©Operative Dentistry, 2014, **39-5,** 530-540

Survival Rate, Load to Fracture, and Finite Element Analysis of Incisors and Canines Restored With Ceramic Veneers Having Varied Preparation Design

CD Bergoli • JBC Meira • LF Valandro
MA Bottino

Clinical Relevance

Fracture loads of canines and maxillary central incisors are not affected by the veneer preparation design (eg, conservative or conventional preparation with palatal chamfer). However, conventional preparation generated higher tensile stress in the ceramic veneer.

SUMMARY

Purpose: To evaluate the survival rate, success rate, load to fracture, and finite element analysis (FEA) of maxillary central incisors and canines restored using ceramic veneers and varying preparation designs.

Methods and Materials: Thirty human maxillary central incisors and 30 canines were allocated to the following four groups (n=15) based on the preparation design and type of tooth: Gr1 = central incisor with a conservative preparation; Gr2 = central incisor with a conventional preparation with palatal chamfer; Gr3 = canine with a conservative preparation; Gr4 = canine with a conventional preparation with palatal chamfer. Ceramic veneers (lithium disilicate) were fabricated and adhesively cemented (Variolink Veneer). The specimens were subjected to 4×10^6 mechanical cycles and evaluated at every 500,000 cycles to detect failures. Specimens that survived were subjected to a load to fracture test. Bidimensional models were modeled (Rhinoceros 4.0) and evaluated (MSC.Patrans 2005r2 and MSC.Marc 2005r2) on the basis of their maximum principal stress (MPS) values. Survival rate values were analyzed using the Kaplan-Meier test ($\alpha = 0.05$) and

Cesar Dalmolin Bergoli, PhD, Federal University of Pelotas, Dentistry School, Pelotas, Brazil

Josete Barbosa Cruz Meira, PhD, São Paulo State University (USP), Biomaterials and Oral Biology Department, São Paulo, Brazil

*Luiz Felipe Valandro, PhD, Federal University of Santa Maria, Restorative Dentistry (Prosthodontics), Santa Maria, Brazil

Marco Antonio Bottino, PhD, São Paulo State University (UNESP), Dental Materials and Prosthodontics, São Jose dos Campos, Brazil

*Corresponding author: R. Floriano Peixoto 1184, Santa Maria, RS 97015-372, Brazil; e-mail: lfvalandro@hotmail.com

DOI: 10.2341/13-179

load to fracture values were analyzed using the Student *t*-test ($\alpha = 0.05$).

Results: All groups showed 100% survival rates. The Student *t*-test did not show any difference between the groups for load to fracture. FEA showed higher MPS values in the specimens restored using veneers with conventional preparation design with palatal chamfer.

Conclusion: Preparation design did not affect the fracture load of canines and central incisors, but the veneers with conventional preparation design with palatal chamfer exhibited a tendency to generate higher MPS values.

INTRODUCTION

Solving esthetic problems in the anterior teeth is a challenge for restorative dentistry. For many years, full coverage restorations were the most highly preferred option for treating esthetic defects.[1] However, such restorations are invasive and cause great loss of tooth structure.

Preparations for ceramic veneers conform to the concept of conservative dentistry with minimally invasive procedures. This has contributed to the widespread use of this technique.[2] In addition, this technique has been used successfully to correct such defects as stains, small fractures, and diastemas and to improve a patient's esthetic condition.[2-5]

Laboratory studies have shown similar load to fracture values between specimens restored using ceramic veneers and varying preparation designs and between healthy teeth or teeth restored using full crowns.[6,9] Besides, researchers have shown survival rates greater than 90% in the first 5 years of clinical function for teeth restored using ceramic veneers,[10-15] concluding that ceramic veneers are a good alternative for restoring anterior teeth.

Clinical studies present the strongest evidence for a material or a restorative technique. However, such studies are expensive and not easy to conduct.[16] Therefore, laboratory studies are important tools for obtaining data because they permit comparison of different materials under standardized conditions.[16] The aging protocols of mechanical cycling subject the specimens to load, temperature, and humidity conditions similar to those experienced in the oral environment. In addition, this test is able to induce crack propagation to the point of catastrophic failure, as observed in clinical function.[17,18]

Nondestructive tests such as finite element analysis (FEA), which are associated with *in vitro* tests, permit a better understanding of the different phenomena that occur in the tested specimens.[19,20] FEA offers a better overview of the stress distribution at an interface or inside a material, thus permitting an accurate check of the system's behavior.[21]

Although clinical studies have reported good survival rates for teeth restored using ceramic veneers, there have been no studies determining which preparation design is best suited for canines and central incisors specifically. In addition, there are no studies elucidating the principal cause of ceramic veneer failures by aging the specimens through mechanical cycling or evaluating the behavior of different teeth restored using laminate veneers on the basis of survival rates.

Hence, this study aims to evaluate the survival rate and mechanical behavior of canines and maxillary central incisors restored using ceramic veneers and varying preparation designs, by using mechanical cyclic aging, load to fracture test, and FEA. The following hypotheses were tested: (1) canines restored using ceramic veneers and varying preparation designs will show the same values of load to fracture and survival rate; (2) maxillary central incisors restored using ceramic veneers and varying preparation designs will show the same values of load to fracture and survival rate; and (3) tensile stress distribution will be similar in all the models, independent of the preparation design.

METHODS AND MATERIALS

The product names, manufacturers, chemical compositions, and batch numbers of the materials used in the study are listed in Table 1.

Selection, Embedding, and Standardization of Specimens

Sixty human teeth (30 canines and 30 maxillary central incisors) were selected for the study. Teeth were analyzed at 4× magnification using the following selection criteria: no caries or previous restorations, no cracks, and presence of completely formed apexes. After the selection process, teeth were cleaned, disinfected, and stored in distilled water (4°C) until use.

To simulate the periodontal ligament, the labiolingual and mesiodistal dimensions were recorded at three different points on the root of each tooth. Utility wax was then liquefied at a temperature of 70°C and applied on the root with a paintbrush up to 3 mm below the cementoenamel junction. New

Table 1: *Material, Manufacturer, Chemical Composition and Batch Number of the Products Used in the Study*

Material	Manufacturer	Chemical Composition	Batch No.
IPS e.max Press	Ivoclar Vivadent, Schann, Liechtenstein	Principal component: SiO_2; additional components: Li_2O, K_2O, MgO, ZnO, Al_2O_5.	P87414
Total Etch	Ivoclar Vivadent, Schann, Liechtenstein	37% phosphoric acid	R22282
Porcelain Conditioner	Dentstply, Petrópolis, RJ, Brazil	10% hydrofluoric acid	229431B
Excite F	Ivoclar Vivadent, Schann, Liechtenstein	Contains phosphoric acid acrylate, 2-hydroxyethyl methacrylate, dimethacrylate, highly dispersed silicone dioxide, initiators, stabilizers, and potassium fluoride in an alcohol solution	R23729
Variolink Veneer	Ivoclar Vivadent, Schann, Liechtenstein	Is composed of dimethacrylates, silicon dioxide; and ytterbium trifluoride; additional content: catalysts, stabilizers, and pigments; total content of inorganic filler is 40 vol%; filler particle sizes range from 40 nm to 300 nm	P71541
Monobond Plus	Ivoclar Vivadent, Schaan, Liechtenstein	Alcohol solution of silane methacrylate, phosphoric acid methacrylate, and sulphide methacrylate	R26662

measurements of the root dimensions, at the same points as those previously measured, were taken until a homogeneous wax thickness of 0.3 mm was obtained.[22]

The specimens were then embedded, up to the same level as the wax, in metal matrices containing autopolymerizing acrylic resin. After the acrylic resin had cured, the specimens were removed from the matrices; the wax was detached from the root surface and removed from the space created in the acrylic resin. Later, an elastomeric material (Impregum, 3M ESPE, St Paul, MN, USA) was manipulated and inserted into this space. The specimen was then repositioned and the excess polyether was removed using a scalpel.

Randomization and Preparation of the Specimens

After the specimens had been standardized, they were randomly allocated to the following four groups based on preparation design and type of tooth: Gr1 = maxillary central incisor with a conservative preparation; Gr2 = maxillary central incisor with a conventional preparation with palatal chamfer; Gr3 = canine with a conservative preparation; and Gr4 = canine with a conventional preparation with palatal chamfer. Randomization was performed by numbering the canines and the incisors from 1 to 30 and generating two sequences of 30 numbers by using a randomization program (Random Allocation, developed by M. Saghaei, Department of Anesthesia, University of Medical Sciences of Isfahan, Isfahan, Iran) to obtain homogeneous groups, thus reducing the possibility of bias in the future results.

Before starting the tooth preparation, a silicone mold of each specimen was obtained to control the veneer preparation thickness. Teeth were prepared by a single trained operator. The conservative preparation involved reducing the facial surface by 1 mm. The conventional preparation with palatal chamfer involved reducing the facial surface by 1 mm and the incisal edge by 2 mm; the chamfer's height and width were 1 mm each. Preparations were extended to the cementoenamel junction and the margins were confined to the enamel. Preparations were executed with a regular rotatory diamond instrument (4137F, KG Sorensen, Cotia, Brazil) and finishing procedures were executed with a fine-grain diamond rotatory instrument (4138FF, KG Sorensen). Each diamond instrument was discarded after preparing three specimens.

Modeling Procedures and Obtaining of Ceramic Veneers

Specimens were molded using an elastomeric material (Express XT, 3M ESPE), and the master casts were obtained in a Type IV dental stone (Elite Rock, Zhermack, Badia Polesine, Italy). On each master cast, the laminate veneer was built up with vegetal wax (GEO, Renfert, Hilzingen, Germany) by using the mold obtained before the tooth preparation. Thereafter, ceramic restorations were fabricated using lithium disilicate ceramic ingots (IPS e.max Press, Ivoclar Vivadent, Schaan, Liechten-

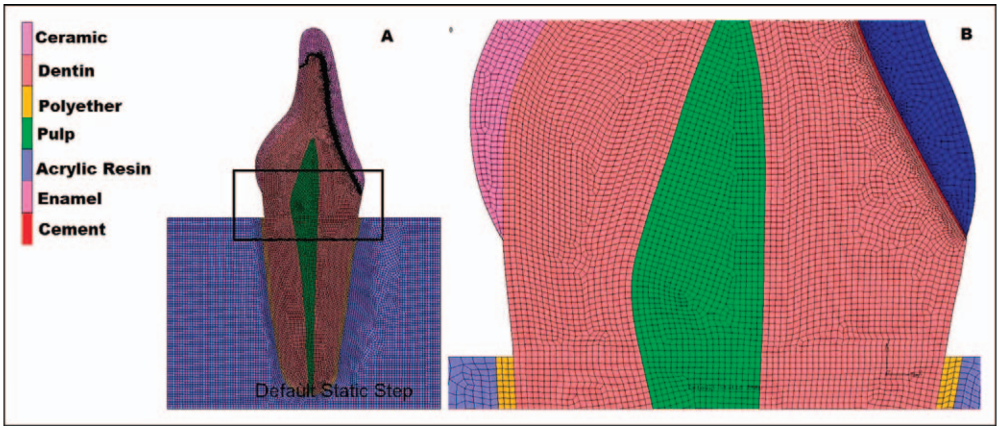

Figure 1. *(A): Mesh obtained (canine with palatal chamfer). (B): Closer view showing the adequate relation between the elements.*

stein) in accordance with the manufacturer's instructions.

Cementation Procedures

The enamel and dentin were conditioned with 37% phosphoric acid (Total Etch, Ivoclar Vivadent) for 20 seconds and 15 seconds, respectively. Surfaces were washed with distilled water and dried with absorbent papers. The total-etch adhesive system (ExciTE F, Ivoclar Vivadent) was applied to the surfaces for 20 seconds, air-sprayed, and then photoactivated (Radii Cal, SDI, Bayswater, Australia) for 20 seconds.

The ceramic surfaces were etched with 10% hydrofluoric acid (Porcelain Conditioner, Dentsply, Petropolis, Brazil) for 20 seconds; a silane coupling agent (Monobond Plus, Ivoclar Vivadent) was applied and allowed to react for 3 minutes. A resin cement (Variolink Veneer, Ivoclar Vivadent) was then applied on the internal surface of each laminate veneer. The restorations were cemented onto the corresponding teeth, excess resin cement was removed, and photoactivation (Radii Cal, SDI) was performed for 20 seconds on each face. All cementation procedures were performed by a single trained operator.

Mechanical Cyclic Aging and Periodic Evaluation

After the cementation procedures were completed, specimens were positioned at a 45° inclination and immersed in water at 37°C in a fatigue simulator (Erios ER 11000, Erios, São Paulo, Brazil). A stainless steel piston with a flat surface was positioned on the incisal portion of each specimen; 4×10^6 cycles were induced with a load of 100 N, at a frequency of 4 Hz. Between the piston and the specimen, a polyester matrix strip was positioned.

After every 500,000 cycles, the specimens were analyzed in a stereomicroscope (Discovery V-20, Zeiss, Göttingen, Germany) for the following outcomes: ceramic veneer irreparable fracture, ceramic veneer decementation, and ceramic veneer cracks. If an event was noted, the specimen received a score that was then used to calculate the survival rate.

Load to Fracture Evaluation

The specimens that did not fail during mechanical cycling were positioned in a universal testing machine (EMIC DL 2000, EMIC, São José dos Pinhais, Brazil) at a 45° inclination. A stainless steel piston with a flat surface was used to induce a load until the specimens fractured.

Failure Mode Evaluation

All fractured specimens were analyzed using a stereomicroscope (Discovery V-20, Zeiss), and the type of failure was classified based on the following criteria: type I = veneer decementation; type II = ceramic veneer fracture without fracture of coronal structure; type III = coronal dental fracture; Type IV = reparable root fracture above the simulated periodontal ligament; and type V = catastrophic root fracture below the simulated periodontal ligament.

Finite Element Analysis

Bidimensional models were obtained via computer-assisted design software (Rhinoceros 4.0). The dental structures were modeled using values from the literature,[23,24] and other structures (periodontal ligament, acrylic resin, resin cement, laminate

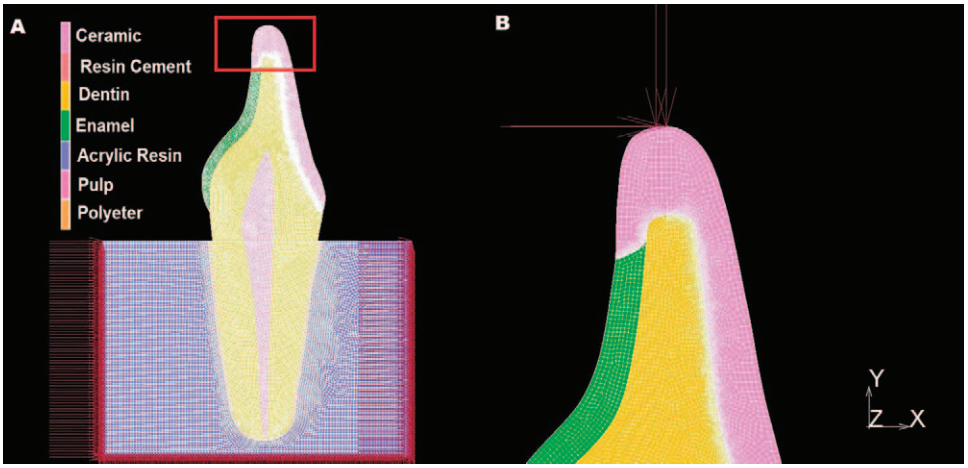

Figure 2. *(A): External elements of acrylic resin were fixed at the x, y, and z axes. (B): Force applied on the elements at the incisal portion.*

veneer) were modeled by replicating the laboratory characteristics and dimensions.

The models were extracted to a preprocessing software (MSC.Patran 2005 r2) and the mesh conditions (Figure 1) were generated by quadrilateral elements (QUAD 4) in the plane strain condition. The number of elements varied for each model as follows: 29,769 elements for canine with conventional preparation with palatal chamfer; 30,723 elements for canine with conservative preparation; 30,456 elements for central incisor with conventional preparation with palatal chamfer; and 29,327 elements for central incisor with conservative preparation.

The external elements of the acrylic resin had their movement restricted in all axes (x, y, and z) (Figure 2A), and a load of 100 N was applied on the incisal region at a 45° inclination (Figure 2B). The materials were considered isotropic, homogeneous, and linear, and their properties were provided in accordance to the literature (Table 2). Finally, the models were analyzed using a postprocessing software (MSC.Marc 2005 r2) to verify the distribution and direction of maximum principal stress (Max σ_1) in the ceramic veneer restoration and on the dentin surface.

Statistical Analysis

Initially, the sample size was calculated. Based on a standard deviation of 150 N, with differences of 200 N between groups, conferring a significance level of 5% and a power sample of 95%, the sample size estimated was 12 specimens per group. However, as the power sample would be almost 99% with a sample size of 15 specimens, we selected 15 specimens per group.

Survival rates were evaluated by Kaplan-Meier and log-rank tests ($\alpha = 0.05$). The load to fracture values were evaluated using the Student *t*-test ($\alpha = 0.05$). One Student *t*-test was performed to compare values between canines, and another Student *t*-test was performed to compare values between central incisors. Statistix 8 (Analytical Software, Tallahassee, FL, USA) software was used for data analysis.

RESULTS

The restorations did not fail after mechanical cycling, generating Kaplan-Meier survival rates of 100% for all the groups and no statistically significant differences between them. Student *t*-tests did not show any influence of preparation design on the load to fracture values (Table 3). The failure mode analysis (Table 4) showed the highest number of catastrophic root fractures (below periodontal liga-

Table 2: *Materials, Elastic Modulus, and Poisson Coefficient*

Material	Elastic Modulus (GPa)	Poisson
Dentin[25]	18.6	0.31
Resin cement[26]	2.6	0.33
Acrylic resin[27]	2.7	0.35
Enamel[28]	46.8	0.3
Lithium disilicate based ceramic (IPS.emax Press)[a]	95	0.3
Dental pulp[29]	0.003	0.45
Polyether[30]	0.05	0.45

[a] Manufacturer's information (Ivoclar Vivadent, Schaan, Lietchteinstein).

Table 3: *Mean, Standard Deviations (Newtons), and Statistical Values After Student t-Test (α=0.05) for the Fracture Load Values*[a]

Preparation	Teeth	
	Canine	Central Incisor
Conservative	705.6 (131.8)[B]	519.3 (171.2)[b]
	(p=0.193)	(p=0.166)
Palatal chamfer	638.8 (141.9)[B]	441.9 (123.4)[b]

[a] Identical letters represent similar statistical results (comparisons between columns).

ment) (Figure 3), followed by coronal dental fractures.

By FEA, groups subjected to the conventional preparation with palatal chamfer showed higher tensile stress values in ceramic restorations (Figure 4) compared with the other groups, when using the restorative material (lithium disilicate ceramic). All models showed tensile stress values in the palatal cervical region of the root; models subjected to conventional preparation with palatal chamfer showed slightly higher values than the other groups (Figure 5).

The directions of the tensile stress vectors both in the ceramic veneer and in the root dentin are shown in Figures 6 and 7, respectively.

DISCUSSION

Some methodologic aspects are important in guaranteeing the quality and reliability of a study. A reliable randomization process and an adequate sample size are examples of aspects that increase the authenticity of a study.[31] In this study, the use of a computer program to randomize the specimens reduced the possibility of bias interfering with the results.[31] Besides this, the power analysis performed was important to avoid any misinterpretation of the results, by rightly rejecting the null hypothesis when it is indeed false.[32]

After mechanical cyclic aging and periodic evaluations, the Kaplan-Meier test did not show statistically significant differences between the groups, thereby confirming the first and second hypotheses of this study. The survival rate values observed in this study (100%) differ from the values observed by Stappert and others.[6] However, Stappert and others[6] cycled their specimens by using an ellipsoidal curve pattern with horizontal and vertical components that generated an impact on the palatal surface. This pattern of cycling could have induced too much stress on the specimens and therefore may explain the difference in the study results.

On the other hand, when we compared the survival rates of this study with those of clinical studies, we observed similarities between the values.[10,12,14,15,33,34] Smales and Etemadi[14] Guess and Stappert[10] and D'arcangelo and others[34] did not record any catastrophic failures in their specimens during the first 4 years of clinical service. The 4×10^6 mechanical cycles performed in our study correspond to 4 years of clinical function,[18] thus reinforcing the similarities between the studies.

The high survival rate values, observed both in this *in vitro* study and in clinical studies, could be related to the excellent adhesion achieved between both the resin cement-ceramic interface and the resin cement-dental substrate interface in this type of restoration. For ceramic, the surface treatment protocol is well established in the literature, showing high and stable bond-strength values.[35-38] As for the tooth substrate, the adhesive procedure performed during the ceramic veneer cementation is basically on the enamel. This guarantees a good pattern of union and is mentioned by some authors as the reason for the success of this restorative technique.[12,14,33,34,39,40]

Another factor that could have influenced the survival rates in this study is the methodology used to detect cracks in the restoration. Evaluation under

Table 4: *Amount and Percentage of Failure Mode for Each Group*

Preparation Groups	Mode of Failure[a]				
	Type I	Type II	Type III	Type IV	Type V
Canine with conservative preparation	0	0	4 (27%)	1 (6%)	10 (67%)
Canine with palatal chamfer	1 (6%)	1 (6%)	0	5 (34%)	8 (54%)
Central incisor with conservative preparation	0	0	3 (11%)	1 (6%)	11 (73%)
Central incisor with palatal chamfer	1 (6%)	1 (6%)	2 (13%)	3 (21%)	8 (54%)
Total	2 (3%)	2 (3%)	9 (15%)	10(17%)	37 (62%)

[a]Type I, veneer decementation; type II, ceramic veneer fracture without fracture of coronal structure; type III, coronal dental fracture; type IV, reparable root fracture above the simulated periodontal ligament; type V, catastrophic root fracture below the simulated periodontal ligament.

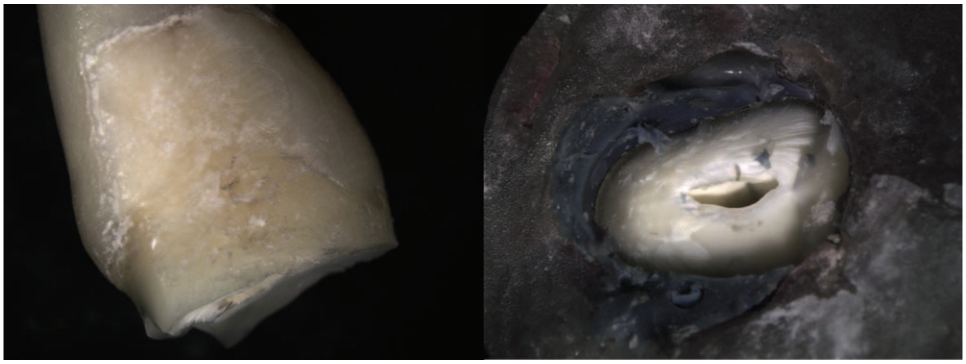

Figure 3. *Representative image of an irreparable root fracture.*

a stereomicroscope, without the use of a dye solution may not be capable of detecting cracks.

In relation to the load to fracture values, the Student *t*-tests did not show any statistically significant difference between the preparation designs, independent of the type of tooth restored, thereby confirming the first and second hypotheses of the study and corroborating the findings of some studies.[6,41,42] On the other hand, the findings of other studies did not agree with our results.[7,9,43,44] The fact that these studies used different design parameters, such as a different region of applied load during the load to fracture test, no aging of the specimens, use of different ceramic materials for tooth restoration, and difference in the thickness of ceramic restorations, could have contributed to the absence of similarities between the results.

The failure mode analysis showed a predominance of root fractures (Table 4). These data are in accordance with findings of other laboratory studies that used the incisal edge to apply the load during the load to fracture test.[6,7,41,42] However, this failure mode was not observed in clinical studies, which show a predominance of ceramic veneer fractures and decementation failures.[10,12,14,15,33,34] This could be a limitation of the load to fracture test. Hence, reproducing failures similar to those seen in clinical function could be an area of improvement for future studies.

We conducted an FEA using a two-dimensional (2D) model instead of a three-dimensional model. Although three-dimensional models can better reproduce the clinical characteristics, in some cases, this model can hinder the obtainment of a fine mesh, especially in thin regions (resin cement and ceramic finish lines).[45] Moreover, there are studies validating the use of 2D models to evaluate restored teeth.[46-48] Magne and Douglas[45] stated that the mechanical events that occur in teeth restored using laminated veneers are in the vestibulolingual plane, thereby supporting the use of a 2D plane strain model for evaluating the scenario.

In the present study, FEA showed a difference in the tensile stress distribution between the models, thereby rejecting the third hypothesis of this study. Independent of the type of tooth, FEA showed that specimens prepared with the conventional design with palatal chamfer generated higher tensile stress values in ceramic restorations compared with teeth

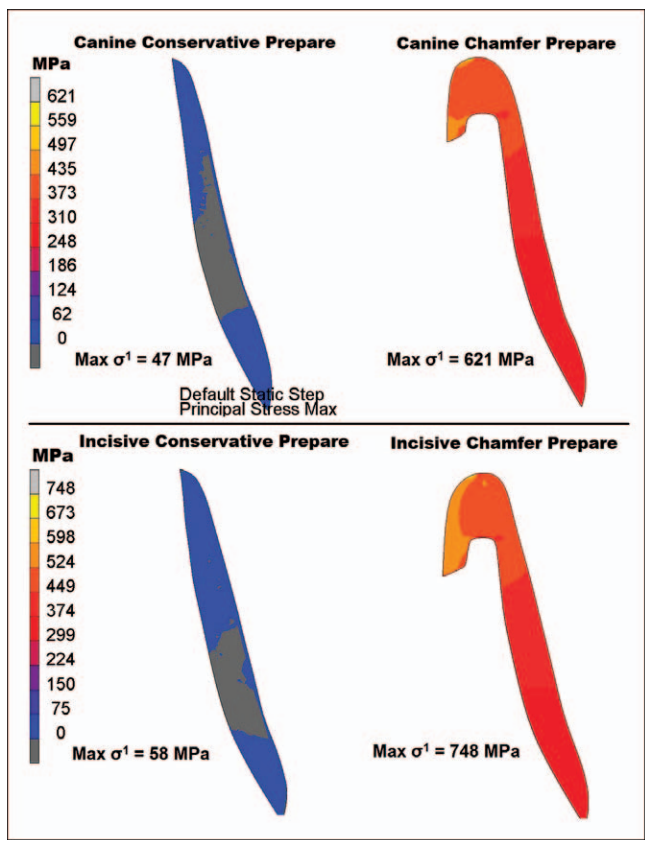

Figure 4. *Maximum principal stress distribution in the ceramic veneer.*

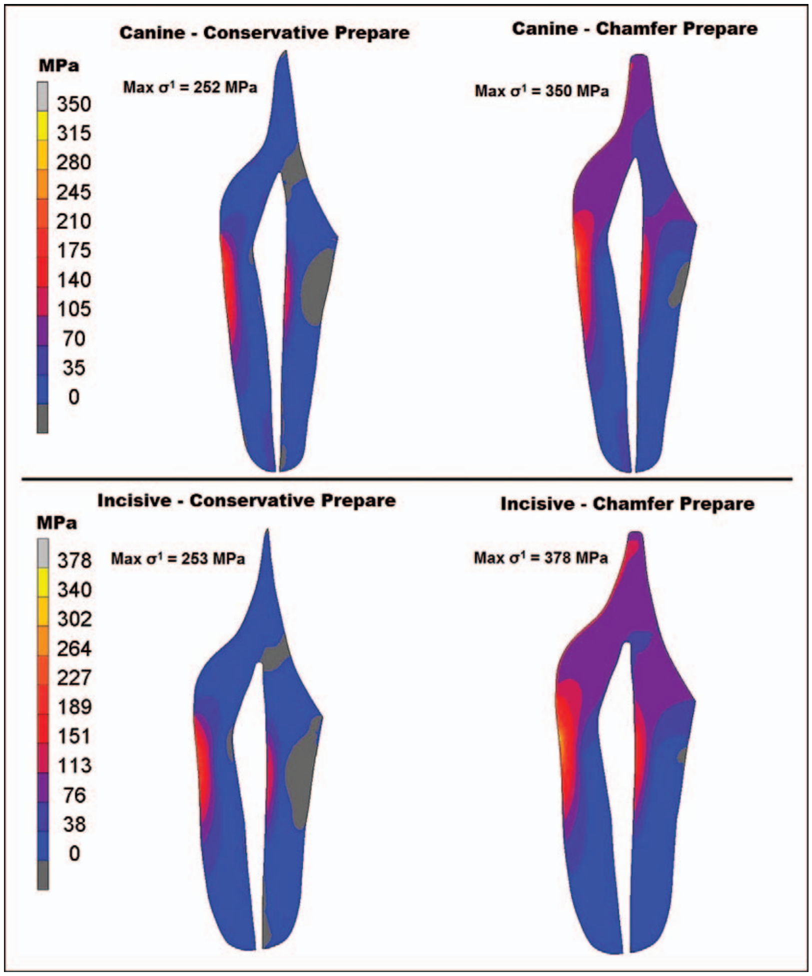

Figure 5. *Maximum principal stress distribution in the root dentin.*

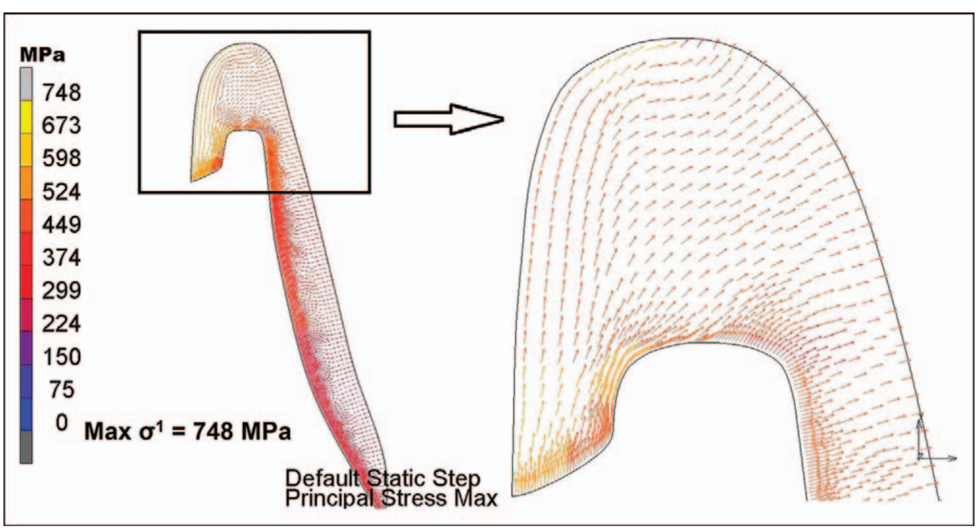

Figure 6. *Values and direction of the maximum principal stress vectors in the ceramic veneer.*

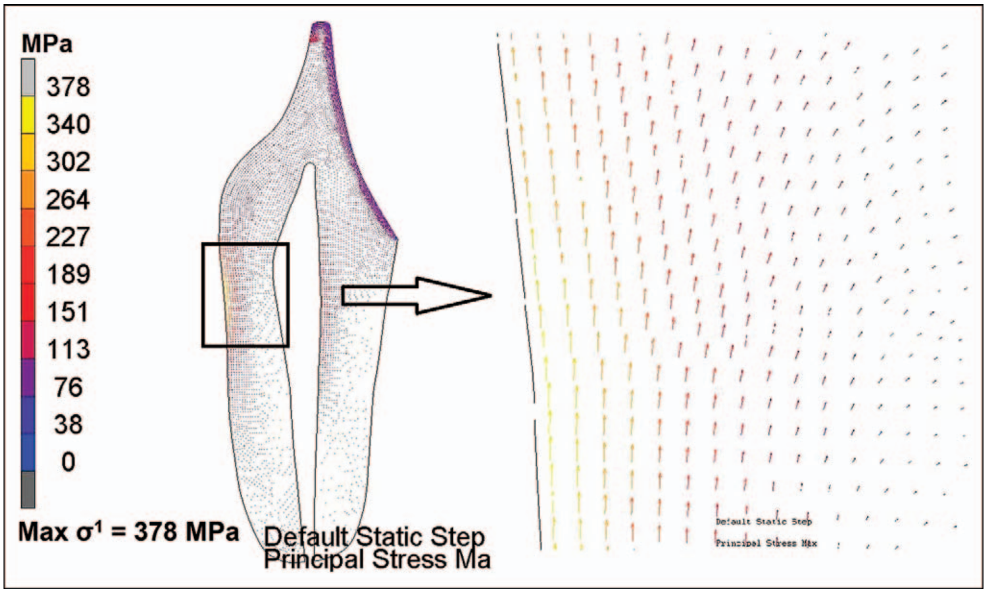

Figure 7. *Values and direction of the maximum principal stress vectors in the root dentin.*

subjected to the conservative preparation (Figure 4). This result is in accordance with that of the Magne and Douglas[45] study but not the study performed by Zarone and others (2005).[49] The difference observed between the present study and Zarone's study could be related to the fact that Zarone used Von Mises stress for analysis, fixed the movement of the elements located on the external surface of the root, and simulated a laminate veneer with a 0.5 mm thickness.

The differences in the tensile stress distribution of the models did not influence the mode of failure between the groups. However, it is possible to suppose that teeth prepared with the conventional design with palatal chamfer present a higher possibility of suffering a restoration fracture. This is corroborated by the direction of the tensile stress vectors seen in the veneer (Figure 6). Although no relation to any mode of failure could be established in the present study, the tensile stress distribution and tensile stress vector directions were in agreement with the mode of failure observed in clinical studies.[10,11,34,50]

The FEA also showed a tensile stress concentration in the root dentin (Figure 5). This distribution, in addition to the tensile stress vector direction in the root dentin, can explain the pattern (Figure 3) and incidence (Table 4) of root fractures observed in this study. The incidence of root fractures could be related to the mechanical properties of the ceramic material used to fabricate the restorations (lithium disilicate, IPS e.max Press, Ivoclar Vivadent) and to the quality of adhesion achieved between the interfaces, turning the lithium disilicate into an interesting material for ceramic veneer restoration. It is possible that if a fragile material (a feldspathic ceramic) had been used, the mode of failure and the results of this research might have been different.

CONCLUSION

Based on the results we conclude that (1) conservative preparations and conventional preparations with palatal chamfer, whether performed on canines or maxillary central incisors, generate similar load to fracture and survival rate values; (2) conventional preparation with palatal chamfer generates higher maximum principal stress concentration in the laminate veneer compared with conservative preparation.

Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

(Accepted 5 October 2013)

REFERENCES

1. Aykor A, & Ozel E (2009) Five-year clinical evaluation of 300 teeth restored with porcelain laminate veneers using total-etch and a modified self-etch adhesive system *Operative Dentistry* **34(5)** 516-523. http://dx.doi.org/10.2341/08-038-C

2. Bottino MA, Valandro LF, & Faria R (2009) *Perception* Artes Medicas, São Paulo.
3. Belser UC, & Magne M (1997) Ceramic laminate veneers: continuous evolution of indications *Journal of Esthetic Dentistry* **9(4)** 197-207.
4. Magne P, Perroud R, Hodges JS, & Belser UC (2000) Clinical performance of novel-design porcelain veneers for the recovery of coronal volume and length *International Journal of Periodontics and Restorative Dentistry* **20(5)** 440-457.
5. Fradeani M, Redemagni M, & Corrado M (2005) Porcelain laminate veneers: 6-12 year clinical evaluation—a retrospective study *International Journal of Periodontics and Restorative Dentistry* **25(1)** 9-17.
6. Stappert CFJ, Ozden U, Gerds T, & Strub JR (2005) Longevity and failure load of ceramic veneers with different preparation designs after exposure to masticatory simulation *Journal of Prosthetic Dentistry* **94(2)** 132-139.
7. Chun YP, Raffelt C, Pfeiffer H, Bizhang M, Saul G, Blunck U, & Roulet JF (2010) Restoring strength of incisors with veneers and full ceramic crowns *Journal of Adhesive Dentistry* **12(1)** 45-54.
8. D'arcangelo C, de Angelis F, Vadini M, D'Amario M, & Caputi S (2010) Fracture resistance and deflection of pulpless anterior teeth restored with composite or porcelain veneers *Journal of Endodontics* **36(1)** 153-156. http://dx.doi.org/10.1016/j.joen.2009.09.036
9. Schmidt KK, Chiayabutr Y, Phillips KM, & Kois JC (2011) Influence of preparation design and existing condition of tooth structure on load to failure of ceramic laminate veneers *Journal of Prosthetic Dentistry* 2011 **105(6)** 374-382. http://dx.doi.org/10.1016/S0022-3913(11)60077-2
10. Guess PC, & Stappert CFJ (2008) Midterm results of a 5-year prospective clinical investigation of extended ceramic veneers *Dental Materials* **24(6)** 804-813.
11. Granell-Ruiz M, Fons-Font A, Labaiq-Rueda C, Martinez-González A, Román-Rodríguez JL & Solá-Ruiz MF (2010) A clinical longitudinal study 323 porcelain laminate veneers. Period of study from 3 to 11 years *Medicina Oral Patología Oral y Cirugía Bucal* **15(3)** e531-537.
12. Layton D, & Walton T (2007) An up to 16 year prospective study of 304 porcelain veneers *International Journal of Prosthodontics* **20(4)** 389-396.
13. Burke FJ, & Lucarotti PSK (2009) Ten-year outcome of porcelain laminate veneers placed within the general dental services in England and Wales *Journal of Dentistry* **37(1)** 31-38. http://dx.doi.org/10.1016/j.jdent.2008.03.016
14. Smales RJ, & Etemadi S (2004) Long-term survival of porcelain laminate veneers using two preparation designs: a retrospective study *International Journal of Prosthodontics* **17(3)** 323-326.
15. Gresnigt MM, Kalk W, & Ozcan M (2013) Randomized clinical trial of indirect resin composite and ceramic veneers up to 3 years follow-up *Journal of Adhesive Dentistry* **15(2**) 181-90. http://dx.doi.org/10.3290/j.jad.a28883
16. Adebayo OA, Burrow MF, & Tyas MJ (2008) Bond strength test: role of operator skill *Australian Dental Journal* **53(2)** 145-150. http://dx.doi.org/10.1111/j.1834-7819
17. Dietschi D, Romelli M, & Goretti A (1997) Adaptation of adhesive posts and cores to dentin after fatigue testing *International Journal of Prosthodontics* **10(6)** 498-507.
18. Wiskott HWA, Nicholls JL, & Belser UC (1995) Stress fatigue: basic principles and prosthodontic implications *International Journal of Prosthodontics* **8(2)** 105-16.
19. Soares CJ, Santana FR, Castro CG, Santos-Filho PCF, Soares V, Qianb F, & Armstrong SR (2008) Finite element analysis and bond strength of a glass post to intraradicular dentin: comparison between microtensile and push-out tests *Dental Materials* **24(10)** 1405-1411. http://dx.doi.org/10.1016/j.dental.2008.03.004
20. Versluis A, Messer HH, & Pintado MR (2006) Changes in compaction stress distributions in roots resulting from canal preparation *International Endodontic Journal* **39**(12) 931-939.
21. Farah JW, Craig RG, & Sikarskie DL (1973) Photoelastic and finite element stress analysis of a restored axisymmetric first molar *Journal of Biomechanics* **6(5)** 511-20.
22. Soares CJ, Pizi ECG, Fonseca RB, & Martins LRM (2005) Influence of root embedment material and periodontal ligament simulation on fracture resistance tests *Brazilian Oral Research* **19(1)** 11-16.
23. Serra OD, & Ferreira FV (1981) *Dental Anatomy* Artes Médicas, São Paulo.
24. Harris EF, & Hicks JD (1998) A radiographic assessment of enamel thickness in human maxillary incisors *Archives of Oral Biology* **43(10)** 825-831.
25. Peyton FA, Mahler DB, & Hershenov B (1952) Physical properties of dentin *Journal of Dental Research* **31(3)** 366-370.
26. Pegoretti A, Fambri L, Zappini G, & Bianchetti M (2002) Finite element analysis of a glass fibre reinforced composite endodontic post *Biomaterials* **23(13)** 2667-2682.
27. Ebadian B, Farzin M, Talebi S, & Khodaeian N (2012) Evaluation of stress distribution of implant-retained mandibular overdenture with different vertical restorative spaces: a finite element analysis *Dental Research Journal* **9(6)** 741-747.
28. Wright KW, & Yettram AL (1979) Reactive force distributions for teeth when loaded singly and when used as fixed partial denture abutments *Journal of Prosthetic Dentistry* **42(4)** 411-416.
29. Toparli M, Aykul H, & Sasaki S (2003) Temperature and thermal stress analysis of a crowned maxillary second premolar tooth using three-dimensional finite element method *Journal of Oral Rehabilitation* **30(9)** 99-105.
30. Farah JW, Clark AE, & Ainpour PR (1981) Elastomeric impression materials *Operative Dentistry* **6(1)** 15-9.
31. Montenegro R, Needleman I, Moles D, & Tonetti M (2002) Quality of RCTs in periodontology—a systematic review *Journal of Dental Research* **81(12)** 866-870.

32. Callegari-Jacques SM (2008) *Bioestatística: princípios e aplicações* Artmed, Porto Alegre.

33. Çotert HS, Dundar M, & Ozturk B (2009) The effect of various preparations designs on the survival of porcelain laminate veneers *Journal of Adhesive Dentistry* **11(5)** 405-411.

34. D'arcangelo C, De Angelis F, Vadini M, & D'Amario M (2011) Clinical evaluation on porcelain laminate veneers bonded with light-cured composite: results up to 7 years *Clinical Oral Investigation* **16(4)** 1071-1079. http://dx.doi.org/10.1007/s00784-011-0593-0

35. Brentel A, Özcan M, Valandro LF, Amaral R, Alarça LG, & Bottino MA (2007) Microtensile bond strength of a resin cement to feldspathic ceramic after different etching and silanization regimens in dry and aged conditions *Dental Materials* **23(11)** 1323-1331.

36. Amaral R, Özcan M, Bottino MA, & Valandro LF (2011) Resin bonding to a feldspar ceramic after different ceramic surface conditioning methods: evaluation of the contact angle, surface pH, and microtensile bond strength durability *Journal of Adhesive Dentistry* **13(6)** 551-560. http://dx.doi.org/doi: 10.3290/j.jad.a19815

37. Leite F, Özcan M, Valandro LF, Amaral R, Bottino MA, & Kimpara ET (2013) Effect of the etching duration and ultrasonic cleaning on microtensile bond strength between feldspathic ceramic and resin cement *Journal of Adhesive Dentistry* **89(3)** 159-173.

38. Vanderlei A, Passos SP, Özcan M, Amaral R, Bottino MA, & Valandro LF (2013) Durability of adhesion between feldspathic ceramic and resin cements: effect adhesive resin, polymerization mode of resin cement and aging *Journal of Prosthodontics* **22(3)** 196-202. http://dx.doi.org/10.1111/j.1532-849X.2012.00934.x

39. Kato Y, Taira Y, Kato C, Suzuki M, & Shinkai K (2009) A case report of a 20-year clinical follow-up of porcelain laminate veneer restorations *Operative Dentistry* **34(5)** 626-630.

40. MacLaren EA, & Lesage B (2011) Feldspathic veneers: what are their indications? *Compendium of Continuing Education in Dentistry* **32(3)** 44-49.

41. Alghazzawi TF, Lemons J, Liu PR, Essig ME, & Janowski GM (2012) The failure load of CAD/CAM generated zirconia and glass-ceramic laminate veneers with different preparation designs *Journal of Prosthetic Dentistry* **108(6)** 386-393. http://dx.doi.org/10.1016/S0022-3913(12)60198-X

42. Lin TM, Liu PR, Ramp, LC, Essig MR, Givan DA, & Pan YH (2012) Fracture resistance and marginal discrepancy of porcelain laminate veneers influenced by preparation design and restorative material in vitro *Journal of Dentistry* **40(3)** 202-209. http://dx.doi.org/10.1016/j.jdent.2011.12.008

43. Castelnuovo J, Anthony HLT, Phillips K, Nicholls JT, & Kois JC (2000) Fracture load an mode of failure of ceramic veneers with different preparation *Journal of Prosthetic Dentistry* **83(2)** 171-180.

44. Chaiyabutr Y, Phillips KM, Ma PS, & Chitswe K (2009) Comparison of load-fatigue testing of ceramic veneers with two different preparation designs *International Journal of Prosthodontics* **22(6)** 573-575.

45. Magne P, & Douglas WH (1999) Design optimization and evolution of bonded ceramics for the anterior dentition: a finite-element analysis *Quintessence International* **30** 661-672.

46. Magne P, Versluis A, & Douglas WH (1999) Rationalization of incisal shape: experimental numerical analysis *Journal of Prosthetic Dentistry* **81(3)** 345-355.

47. Morin DL, Douglas WH, Cross M, & De Long R (1988) Biophysical stress analysis of restored teeth: experimental strain measurements *Dental Materials* **4(1)** 41-48.

48. Morin DL, Cross M, Voller VR, Douglas WH, & De Long R (1988) Biophysical stress analysis of restored teeth: modelling and analysis *Dental Materials* **4(2)** 77-84.

49. Zarone F, Apicella D, Sorrentino R, Ferro V, Aversa R, & Apicella A (2005) Influence of tooth perparation design on the stress distribution in maxillary central incisors restored by means of alumina porcelain veneers: a 3D-finite element analysis *Dental Materials* **21(12)** 1178-1188.

50. Beier US, Kapferer I, Burtscher D, & Dumfahrt H (2012) Clinical performance of porcelain laminate veneers for up to 20 years *International Journal of Prosthodontics* **25(4)** 79-85.