

Research Article



Influence of thickness and incisal extension of indirect veneers on the biomechanical behavior of maxillary canine teeth

Victória Luswarghi Souza Costa, João Paulo Mendes Tribst ,
Eduardo Shigueyuki Uemura, Dayana Campanelli de Moraes,
Alexandre Luiz Souto Borges

Department of Dental Materials and Prosthodontics, São Paulo State University (UNESP), Institute of Science and Technology, São José dos Campos, SP, Brazil



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Costa VLS, Tribst JPM, Uemura ES, Moraes DC,
Borges ALS

*Correspondence to

João Paulo Mendes Tribst, DDS

PhD Student, Department of Dental
Materials and Prosthodontics, São Paulo State
University (UNESP), Av. Eng. Francisco José
Longo, 777 Jardim São Dimas, São José dos
Campos, SP, Brazil.
E-mail: joao.tribst@ict.unesp.br

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ABSTRACT

Objectives: To analyze the influence of thickness and incisal extension of indirect veneers on the stress and strain generated in maxillary canine teeth.

Materials and Methods: A 3-dimensional maxillary canine model was validated with an *in vitro* strain gauge and exported to computer-assisted engineering software. Materials were considered homogeneous, isotropic, and elastic. Each canine tooth was then subjected to a 0.3 and 0.8 mm reduction on the facial surface, in preparations with and without incisal covering, and restored with a lithium disilicate veneer. A 50 N load was applied at 45° to the long axis of the tooth, on the incisal third of the palatal surface of the crown.

Results: The results showed a mean of 218.16 μ strain of stress in the *in vitro* experiment, and 210.63 μ strain in finite element analysis (FEA). The stress concentration on prepared teeth was higher at the palatal root surface, with a mean value of 11.02 MPa and varying less than 3% between the preparation designs. The veneers concentrated higher stresses at the incisal third of the facial surface, with a mean of 3.88 MPa and a 40% increase in less-thick veneers. The incisal cover generated a new stress concentration area, with values over 48.18 MPa.

Conclusions: The mathematical model for a maxillary canine tooth was validated using FEA. The thickness (0.3 or 0.8 mm) and the incisal covering showed no difference for the tooth structure. However, the incisal covering was harmful for the veneer, of which the greatest thickness was beneficial.



Keywords: Dental veneer; Finite element analysis; Prosthesis design

INTRODUCTION

Over the years, the demand for aesthetic improvements has increased, as has the demand for aesthetic veneers [1]. Anterior teeth may receive indirect veneers to correct defects such as color modifications and shape abnormalities [2]. Veneers have emerged as an alternative to full crowns [3], since they remove little to no dental structure [4] and minimize the risk of endodontic complications attributed to full-crown preparations [5]. In contrast, approximately 63% to 73% of the healthy dental structure is removed when a full-crown preparation is performed [6]. For this reason, aesthetic veneers have become a favorable

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ORCID iDs

João Paulo Mendes Tribst 
<https://orcid.org/0000-0003-2627-8628>
Alexandre Luiz Souto Borges 
<https://orcid.org/0000-0002-5707-7565>

alternative because they conserve a greater amount of healthy dental structure (only about 3% to 30% of the structure is removed), and the enamel adhesion is more reliable [4]. The risk of failure for dentin adhesion is higher [7], so the minimum possible thickness should be used to obtain aesthetically appealing results and adequate resistance for restoration durability [4].

Despite the aesthetics and functional success achieved by full-crown treatment, failure may be caused by a fracture in the prosthetic piece [7], as well as for other reasons. More conservative preparations for veneers may be stronger when restricted to the facial surface close to unprepared teeth [8], although this results in thinner restoring material at the incisal margin [9]. The IPS e.Max Press ceramic (Ivoclar Vivadent, Schaan, Liechtenstein) was developed with a structural resistance over 440 MPa [10]. It can be produced through 2 durable manufacturing methods: pressing or machining [11]. After crystallization, lithium metasilicate crystals are transformed into lithium disilicate crystals (70% of the volume), which are responsible for the material's high resistance [12].

The dental preparation influences the durability, color, translucency, and tone of the ceramic restoration, as it determines the contour from inside the surface and the thickness of the ceramic piece. During the preparation of the cervical third, the gingival margin of the veneer must be lightly subgingival for the anterior teeth, as no difference is found regarding healthy and gingival contours when compared to supragingival margins [13]. For the incisal margin, modifications may be made; in a 'window' preparation, there is greater conservation of enamel structure (resulting in a visible line between enamel, cement, and ceramic), while in a 'feather' preparation, the veneer extends over the incisal area of the facial surface. Furthermore, in bevel preparations, the incisal region is completely covered, and in the 'overlap' preparation (**Figure 1**), the incisal third of the palatal surface is covered [14]. The choice of the veneer extension type in the incisal third is generally associated with the desired aesthetics, not the resistance of the restoration [15].

Finite element analysis (FEA) enables predictions of the stress concentration on structures (in the dental remnant, prosthetic element, and adhesive interface) by means of a quantitative computer simulation, thus providing knowledge about possible fracture origin areas [16,17]. Previous studies have reported divergences between FEA results and those of prospective clinical studies; when compared to an incisal shoulder edge, the palatal chamfer showed more harmonic stress distribution [18] and better resistance to fatigue [19] when tested in FEA, but this difference was not clinically verified [20]. Because of such divergences, it was suggested that quantitative models should be validated prior to stress concentration evaluations [21]. The strain gauge is currently a tool that enables measuring microstrain in

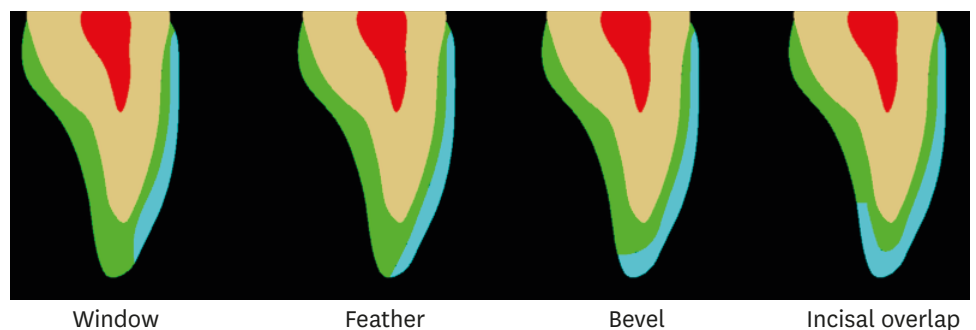


Figure 1. Illustration of the window, feather, bevel, and overlap preparations of ceramic veneers.

the dental element under loading in both *in vivo* [5] and *in vitro* studies [22,23]. It consists of sensors fixed to a dental surface capable of recognizing the generated deformation through a process analogical to that of a digital information converter.

This study aimed to validate a 3-dimensional (3D) model of a maxillary canine tooth and to analyze the stress generated when the tooth underwent different types of preparations for ceramic veneers with and without incisal covering with 2 different thicknesses through 3D FEA. The first null hypothesis was that different preparation designs would not influence the stress concentration, and the second null hypothesis was that the thickness would not influence the stress concentration.

MATERIALS AND METHODS

Preparation of specimens

The Ethics Committee (Institute of Science and Technology – UNESP) approved this study under the review protocol approval number 0713616.3.0000.0077. Eight extracted canine teeth were collected, and it was ensured that they did not present caries, restorations, or wear on the cusp tip that could modify their anatomy. Teeth were stored in saline solution for 30 days. The following dimensions of the teeth were measured using a pachymeter: mesiodistal width (10.17 ± 0.58 mm), cervico-occlusal height (7.2 ± 0.58 mm), and tooth length (24.3 ± 1.2 mm).

The teeth were marked 2 mm below the cemento-enamel junction, and the root portion apical to demarcation was inserted in fused No. 7 wax, creating enough thickness to simulate the periodontal ligament space. The teeth were inserted in a sufficient amount of polyurethane resin (Polyurethane F160, Axson, Cergy, France) to cover the entire root portion until 2 mm from the cemento-enamel junction. A polyether adhesive (3M ESPE, Irvine, CA, USA) was applied over the root portion and over polyurethane. A sufficient amount of polyether (Impregum Soft, 3M ESPE) was proportioned to fill the gap left by the removed wax, and each tooth was repositioned using a dental delineator.

The facial surface of the teeth was marked to locate the central region and then cleaned with isopropyl alcohol. Strain gauges (KFG-1120-C1-11L1M2R, KYOWA electronic instruments Co., Ltd., Tokyo, Japan: resistance, $119.6 \pm 0.4\% \Omega$; gauge length, 1 mm; gauge factor, $2.08\% \pm 1.0\%$) were attached with cyanoacrylate adhesive (Super Bonder Loctite, São Paulo, SP, Brazil) [23]. The wires of the strain gauges were welded to a circuit board on which copper wires were also welded, and then attached to a terminal to capture the information generated by the devices (Model 5100B Scanner - System 5000, Instruments Division Measurements Group, Inc., Raleigh, NC, USA). A multimeter was used to verify the absence of electric terminal defects and the soldering points of the wires (Minida ET 2055, Minida, São Paulo, SP, Brazil).

In vitro loading

The samples were placed on a steel base inclined at 45° , and a blunt tip of 2 mm in diameter was used to apply a load of 50 N for 20 seconds (**Figure 2**). With the tip touching the palatal surface in the incisal third at a single point measuring 2 mm in diameter, the generated microdeformations were interpreted by software (StrainSmart, Vishay Measurements Group, Raleigh, NC, USA).

Three-dimensional modeling

A maxillary canine tooth was scanned (Figures 2 and 3) using stereolithography and exported to CAD software (Rhinoceros 5.0, SR8, McNeel North America, Seattle, WA, USA), in which the external structures were modeled based on the mean values measured in an *in vitro* study.

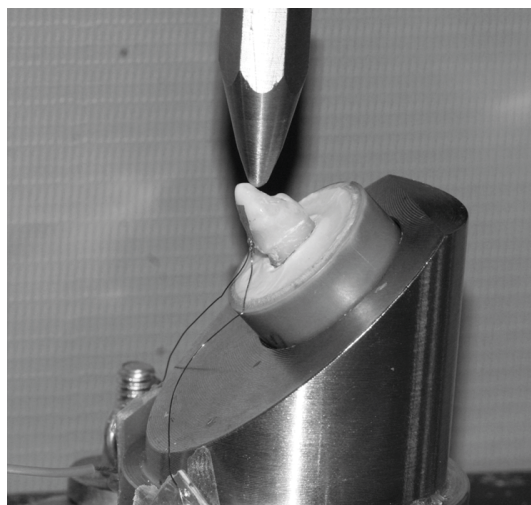


Figure 2. The sample was placed on a metal base with an inclination of 45° and a 50 N load was applied.

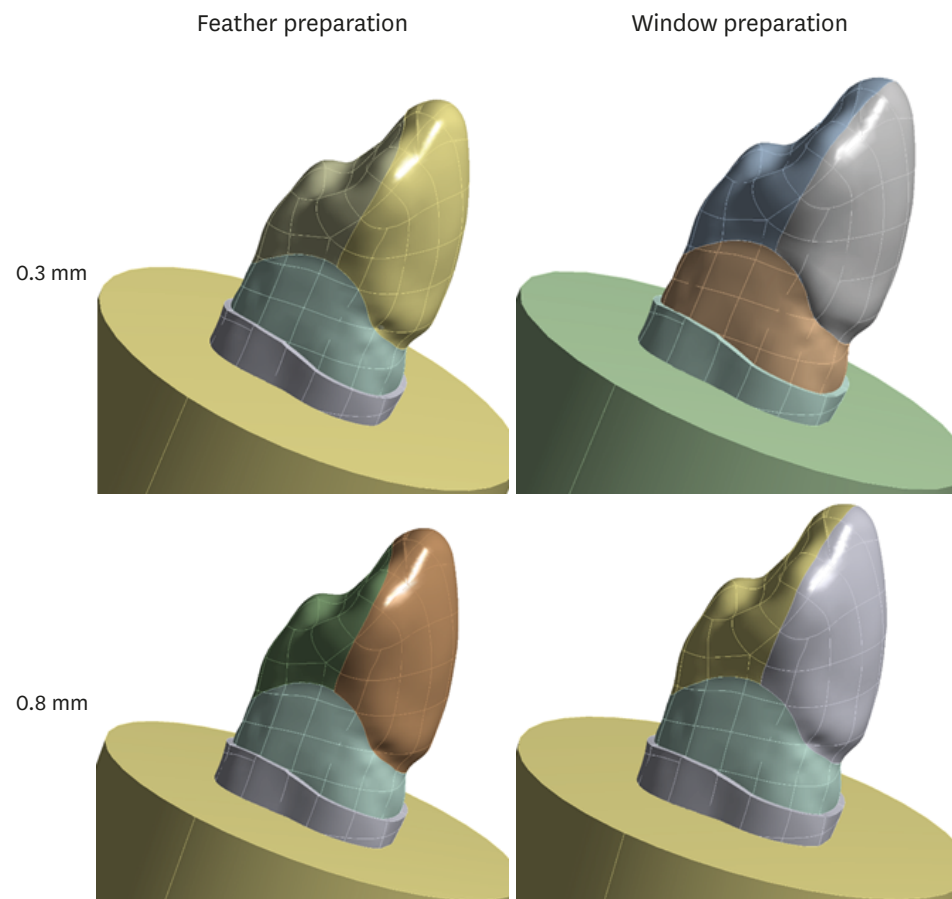


Figure 3. Teeth with preparation and restoration according to specifications.

After the outer surface was finished, the crown contour was outlined in the cervical region in order to discriminate the enamel and dentin structures. The enamel, dentin, and pulp structures were then modeled in depth using the outline obtained in 3D.

The periodontal ligament external to the root portion, 2 mm below the cementoenamel junction, was modeled with a thickness of 0.1 mm and a resin cylinder (25 mm diameter) was modeled (corresponding to the laboratory specimens). With the rigid structure complete, preparations were made by removing the facial and incisal structures as appropriate for each analyzed group: 0.3 mm with and without incisal covering and 0.8 mm with and without incisal covering. The models then received restorations that returned them to their initial form (**Figure 3**).

Using analysis software (ANSYS 17.2, ANSYS Inc., Houston, TX, USA) the model was transformed into a mesh with 172,467 tetrahedral elements and 98,467 nodes (**Figure 4**). The physiological characteristics of the teeth and ideal contacts were considered. The set was fixed by the base of the alveolar bone. The materials were considered isotropic, linearly elastic, and homogeneous [24]. The values of elastic modulus and the Poisson coefficient were chosen based on previous studies and are presented in **Table 1**.

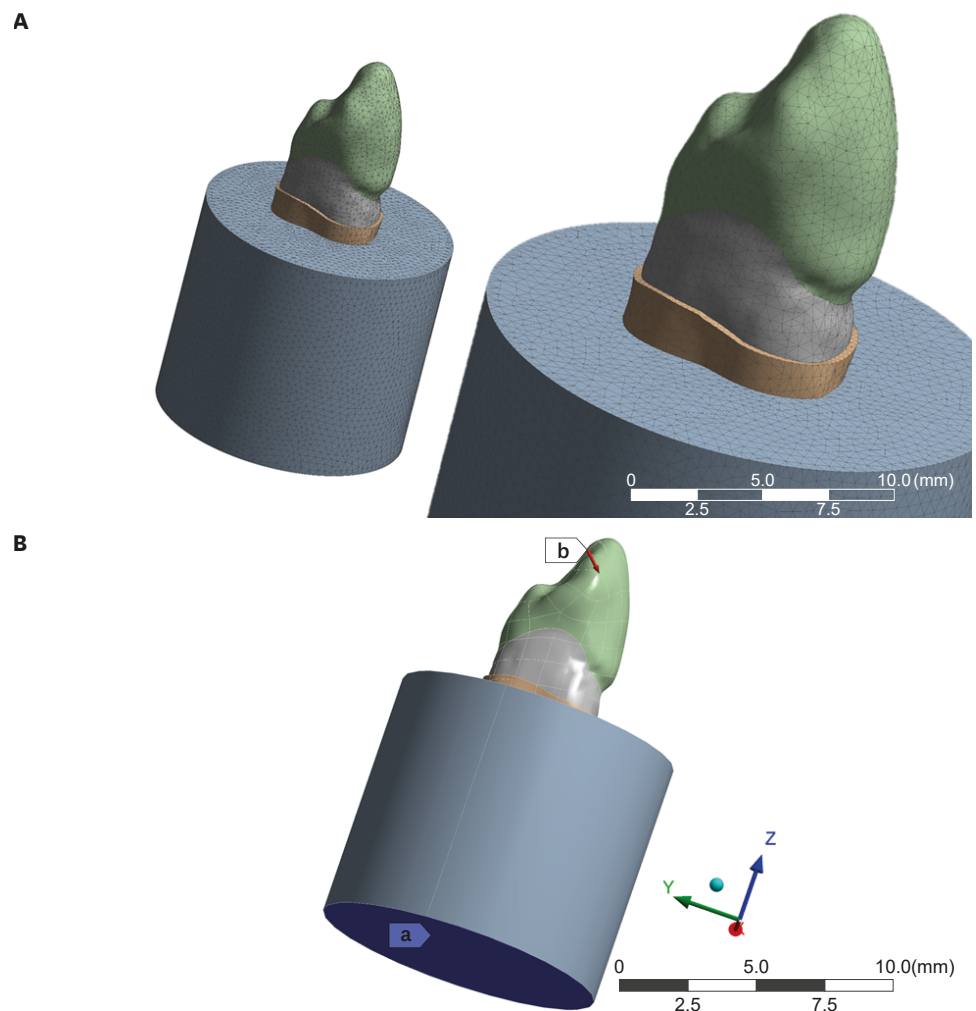


Figure 4. (A) Generation of mesh with a complex geometry with a finite number of elements; (B) Loading and boundary conditions: a, the fixation area; b, the loading point inclined at 45°.

RESULTS

Validation of the numeric model by an *in vitro* strain gauge

In the analysis using a strain gauge, static loading was performed for 20 seconds, and the results are shown in **Table 2**. For a comparative analysis of the data obtained by the *in vitro* experiment, the computer model was analyzed for compressive deformation (minimum principal elastic strain) of the area corresponding to the strain gauge area. The analyzed area is highlighted in **Figure 5**. The theoretical values obtained varied at each node of each element present in the area from 111.87 to 378.66 μ strain, with a mean of 210.63 μ strain. In a comparison with the *in vitro* values from **Table 2** (192.57 μ strain), it can be noted that the theoretically computed value was 8.57% higher than that measured in the laboratory experiment, so the simulation was accepted as valid.

Table 1. Mechanical properties used in the computational simulation

Material	Elastic modulus (GPa)	Poisson ratio	Reference
Enamel	84.1	0.33	[25]
Dentin	18.6	0.32	[25]
Polyether	0.0068	0.45	[26]
Polyurethane	3.6	0.3	[26]
Lithium disilicate	91	0.32	[25]

Table 2. Strain values (mm/mm) obtained using strain gauges corresponding to the *in vitro* generated measurements

Tooth	Maximum	Minimum	Mean \pm standard deviation
1	237.83	90.69	180.71 \pm 25.39
2	165.43	83.69	138.01 \pm 16.84
3	195.40	120.28	166.36 \pm 14.88
4	182.17	106.65	154.61 \pm 15.16
5	167.72	114.83	142.04 \pm 14.73
6	187.62	134.68	161.53 \pm 14.85
7	186.84	136.63	162.16 \pm 14.79
8	249.51	190.34	218.16 \pm 15.16
Mean	192.565	122.22	165.44 \pm 16.47

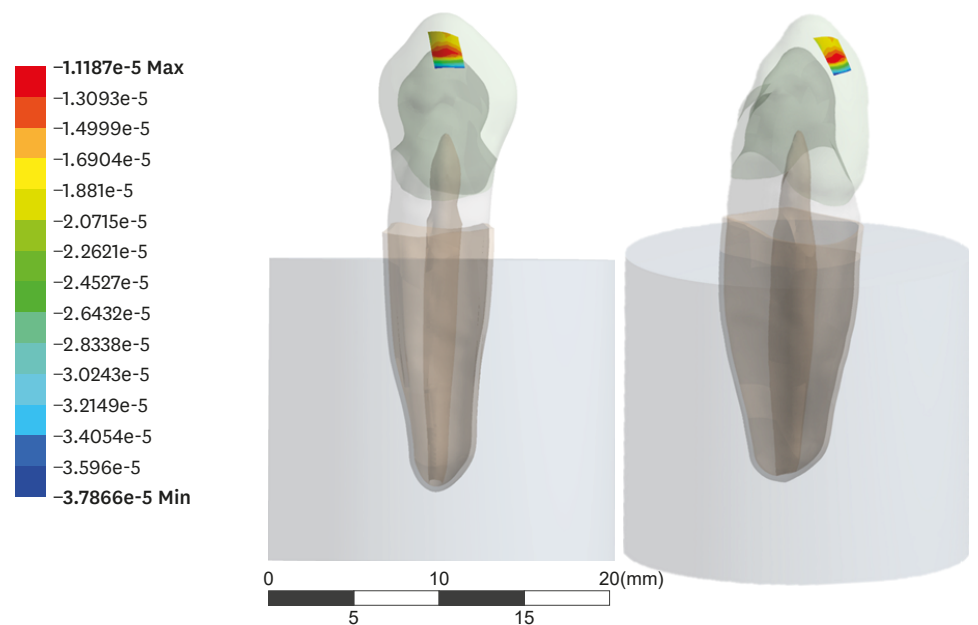


Figure 5. Representative area of the strain gauge-bonded area (shown in color) during the analysis of the minimum principal elastic strain.

Analysis of the stress concentration in restored teeth

According to the analysis, the palatal surface of the root was the tooth area with the highest tensile stress concentration for all preparation types (**Figure 6**), with values varying from 10.72 to 11.19 MPa, and variations of less than 3% of the mean value (11.02 MPa).

The veneers presented stress concentration in the incisal third, with higher values on the facial side (3.02–5.29 MPa), and variations between preparations reached 40% of the mean value (3.8 MPa). Higher stress concentrations in this area were obtained in thinner veneers (0.3 mm), regardless of the veneer extension. Moreover, the incisal covering led to a new stress concentration zone in the veneer, in the palatal region of the tooth-restoration interface, where the highest values were obtained (48.13 MPa). The results obtained for the veneers are presented in **Figures 7 and 8**.

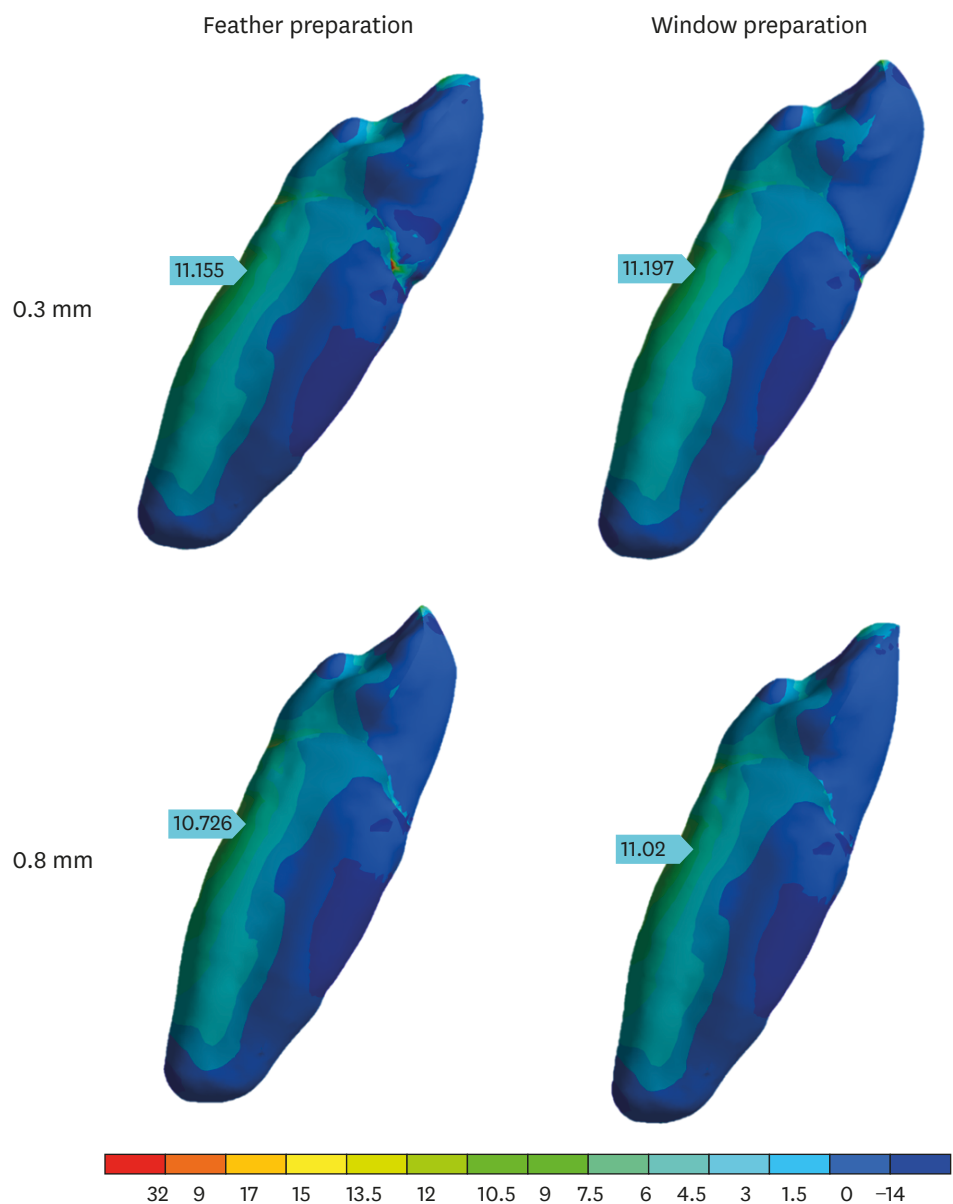


Figure 6. Lateral view of the tooth with the distribution of tensile stresses in the tooth in each of the specified preparations.

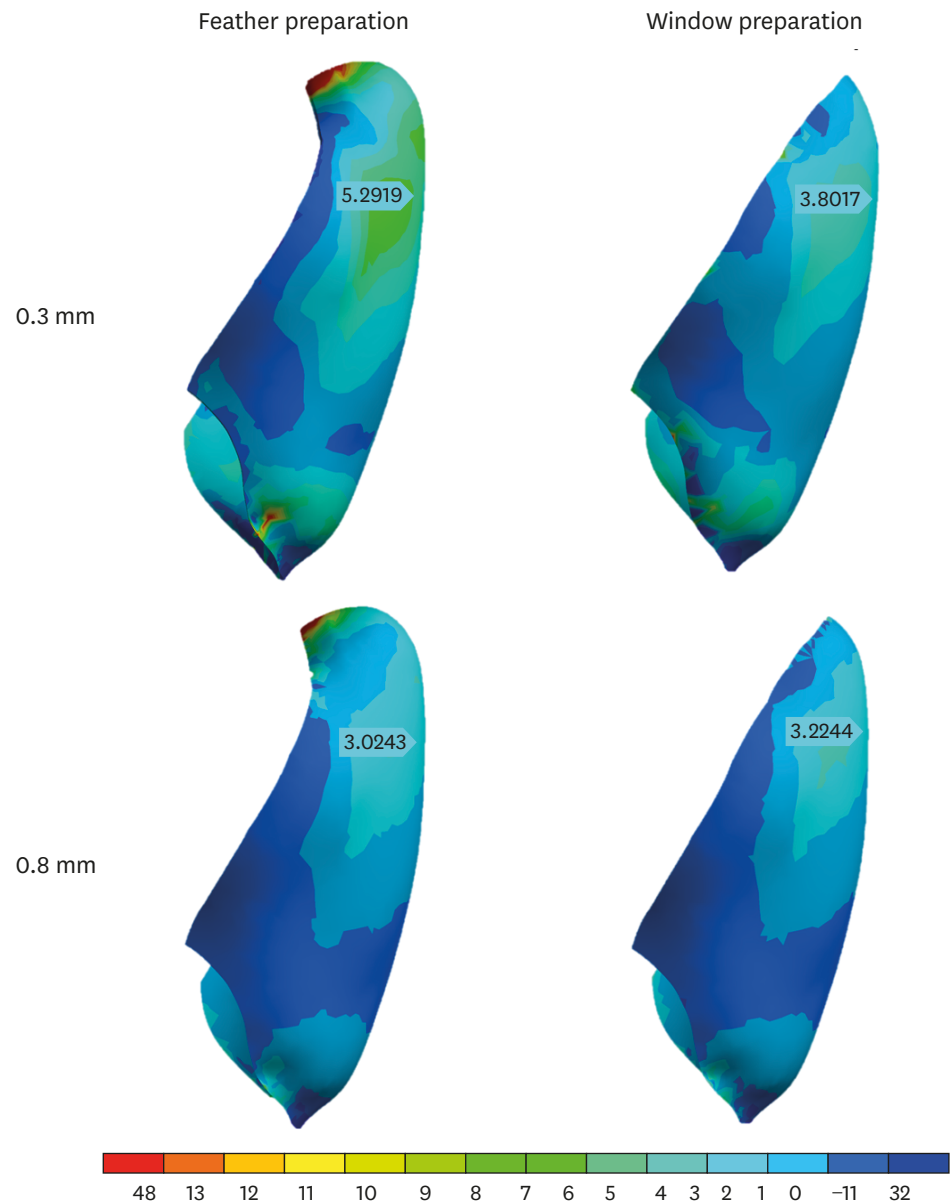


Figure 7. Lateral view of the distribution of tensile stress in veneers in each of the specified preparations.

DISCUSSION

The present study aimed to evaluate the distribution of stress in 2 different types of indirect veneers with 2 different thicknesses. The results demonstrated that both factors influenced the results, so both null hypotheses were rejected. The results were obtained only after the 3D model was validated through an *in vitro* experiment.

Experimental validation of FEA has been widely performed, and comparable results have been obtained in both *in vitro* and FEA experiments [21-23,27-29]. A literature review performed by Chang *et al.* [30] in 2018 found that among 450 publications over the last 10 years about dental implants using FEA, only 47 articles used some kind of validation (clinical or laboratory

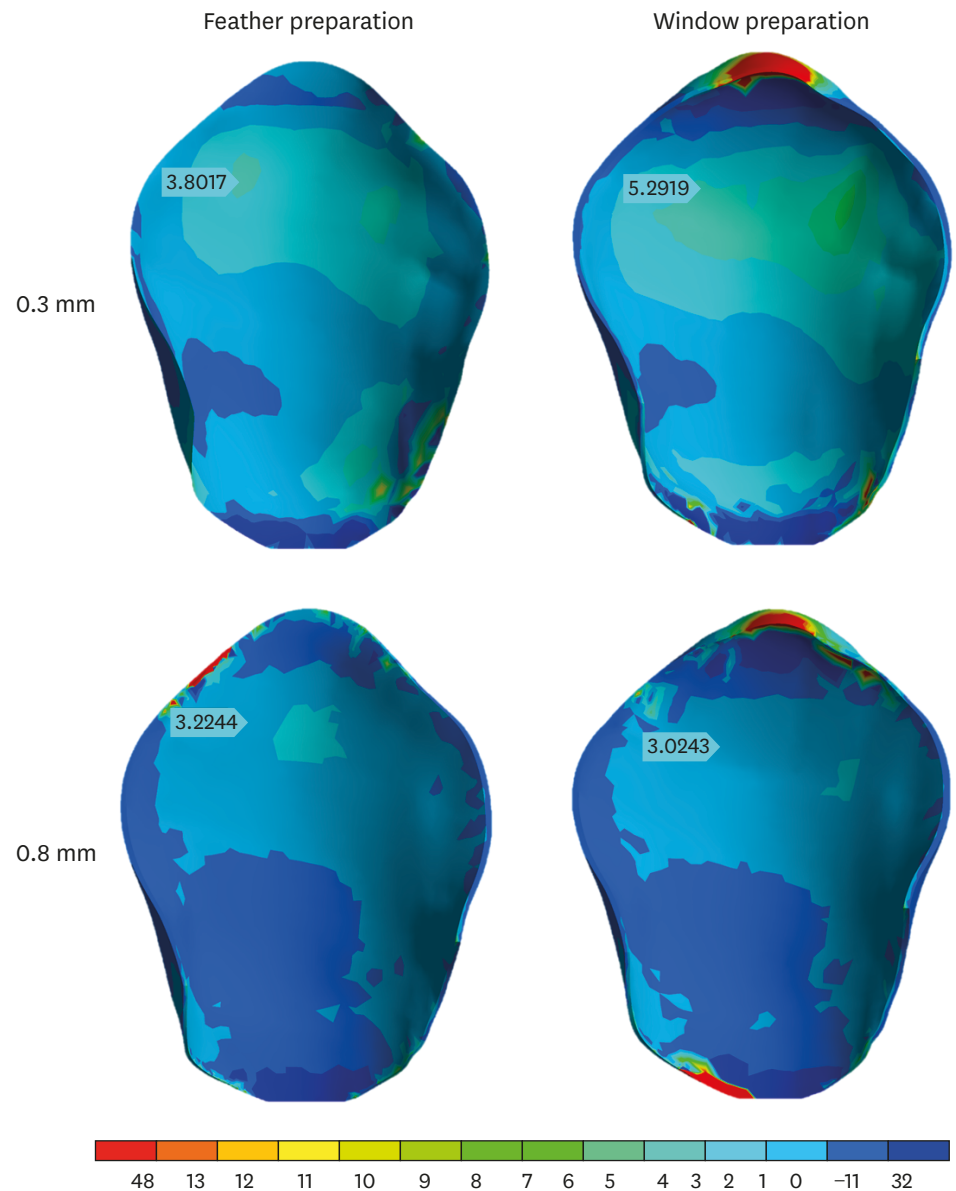


Figure 8. Palatal view of the distribution of tensile stress in veneers in each of the specified preparations.

experiments, findings in the literature, or another kind of validation), and the strain gauge method of laboratory testing was used in 15 of those 47 articles. That review recognized that simplifying the biomechanical behavior of tissues and ignoring the characteristics of each individual for computer analysis may neglect some aspects, resulting in inaccuracies in the predicted behavior of structures in the studied circumstances. Even though FEA does not provide values that perfectly correspond to reality, it enables observations of the behavior at specific spots of the studied structures, which is impossible in *in vivo* or *in vitro* studies. Even so, a study by Stappert *et al.* [8] showed that, given the limitations of a purely theoretical study, it was possible to validate the model by obtaining close values in both *in vivo* and *in vitro* studies. In the present study, the area chosen for analysis was the same area of strain gauge fixation used in the *in vitro* experiment. In FEA, the obtained values of minimum principal elastic strain

varied from 111.87 to 378.66 μ strain, with a mean value of 210.63 μ strain (**Figure 5**); in the *in vitro* experiment, the mean values varied from 138 to 218 μ strain (**Table 2**). Considering the anatomic variations of each tooth, it may be considered possible to obtain results through FEA that are similar to those obtained *in vitro*.

The use of aesthetic veneers on unprepared teeth does not produce more aesthetically-pleasing results than on prepared teeth; in addition, placing veneers on unprepared teeth is aggressive to soft tissues and inferior in terms of resistance to fracture [31]. When comparing an unprepared tooth restored with ceramic material to teeth that have been subjected to different preparations (strictly facial preparation, facial preparation with incisal covering, and full-crown preparation), Stappert *et al.* [8] found a higher fracture rate in masticatory movement simulations in the unprepared group, with fractures affecting the remaining dental structure, mainly the root portion, and not the restoring material. Nevertheless, the same study observed 80% more crack formation in the full-crown preparation and restoration group than in the other groups.

Studies have reported highly divergent results regarding the benefits of incisal covering. In a study of incisors, Hui *et al.* [32] showed negative consequences of this covering in terms of the resistance of the restorative material, while Highton *et al.* [33] defended this modality by considering the stress that developed in the veneer using photoelastic analysis. Longitudinal studies have reported no difference in the prognosis of indirect veneers depending on the crown preparation extension [8,34]. These studies agreed with those by Stappert *et al.* [8] and Meijering *et al.* [34], showing that the tooth was not reinforced by the incisal covering. As in the study by Hui *et al.* [32], it was found that the incisal covering led to a new area of stress concentration on the palatal side of the restoration.

Thicker veneers generally show more favorable results [35]. In the present study, using colorimetric analysis, we observed a lower stress concentration in thicker veneers (0.8 mm). This difference was observed on both the facial and palatal sides, corroborating the study by Ge *et al.* [35], in which higher thickness of the material was found to be beneficial for the restoration. By verifying that the stresses generated in the tooth were similar in different-thickness preparations (0.3 and 0.8 mm), this study suggests that there is no damage to the dental element when more invasive preparations are needed (**Figure 6**). Despite this observation, the veneer thickness presents higher stress concentration values in thinner restorations (0.3 mm) [7,8]. Even though the maximum stress values do not overcome the material's limit to failure, higher thicknesses may contribute to greater longevity of the restoration.

The conducted test exclusively aimed to analyze the stress generated in teeth subjected to different preparation types and different veneers by simulating a single physiological occlusal loading; it was not the goal of this study to analyze material failure, as has been done in previous studies [32,36]. In addition, the load of 50 N to the teeth simulated a physiological load (between 25 N and 50 N) [37], and parafunctional loading, which can reach 6 times over physiological values, was not considered [38].

The data presented by FEA in this study are approximate, which is a limitation of the methodology. Although the dental and periodontal tissues were considered in their entirety, their structures are homogeneous and isotropic, which is not the case *in vivo*. The veneers were considered to be directly bonded to enamel, disregarding the bonding material between them. The buccal cavity contains specific factors that were not considered in the experiment,

such as moisture, which is considered to play an important role in ceramic failure by stimulating the growth of microcracks [36], and temperature changes [4], which are capable of affecting the material and its properties over time.

CONCLUSIONS

Within the limitations inherent to a valid mathematical FEA model of a maxillary canine tooth, there were no significant differences in the stress concentration within the remaining tooth structure between different preparations and veneer extension thicknesses. However, in the veneer, the higher-thickness veneer showed better stress distribution with lower tensile stress concentration, and the more extensive preparations, such as the feather type, exhibited new stress concentration zones on the palatal side of the restoration.

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