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Stress concentration point in feldspar and lithium disilicate veneers, using finite element methods

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Abstract

This study aimed to evaluate the stress concentration point in lithium disilicate and feldspar dental veneers using finite element techniques. Three-dimensional models were developed from ivorina teeth in a central incisor, considering the parameters of a standard restoration for an ideal thickness for the material. The simulation was performed under functional loads (174.6 N–220.24 N) and clinically representative conditions. The results indicated that lithium disilicate exhibited a maximum stress concentration of 268.4 MPa, with a safety factor of 1.78. In contrast, feldspathic ceramic exhibited maximum stresses of 127.2 MPa, with a lower safety factor (1.26). The stress distribution pattern between the two materials was different; the disilicate showed greater concentration at the incisal-cement junction, while the feldspar exhibited stresses dispersed toward the incisal third. The results show that disilicate offers better mechanical strength and lower deformation thanks to its better stress distribution compared to feldspathic ceramics. This study offers relevant information for planning aesthetic treatments with dental veneers according to the specific characteristics of each material.

Keywords: Lithium disilicate, feldspar, dental veneers, ceramics, fracture point

Introduction

The modification of the appearance of teeth during filming in 1930 through the use of restorations in the anterior sector gave rise to what would later be called dental veneers, which, with the passage of time and the development of adhesive techniques accompanied by a correct design and preparation protocol, are destined to remain in the oral environment for several years without losing their characteristics. (Edelhoff *et al*., 2018). Since their origins, veneers have been used to restore the vestibular, incisal and part of the proximal surfaces of teeth that require aesthetic restorations (Assaf *et al*, 2023) [12].

Veneers can be made of different materials and are used in different clinical situations, for example, in cases where color changes in non-vital teeth do not respond adequately to whitening treatments, pigmentation due to the use of tetracyclines, excessive staining due to fluorosis, amelogenesis imperfecta, and they can also be used in cases where there are dental fractures. (El- Mowafy, El- Aawar, El- Mowafy, 2018) [2]. The popularity of dental veneers is due to the fact that it is a minimally invasive and highly aesthetic treatment, which provides excellent biocompatibility with periodontal tissues and has the advantage of providing color stability over time, obtaining better results than direct resin veneers (Gresnigt, *et al*., 2021) [11]. Dental porcelains have great aesthetic results, with feldspar being one of the most used materials for making ceramic laminates in the anterior sector (Almeida, Oliveira & Caldas 2020) [9].

The disilicate was introduced to the market in 1998 under the name IPS Empress 2 by the company Ivoclar. Vivadent, which was modified in 2005 into two variants and renamed IPS e.max Press and IPS e.max CAD, being the CAD version of disilicate, can be machined for the manufacture of restorations, because when found in metasilicate it does not have much hardness. (Zarone, *et al*., 2019) [7] To obtain the disilicate, it must be crystallized using an oven at 840 ° C for 25 minutes, in this way different advantages of the material can be obtained, including its resistance which is above 360 Mpa. (Abad *et al*., 2021). Thanks to its aesthetic and mechanical properties, lithium disilicate has various clinical applications, among which its use in aesthetic veneers, inlays, onlays, overlays, crowns and 3-unit fixed prostheses in the anterior sector stands out (Abdulrahman *et al*., 2021) [3]. From a clinical point of view, for a restorative treatment to be considered successful, it must not only meet aesthetic requirements, but must also provide masticatory resistance without failure (AlMashaan Aldakheel, 2022) [10].

During the Crystallization stage the disilicate contains a volume of 70% of 1.5 micron crystals, which allows to increase its resistance and it is important to take into account that the cooling process can modify the characteristics of the material, for example, a restoration subjected to 2 or more crystallization cycles can alter the optics of the material becoming opaque, therefore it is of vital importance to take into consideration the crystallization cycles to which the material is subjected during its laboratory phase to avoid later problems (Li, Chow, & Matinlinna, 2014).

Feldspathic ceramics, compared to disilicate, offer a more aesthetic and natural result due to their degree of translucency, in addition to being less invasive in their preparation (Sorin, *et al*. 2022). Among the biomechanical properties offered by feldspathic ceramics is a flexural strength of 62 to 90 Mpa, compressive strength 90 to 120 Mpa (Alghazzawi *et al*, 2022) [15]. Due to their flexural strength, there is no significant difference.

Zlatanovska *et al*., 2019 [13], mention that the concentration of stress in dental veneers depends on the type of preparation and the material they are made of. It is essential to keep in mind that several studies indicate that the highest stress index is found on the incisal edge of the veneers and very rarely in the marginal area. Another factor predisposing to fracture in restorations is the masticatory force in the incisor sector, which ranges between 220.24 N in men and 174.6 N in women (Curequeo *et al*., 2015).

The different materials throughout history that have been used for the purpose of making ceramic laminates are leucite and fluorapatite-based ceramics, which can provide a resistance around 100 MPa, a considerably lower resistance if we compare it with lithium disilicate which has a resistance of 360 MPA but provides better aesthetic characteristics, which is the main objective that clinicians seek when performing aesthetic treatments in the anterior sector (Al-Ali, Khalifa *et al*., 2023) [5].

The clinical success of feldspar restorations lies in a correct diagnosis and technique in order to obtain an aesthetic and functional result, taking into account that during the preparation for veneers the wear must be controlled and there are several techniques to control wear, including the use of a Mock up to prevent excessive or incorrect reduction or use of silicone nuances. (Tuzzolo Neto *et al*., 2018) [6] Against the above, this study aims to compare the starting point of fracture and the force that causes it, of feldspar and disilicate used in the manufacture of dental veneers, through simulation through finite elements.

Methodology

An experimental, comparative, cross-sectional and *in vitro* study was developed using computational simulation based on the finite element method (FEM) to analyze the stress concentration in dental veneers made of feldspathic ceramics and lithium disilicate.

Preparation and Digitization of Models

ivorine central incisors were selected as dental substrates due to their morphological similarity to human teeth, making them a valid alternative for *in vitro* studies (Tuzzolo Neto *et al*., 2018) [6]. The preparation of the pieces was carried out by a uniform reduction of 0.5 mm on the vestibular surface, following the minimally invasive clinical protocol for the placement of ceramic veneers (Gresnigt *et al*., 2021) [11]. This controlled wear was executed with three-wheel diamond burs to mark wear grooves and a round-tipped truncated cone bur to mark a slight chamfer and bevel finishing line on the incisal edge. In order to control the revolutions of the carving handpiece, an electric motor with a multiplication ratio of 1:5 was used, under continuous irrigation in order to avoid thermal alterations in the substrate.

mock-up silicone condensation guides were used, previously designed with Zetalabor condensation silicone from Zhermack. This procedure allowed standardizing the amount of tissue removed and guaranteed a uniform thickness in future restorations, thus reducing biomechanical variables during the analysis (Tuzzolo Neto *et al*., 2018; Edelhoff *et al*., 2018) [6].

Once the preparation was completed, the tooth was polished with the Shofu Super-Snap system following the sequence recommended by the manufacturer (medium violet, fine green, super fine red) at 10,000 rpm, eliminating irregularities and creating a homogeneous surface. After polishing, the tooth was digitized using a high-precision SHINING 3D® scanner, capable of capturing morphological details with micrometric accuracy. STL (Standard Tessellation) files were generated. Language), which contain the three-dimensional geometry of the carved surfaces. These files were then converted to the STP (Standard for the Exchange of Product model data), compatible with computer-aided simulation (CAE) software. This conversion was essential to enable the integration of the geometric model into the finite element analysis environment, where stress concentrations were evaluated under different loading conditions (Li, Chow, & Matinlinna, 2014).

This digitization and conversion process guarantees the geometric fidelity of the veneers, which is a crucial step in studies that seek to correlate structural parameters with simulated mechanical behavior (Zarone *et al*., 2019) [7]. Furthermore, the use of CAD/CAM technology ensures the reproducibility of restorative designs and allows for rigorous control of experimental variables.

Fig 1 Zetalabor silicone matrix for calibration of the wear of the vestibular and incisal surface of tooth 11 of ivorina

Fig 2: Final carving of ivorine tooth 11 prior to scanning with the SHINING 3D® scanner.

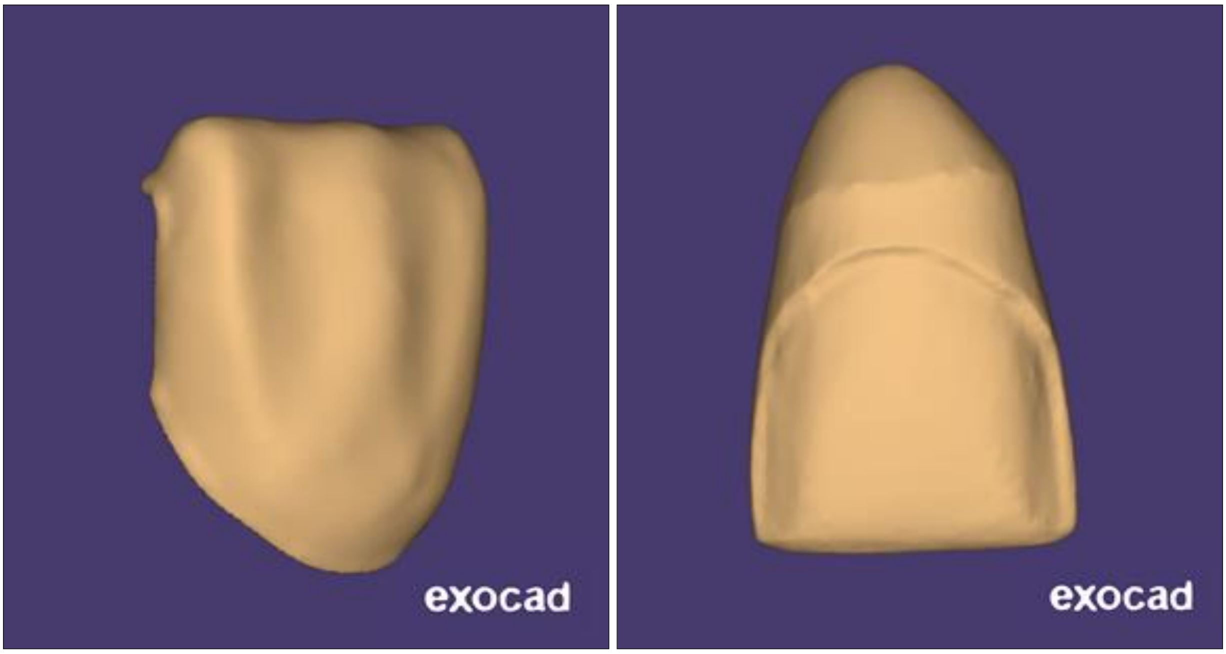

Fig 2EXOCAD® veneer design following the minimum thickness parameters of the restorative material.

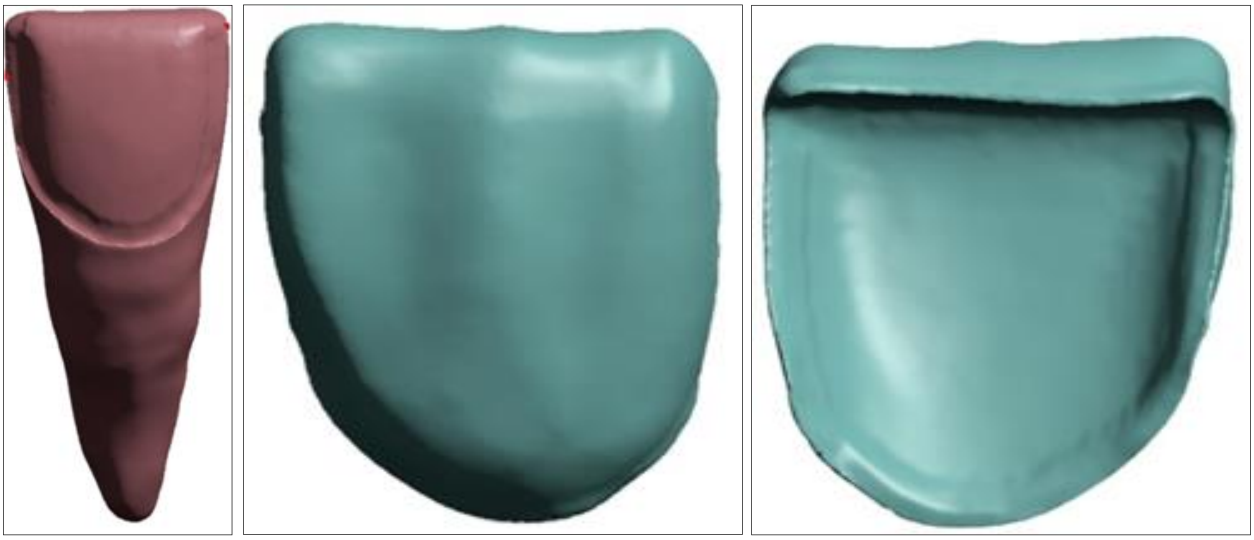

Fig 3 Geometric Model of Veneers

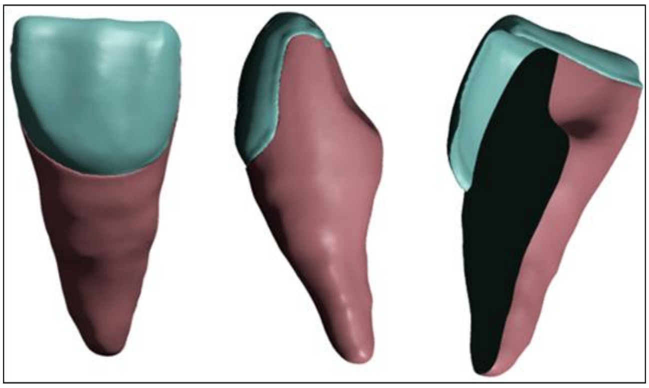

Fig 4 Integration of the final model

Design and Simulation in CAD/CAE

The restorations were designed using EXOCAD® software, recognized for its precision in planning dental prostheses from scanned data. In this CAD (Computer-Aided Design) environment, differentiated veneers were generated according to the restorative material: feldspathic ceramic and lithium disilicate. The morphology of the restorations was adapted to the anatomical pattern of the substrate, maintaining a uniform thickness in accordance with the previously prepared preparation (Almeida, Oliveira & Caldas, 2020) [9].

Once the initial design was obtained, the files were processed in Meshmixer® (Autodesk Inc.), a 3D manipulation tool that allowed for fine topological adjustments. This software was used to optimize the geometry, eliminate mesh imperfections, and prepare the models for subsequent analysis in the CAE environment. In this phase, smoothing, remeshing, and geometric integrity verification algorithms were applied to ensure surface continuity, a critical aspect in mechanical behavior simulations (Li, Chow, & Matinlinna, 2014).

The mechanical simulation was performed using Computer-Aided Engineering (CAE) software with finite element analysis (FEA) capabilities. The 3D models were imported in STP format, where the contacts between the ceramic restoration and the underlying tooth were defined, considering fully bonded bonds. This definition is critical, as it directly influences stress transmission in the restorative system (Zarone *et al*., 2019) [7].

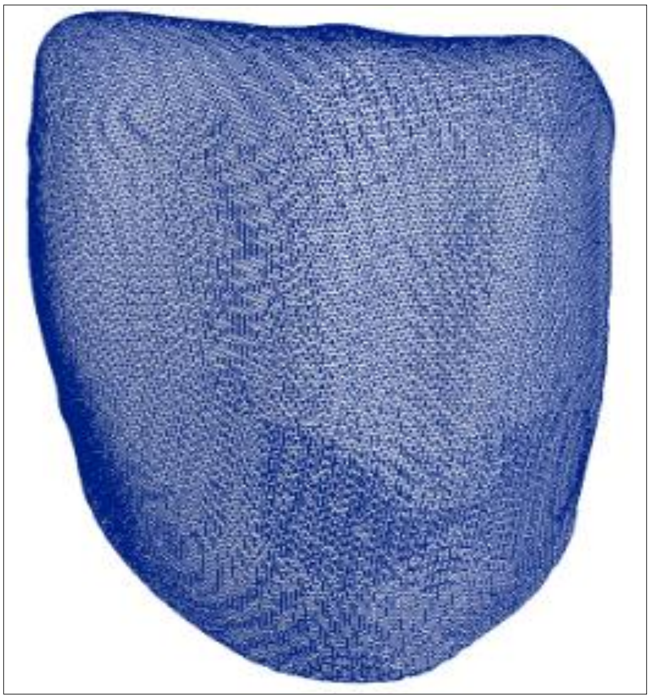

Fig 5 Solid mesh of the previously designed veneer

In the CAE environment, specific boundary conditions were assigned that replicate clinical behavior, and surface contact configurations were established that reflect the adhesive behavior between the veneer and the substrate. This approach seeks to accurately reproduce the biomechanical response of restorations to functional loads, facilitating quantitative analysis of stress concentrations and potential failure zones (Abad- coronel *et al*., 2021) [8].

Assignment of Mechanical Properties

To ensure a realistic and reliable simulation in the finite element analysis, each three-dimensional model was assigned specific mechanical properties according to the type of restorative material: lithium disilicate and feldspathic ceramic. The parameters considered included the modulus of elasticity (E), tensile strength, compressive strength, and Poisson's ratio (ν). These values were extracted from systematic reviews, *in vitro* experimental studies, and manufacturers' data sheets, ensuring representativeness and currency of the data used (Almeida *et al*., 2020; Abad- Coronel *et al*., 2021; Al-Ali *et al*., 2023) [5, 8, 9].

Below is a comparative summary of the properties assigned to each material in the CAE environment:

Table 1 Mechanical Properties of the Material

Mechanical Property	Lithium Disilicate	Feldspathic Ceramics
Modulus of Elasticity (E)	95 – 105 GPa	60 – 70 GPa
Tensile Strength	300 – 400 MPa	60 – 75 MPa
Compressive Strength	> 800 MPa	90 – 120 MPa
Flexural Strength	360 – 400 MPa	62 – 90 MPa
Poisson's ratio (ν)	0.22 – 0.25	0.21 – 0.23
Vickers hardness	580 – 620 HV	460 – 500 HV
Density	2.4 – 2.6 g/cm³	2.3 – 2.4 g/cm³

These properties were essential for simulating the structural behavior of each restoration under functional loads, allowing for results representative of their clinical performance. The significant differences in strength and stiffness between the two materials directly influence stress concentrations and the location of potential fracture zones.

Application of Charges and Boundary Conditions

In the computational simulation, loading and boundary conditions reproducing the clinical environment of the anterior sector were incorporated, with the objective of evaluating the biomechanical behavior of veneers made of lithium disilicate and feldspathic ceramic. Vertical loads of physiological magnitude, directed perpendicular to the incisal edge, were applied to the palatal surface of the restorations. These loads were determined based on reported values of maximum bite force in central incisors, ranging from 174.6 N to 220.24 N, representative of differences between sexes (Curiqueo *et al*., 2015) [14].

The application region was defined as a 1 mm² circular surface centered on the middle third of the incisal edge, an area identified as critical due to its susceptibility to fracture under load (Zlatanovska *et al*., 2019) [13]. This condition allowed for accurate simulation of the functional impact during mastication, generating a stress pattern similar to that observed clinically.

Boundary conditions were applied to the tooth root, restricting all degrees of freedom to simulate natural bone support, allowing for proper stress distribution in the restorative system (Edelhoff *et al*., 2018). In addition, a 50 µm cement joint was defined between the veneer and the dental substrate, modeled as a *bonded* contact, representing perfect adhesion with no relative slippage, consistent with current adhesive cementation protocols.

The analysis was carried out under controlled environmental conditions, considering a relative humidity of 97% and a constant temperature of 37°C, to faithfully replicate the intraoral environment.

Table 2 Environmental Conditions

Parameter	Value / Condition	Description
Magnitude of applied load	174.6 N – 220.24 N	Vertical force simulating incisal function (Curiqueo *et al*., 2015) [14]
Load application area	1 mm²	Palatal area of the incisal edge
Movement restriction zone	Root of the tooth	All degrees of freedom restricted
Type of veneer-tooth bond	Bonded	50 µm cement joint
Thickness of the cement layer	50 µm	According to standardized clinical protocol
Simulated ambient temperature	37 °C	Intraoral physiological condition
Relative humidity of the simulated environment	97%	Simulation of a saturated oral environment

This set of parameters allowed for the establishment of a robust and clinically representative mechanical model, facilitating the accurate evaluation of the structural behavior of ceramic restorations under real-life functional conditions.

Conclusion

Finite element analysis revealed significant differences in the mechanical behavior of lithium disilicate and feldspathic ceramic veneers under simulated occlusal loading. Lithium disilicate veneers exhibited higher mechanical strength, reflected in higher stress concentrations than their feldspathic counterparts, but with lower strain and displacement levels. Furthermore, they exhibited a higher safety factor and more concentrated stress distribution, suggesting greater structural rigidity. In contrast, feldspathic ceramic veneers exhibited more flexible behavior, with greater deformation and more dispersed stress distribution, which could translate into greater susceptibility to structural failure in critical areas. Overall, the results support the use of lithium disilicate as a more favorable option in clinical situations demanding greater strength and durability.

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