

Original article

Influence of buccal cusp reduction when using porcelain laminate veneers in premolars. A comparative study using 3-D finite element analysis

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Abstract

Objectives: Based on a maxillary premolar restored with laminate veneer and using the 3-D finite element analysis (FEA) and μ CT data, the aim of this study was to evaluate the influence of different types of buccal cusp reduction on the stress distribution in the porcelain laminate veneer and in the resin luting cement layer.

Methods: Two 3-D FEA models (M) of a maxillary premolar were built from μ CT data. The buccal cusp reduction followed two configurations: Mt – buccal cusp completely covered by porcelain laminate veneer; and Mp – buccal cusp partially covered by porcelain laminate veneer. The loading (150 N in 45°) was performed on the top of the buccal cusp. The finite element software (Ansys Workbench 10.0) was used to obtain the maximum shear stress (τ_{\max}) and maximum principal stress (σ_{\max}).

Results: The Mp showed reduced the stress (σ_{\max}) in porcelain laminate veneer (from –2.3 to 24.5 MPa) in comparison with Mt (from –5.3 to 27.4 MPa). The difference between the peak and lower stress values of σ_{\max} in Mp (–6.8 to 26.7 MPa) and Mt (–5.3 to 27.4 MPa) was similar for the resin luting cement layer. The structures not exceeded the ultimate tensile strength or the shear bond strength.

Conclusions: Cusp reduction did not affect significant increase in σ_{\max} and τ_{\max} . The Mt showed better stress distribution (τ_{\max}) than Mp.

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Keywords: Laminate veneers; Dental Ceramics; Finite element analysis; Numerical analyses

1. Introduction

With the development of restorative materials and adhesive procedures, porcelain laminate veneers are steadily increasing in popularity among today's dental practitioners for conservative restoration of unaesthetic teeth, with highly predictable rates of success in the anterior region [1,2]. This author [2] showed success rates of 92% after 5 years and 64% after 10 years of clinical assessment, while others [3] showed even better results, with a success rate of 94.4% after 12 years of assessment.

The success of porcelain laminate veneers is subject to correct dental reduction, bonding to the substrate and the development of ceramic systems [4]. Thus, whenever possible, the preparation margins must be restricted to the enamel; to reduce the possibility of failures resulting from the limitations of bonding to dentine [5]. The resin luting cement must be capable of absorbing the tensile loads, reducing the adverse effects on the porcelain laminate veneer, and acting in order to maintain the stability of the tooth-restoration complex [6].

In spite of the technological advancement in ceramic systems, with improved mechanical properties, which allow it to be used in the posterior dentition [7,8], it is noticed that the use of porcelain laminate veneers is restricted to the anterior region and there is no consensus about the use of porcelain laminate veneer in the posterior region. This is because ceramic systems, although systematically improved [7–9], show mechanical limitations when used in the posterior region due to the inherent incapability

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of ceramics to satisfactorily absorb the tensile forces by plastic deformation, resulting in the appearance of small cracks, fractures and defects which lead to failures of the system [10].

However, when the dental bonding procedures are well established, the adhesive layer provided by the cementing agent partially absorbs the stresses acting on it, and redistributes them inside the supporting dental structure, improving mechanical behavior of the porcelain laminate veneer and preserving the integrity of the tooth-restoration interface, in the same way as occurs in partial ceramic restorations of the inlay type [6]. In this way, Magne and Douglas [11] in a similar manner to Stokes and Hood [12] observed that teeth treated with porcelain laminate veneers in the anterior region reproduced the mechanical and structural behavior of an intact tooth when the laminate was bonded to the dental substrate.

Alterations of shape or color in healthy posterior teeth not subjected to another treatment modality of esthetic correction represent one of the clinical conditions that demand the use of a very thin porcelain laminate veneer in the posterior region [13]. However, there is consensus about that with no mechanical studies evaluating the stress distribution in the porcelain laminate veneers and in the resin luting cement in premolar teeth. Besides, there is no indication whether the porcelain laminate veneer must partially or completely cover the buccal cusp. Although there is no clinical proof, one suspects that the occurrence of failures is not high, in the view of the improvement of bonding procedures and restorative materials.

The complete covering of the vestibular and palatine cusps in teeth restored with resin composite improved retention and resin strength [14], diminishing the occurrence of failures. Therefore, one suspects that completely covering the buccal cusp when applying porcelain laminate veneers to premolars provides the set with greater retention and strength, increasing the predictability of success.

Based on the above reasoning, the aim of this study was to use the three-dimensional finite element method to evaluate the influence of two different types of buccal cusp reduction (partial or complete) on the stress distribution in the porcelain laminate veneer and in the resin luting cement in a maxillary first premolar. The follow hypothesis was tested: the complete buccal cusp reduction model showed higher stress concentration than the model with partial buccal cusp reduction.

2. Materials and methods

After the project has been approved by the Research Ethics Committee (#200801845), an intact maxillary first premolar tooth was obtained from the tooth bank of Department of Dental Materials and Prosthodontics to obtain the micro-computed tomography image (μ CT).

From a total of 720 slices obtained after scanning the tooth by μ CT (CT40, Scanco Medical, Bassersdorf, Switzerland), 82 slices were selected for three-dimensional reconstruction in the SolidWorks 2007 program (SolidWorks Corp., Concord, MA, USA), with all the structures inherent to the natural tooth (enamel, dentine and dental pulp) except for the non creation of a cement layer (Fig. 1) [15].

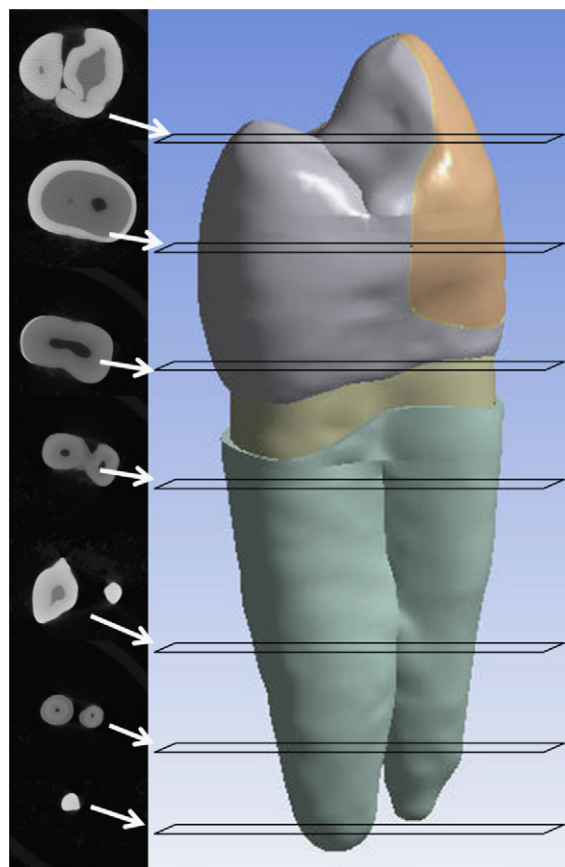


Fig. 1. Tooth reconstructed in the SolidWorks software based in some slices obtained by using μ CT data (CT40, Scanco Medical, Bassersdorf, Switzerland).

In the SolidWorks program, the 82 slices were equally distributed following the length of premolar. The volume of enamel, dentine and dental pulp was individually created. Based on each volume, Boolean's operation were used to create the enamel layer and the dentine with the pulp chamber void. After that, a model with the entire intact tooth was created combining those different parts.

From this model (M), 2 geometric models were made varying the reduction of the buccal cusp, as follows: Mp – composed of the first premolar tooth restored with a porcelain laminate veneer (IPS e.max Press – Ivoclar Vivadent, Schaan, Lichtenstein), with partial reduction of the buccal cusp and Mt – similar to Mp, but with complete reduction of the buccal cusp involving the grinding slope (Fig. 2).

The common characteristics of each model were similar among them, such as the reduction of the buccal surface corresponding to the preparation for the porcelain laminate veneers (0.5 mm), partial or complete reduction of the buccal cusp (0.5 mm of thickness) (Fig. 3), cementing agent layer (50 μ m) [16], porcelain thickness (0.45 mm) and periodontal ligament (0.25 mm). The reduction of the buccal cusp after the tooth preparation was extended to the middle of the proximal surface in the two models (Mp and Mt) following the cervical profile of the enamel–dentine junction. For the occlusal surface, the Mt showed an uniformly reduction in all buccal cusp. This was not applied to the Mp.

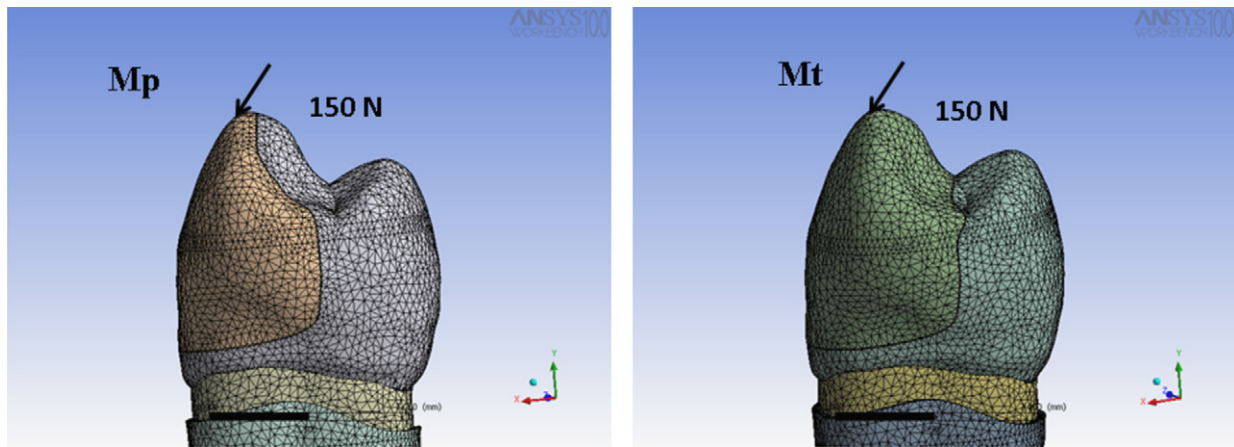


Fig. 2. Diagram showing the finite element mesh for Mp and Mt. Also show the position, direction (45° of the tooth long axis) and intensity of the load (150 N).

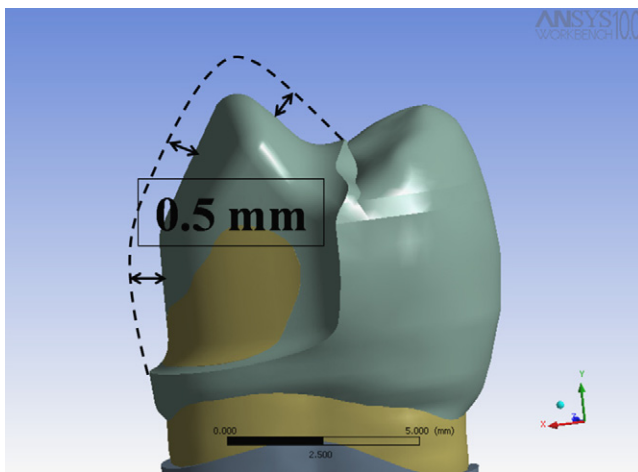


Fig. 3. Thickness of dental reduction (0.5 mm) of the buccal surface in a proximal view.

The models created in the program SolidWorks 2007 (SolidWorks Corp., Concord, MA, USA) were exported in “.iges” files format to the finite element program Ansys Workbench 10.0 (Swanson Analysis Inc., Houston, PA, USA) for the recognition of the regions, determination of the mechanical properties and generation of the finite element mesh (Fig. 2). All the materials were considered homogenous, linearly elastic and isotropic with mechanical properties (Modulus of elasticity (E) and Poisson's ratio (ν)) established in accordance with the specific literature (Table 1) [17–19]. Mp and Mt did not showed the preparation limits in dentine, although the dentine had been partially exposed in the cervical third after simulation of the tooth reduction. The bond between the porcelain laminate veneers and the dental substrate through the resin luting cement layer (Variolink II – Ivoclar Vivadent, Schaan, Lichtenstein) was considered perfect in the two models studied.

A parabolic tetrahedral interpolation solid element with 10 nodes and a mesh composed of 0.2 mm-sized elements were used following the convergence of analysis [20] (Swanson Analysis Inc., Houston, PA, USA). The models showed 379,974 (Mp) and 383,431 (Mt) elements and 248,275 (Mp) and 249,819 (Mt) nodes (Fig. 2).

Table 1

Elastic properties of the materials (elastic modulus [GPa] and Poisson's ratio).

Material	Elastic modulus	Poisson's ratio
Enamel [17]	80,000	0.3
Dentine [17]	15,000	0.31
Periodontal ligament [18]	175	0.45
Laminate veneer (IPS e.max Press) ^a	65,000	0.24
Resin luting cement ^a	8,300	0.3
Pulp [19]	2	0.45

^a Modulus of elasticity and Poisson's ratio provided by the manufacturer (Ivoclar Vivadent).

For the boundary conditions, a displacement equal to zero was considered for the perpendicular directions ($x = z = y = 0$), applied to the external surface corresponding to the periodontal ligament in each model.

Simulating the disocclusion guide in the partial group, or complete group, with dental contact between the arches during lateral shift of the mandibular movement, a load of 150 N [21] was applied on the nodes representative of the top of the cusp, at an inclination of 45° with the tooth long axis [21], for both models (Fig. 2).

After loading, the stress analysis was performed to obtain the maximum principal stress (σ_{\max}) and maximum shear stress (τ_{\max}). According to the literature [22–24] these analysis criteria are appropriate for predicting failures in non-ductile materials, such as ceramic, adhesive layer and resin luting cement [23–25]. Thus, the predictability of success of the porcelain laminate veneers and resin luting cement layer was established by comparing the values of σ_{\max} obtained in the study with values for the ultimate tensile strength (UTS) and the values of τ_{\max} to the values of shear bond strength (SBS) in the enamel and dentine established in shear stress tests [22].

3. Results

After obtaining the maximum principal stress for the porcelain laminate veneers and resin luting cement layer, and the values of maximum shear stress for the resin luting cement layer, it was possible to make a comparative analysis between the models Mp and Mt based in Fig. 4. The stress distribution for the analyzed structures is shown in Figs. 5 and 6.

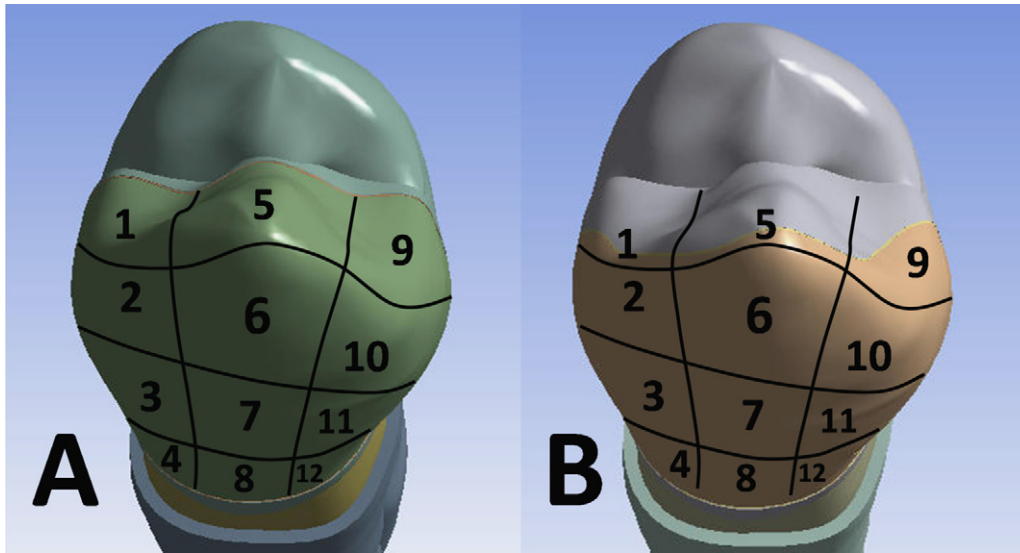


Fig. 4. Areas (from 1 to 12) selected to separately analyses the maximum principal stress (σ_{\max}) and the maximum shear stress (τ_{\max}) in the porcelain laminate veneers and the resin luting cement layer for Mt (A) and Mp (B).

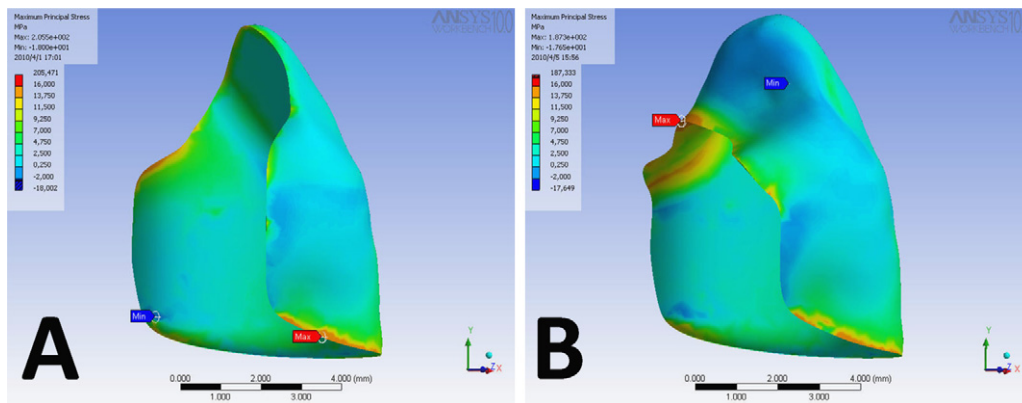


Fig. 5. Stress distribution in the porcelain laminate veneer. (A) σ_{\max} in Mp; (B) σ_{\max} in Mt.

3.1. Maximum shear stress (τ_{\max})

In general, Mt showed lower stress concentration (τ_{\max}) in 8 of the 12 (Fig. 4) areas analyzed when compared with Mp. Area 10 showed the lowest stress difference between the two models (1%), and area 1 showed the greatest difference (44%) (Fig. 7).

3.2. Maximum principal stress (σ_{\max})

It was observed that the model with partial cusp covering (Mp) showed higher stress concentration (σ_{\max}) (−18.002 to 205.470 MPa) when compared with the model with complete cusp reduction (Mt) (−17.649 to 187.330 MPa).

3.3. Porcelain laminate veneers

In general, Mt showed the highest stress concentration values of σ_{\max} (from −5.3 to 27.4 MPa) (Fig. 8) when compared with

Mp (from −2.3 to 24.5 MPa). Mt showed the highest stress concentration values of σ_{\max} in 7 of the 12 areas analyzed when compared with the respective areas of Mp (Fig. 8). Area 12 showed the a small difference of σ_{\max} between the two models (2%), and area 11 showed the greatest difference (85%) (Fig. 8). Mt showed the highest stress concentration values of σ_{\max} in areas 1, 5 and 9, and it was higher by 33%, 52% and 12%, respectively when Mp was compared with Mt.

3.4. Resin luting cement layer

Difference between the peak and lower stress values of σ_{\max} between Mp (from −6.8 to 26.7 MPa) and Mt (from −5.3 to 27.4 MPa) for the resin luting cement layer was lower than the values found for the porcelain laminate veneers. Area 8 showed the highest values of σ_{\max} , irrespective of the model. The Mt showed the highest stress concentration values of σ_{\max} in areas 5, 8, and 12 (Fig. 9).

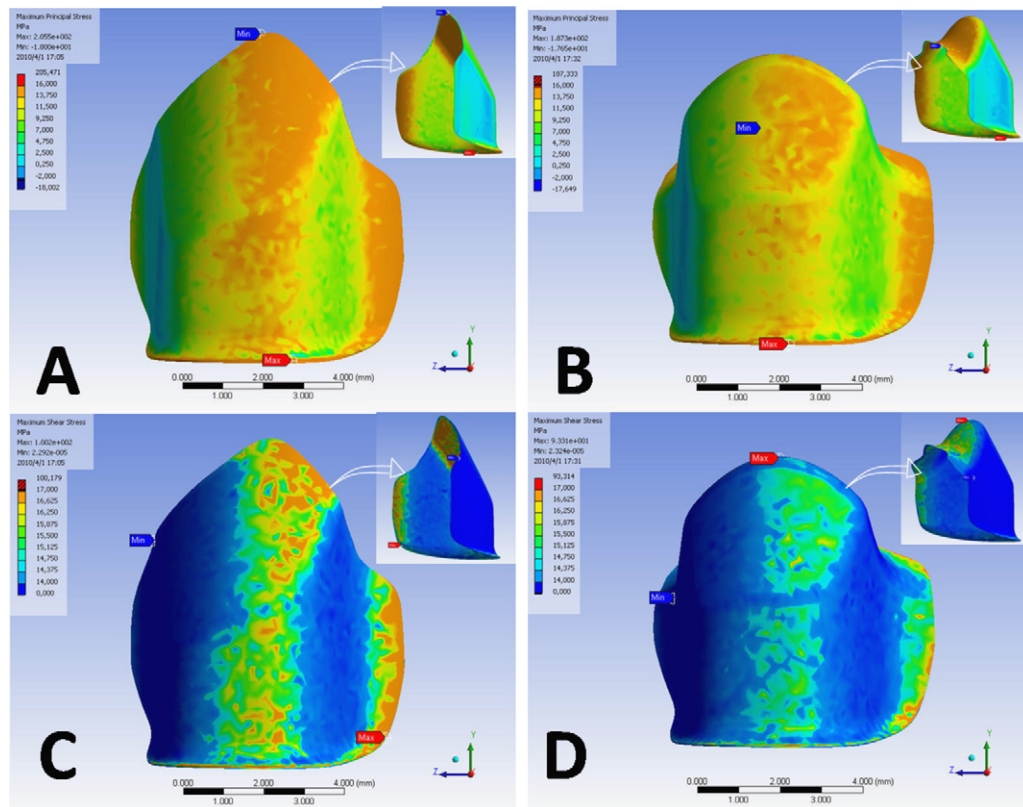


Fig. 6. Stress distribution in the resin luting cement layer. (A) σ_{\max} in Mp; (B) σ_{\max} in Mt; (C) τ_{\max} in Mp; (D) τ_{\max} in Mt. For each situation, an inclined view of the cement layer can be observed.

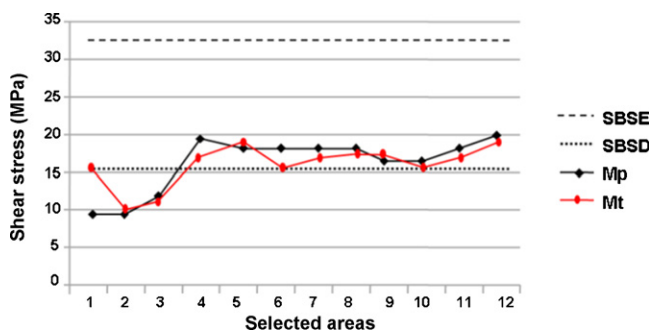


Fig. 7. Values of shear stress (MPa) of the resin luting cement layer in Mp and Mt and the values of resistance to rupture for dentine (SBSD) and enamel (SBSE).

4. Discussion

Certain variables in biomedical devices cannot be monitored and measured using in vivo models due ethically questionable when performed on live subjects. For this virtual models and simulation approaches from the engineering industry, such as finite element (FE) analysis have been utilized and becoming a powerful tool to evaluate biomedical materials [26].

For complicated features, such as teeth and craniofacial structures, an accurate 3D geometry is one of the important keys to obtain successful finite element data [27,28]. In this study to obtain perfect tooth geometry the premolar was scanned through a micro-computed tomography (μ CT), obtaining several slices of the tooth. Starting these slices,

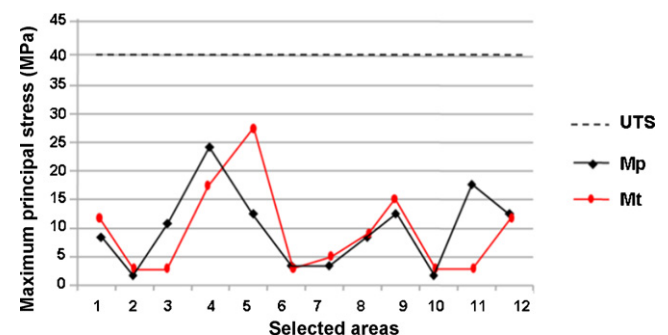


Fig. 8. Values of σ_{\max} (MPa) of the porcelain laminate veneers in Mp and Mt, and the value of rupture (UTS).

modeling software was used to recreate the volume and outer contour of the tooth. Based on this volume, modeling operations, such as Boolean's operations, were made in the initial model of the tooth, creating and modifying the volume and contour of the internal structures, such as enamel, dentine and pulp. Additionally, the study variables were created (partially or totally buccal cusp reduction).

There is limited clinical use of porcelain laminate veneers in premolar teeth. One suspects that the occurrence of failures is high, compromising the success of the restoration [5,10]. However, the results obtained in this study indicate a possibility of using porcelain laminate veneers in premolar teeth.

The values of σ_{\max} and τ_{\max} for the porcelain laminate veneers and the resin luting cement layer did not exceed the

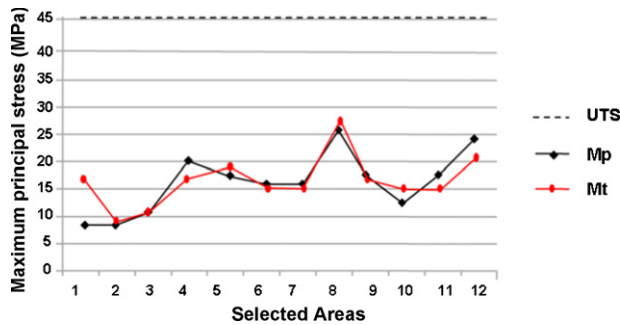


Fig. 9. Values of σ_{\max} (MPa) of the resin luting cement layer in Mp and Mt, and the ultimate tensile strength (UTS).

values for the ultimate tensile strength (UTS) of these materials and bond strength values to the enamel and dentine established by specific literature (Figs. 7–9).

The porcelain laminate veneers showed higher stress values of σ_{\max} for Mt, near the point of loading (area 5:27.4 MPa) being 32% lower than the ultimate tensile strength for ceramic (UTS: 40 MPa), in agreement with others studies [22,29], who showed greater stress near the point of force application in inlays and porcelain laminate veneers, respectively.

Since the load considered in this study was not too high for a posterior dentition (150 N) [21], the σ_{\max} values did not come close to the fracture load. To represent risk of porcelain laminate veneers and resin luting cement failure, the load should approximately be of 220 N and 250 N, respectively, considering the direction and loading conditions of this study. Moreover, for failures to occur in the resin luting cement layer bonded to dentine, the applied force should be 300 N. However, additional contacts and different magnitudes during “in vivo” disocclusion might enhance the risk of rupture anticipating the failure of porcelain laminate veneer.

In this connection, a patient who presents parafunction with excursive occlusal forces and clenching ranging from 400 N to 700 N [21] could overload the ceramic and the cement layer beyond the limits established for the fracture load of these materials. In the analysis of the two models, a better mechanical behavior (lower stress concentration) was observed for Mp compared with Mt in the presence of tensile forces for both materials (ceramic and resin luting cement), suggesting that the porcelain laminate veneers and the cement layer of Mt were more susceptible to the occurrence of failures when compared with Mp.

For both models, the peak of σ_{\max} occurred at the margins of the resin luting cement layer related to the enamel. Different schemes of loading in premolar restored with laminate veneers should be applied to explore a failure scenario in different conditions. However, this data enhance the influence of the cement layer in the success of the treatment, since defects in the cementation line diminish the physical properties of the material [29], such as strength and rigidity in the oral environment, mainly after water absorption at the cement/tooth interface [30]. And this has been particularly important when dentine is the available as dental substract [31].

In this study, the margins of the porcelain laminate veneers were limited to the enamel. In association with the linear aspect

of this study, the limits based on enamel can explain the adequate behavior of the porcelain laminate veneers and resin luting cement layer, which showed values of σ_{\max} and τ_{\max} lower than the values of UTS and SBS, respectively, for the models Mp and Mt. Only two areas (8 and 12) showed exposure of dentine after tooth reduction simulation, nevertheless, the values of σ_{\max} and τ_{\max} in those two areas were not discrepant when compared with the values found in other areas (Figs. 7–9). The simulation for all finish line in dentine and variations of the quality of bond between resin luting cement layer and dentine should be considered to add important data to this discussion.

In view of that, the hypothesis of the studied can be rejected, since the models showed similar stress distribution.

Assessing the criteria adopted for predicting failures in the shear stress (SBS), Mp showed higher value of τ_{\max} in area 12 (20.0 MPa) and Mt showed higher value of τ_{\max} in areas 5 and 12 (18.7 MPa), both related to the enamel, and these values were 39% and 43% lower than those established for failure (SBS, enamel: 32.8 MPa) [22], respectively. Clinically, there is concern as regards the failures present in porcelain laminate veneers, such as delamination [13]. Thus, the results for maximum shear stress represent concrete and positive data with regard to the use of porcelain laminate veneers in premolar teeth in the presence of the load adopted.

Furthermore, the study is linear with all the structures bonded in an ideal manner, with a cementation line of constant thickness along the entire surface. This simulation might not be clinically prevalent. However, it is the basis to discuss future data against the different thickness of the resin luting cement layer and of some contaminants, which can anticipate a failure scenario [32].

In view of that, it is worth emphasizing that the simulation shown in the study represented a limit situation due to the reduced ceramic thickness, with a very precise clinical indication. Clinically, this might represent the option of treatment for discolored teeth or small changes in the tooth shape [5,33].

If there were the need to correct the ceramic shape, this could be done by adopting different thicknesses, creating different behaviors to those obtained here. It must also be emphasized that a greater reduction of the cusp, routinely recommended at 1.5 mm [11] when there is occlusal reduction, would result in different intensities and distribution of stress. Certainly these aspects need further investigation.

Therefore, it is believed that porcelain laminate veneers could be used with predictable success. Moreover, the use of reinforced ceramic systems associated with greater protection of the cusp with vertical wear of over 0.5 mm may positively influence the distribution of stresses, increasing strength of the set and improving mechanical behavior of the laminate in the face of the forces acting on it.

Therefore, although further virtual simulations are required to gain a better understanding of the stress concentration of the laminate veneers in premolars the results of the present study add useful data to previous clinical and in vitro findings. Additional clinical studies are needed to prove the indications of these kind of restoration in premolars. Additionally, should be evaluate the stress behavior of these restorations when

subjected to high chewing forces, as do patients with parafunctional habits.

5. Conclusion

Within the limitations of this study the type of cusp reduction had no influence on the significant increase in the maximum principal stress and maximum shear stress based on the loading pattern adopted. The use of laminate veneers in premolar for patients with parafunction should be carefully evaluated.

Conflict of interest statement

All authors must disclose any financial and personal relationships with other people or organizations that could inappropriately influence (bias) their work.

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