerical stability. Boundary conditions simulated perfect adhesion between the veneer and tooth substrate.
Static oblique loading was applied to the incisal edge at a 30-degree angle to simulate functional contact. Cyclic loading was also applied to evaluate fatigue behavior, representing repetitive masticatory forces over time. Von Mises stress, total displacement, and fatigue life were calculated for each material.

Results
The finite element simulations revealed distinct differences in biomechanical behavior among the evaluated materials.

Monolithic zirconia demonstrated the lowest stress concentration and minimal displacement under static loading. Lithium disilicate exhibited intermediate stress and displacement values, while feldspathic ceramic showed the highest stress concentration and greatest deformation. Fatigue analysis further emphasized these differences. Monolithic zirconia presented the longest fatigue life, lithium disilicate showed moderate resistance, and feldspathic ceramic exhibited early crack initiation under cyclic loading.

Discussion

The findings of this study highlight the significant influence of material properties on the biomechanical performance of dental veneers. The superior performance of monolithic zirconia can be attributed to its high elastic modulus and fracture toughness, which allow effective stress distribution and resistance to crack propagation. Lithium disilicate demonstrated balanced behavior, combining mechanical reliability with favorable aesthetics.

In contrast, feldspathic ceramic showed limited resistance to both static and cyclic loading, explaining its higher fracture incidence reported in clinical studies. These results support the use of zirconia or lithium disilicate in patients with higher functional demands. Although finite element analysis provides valuable predictive insight, clinical validation remains essential.

Conclusion

Material selection plays a critical role in the mechanical performance of dental veneers. Monolithic zirconia exhibited superior stress distribution and fatigue resistance, followed by lithium disilicate, while feldspathic ceramic showed the least favorable performance. Both aesthetic and functional factors should guide clinical decision-making to ensure long-term success.

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