Influence of occlusal anatomy on acrylic resin CAD/CAM crowns fracture load and stress distribution

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Abstract

Objectives: This study compared the influence of occlusal anatomy on acrylic CAD/CAM crowns fracture load and stress distribution. The null hypothesis was that there would be no difference between the provisional crowns fracture load and stress according to different occlusal anatomy.

Methods: A full-crown preparation was simulated using dentin analogue (G10, Protec, São Paulo, Brazil) totaling 20 identical preparations. Next, twenty acrylic crowns were milled using different occlusal design parameter (Young or Adult) available in the software database. The crowns were cemented (Temp-bond, NE Kerr Dental, Brea, CA, USA) and fractured using a compressive load (0.5 mm/min of cross-head speed). Data were analyzed by using one-way ANOVA and Tukey tests (p< 0.05). A similar geometry was modeled and exported to the analysis software to perform a static structural analysis. The maximum principal stress was calculated using the finite element method with 300 N chewing load simulation.

Results: The occlusal anatomy significantly influenced the load-to-fracture (p<0.05). Young design showed lower fracture load (1139±132 N) than Adult design (2007±345 N). The tensile stress distribution showed a similar pattern for both groups however the highest stress peak was calculated for Young design (76 MPa) in the occlusal surface.

Conclusion: The anatomy design with higher cusp angulation and occlusal sulcus more evident can increase the stress concentration and reduce the fracture load for acrylic resin CAD/CAM crowns.

Introduction

Temporary crowns are indicated to be used as an intermediate restoration between the time of tooth preparation and the final indirect restoration procedure [1,2]. There are two major approaches for fabrication of temporary crowns: direct (manual) and indirect methods (CAD/CAM) [1].

Computer-aided design and computer-aided manufacturing (CAD-CAM) method allow the manufacture of acrylic crowns in pre-polymerized conditions, which improves mechanical properties, reduces discoloration, and increases the anatomy precision and reduces the marginal gap [3]. Another advantage of polymer-based CAD/CAM materials is their good machinability [4].

The literature reports that the provisional CAD/CAM fixed dental prosthesis [5] and crown [1] exhibit a higher mechanical strength compared to directly fabricated, when manufactured with the same material [5].

Despite the restorative technique, another factor that was strongly linked to fractures of dental restorations is their occlusal anatomy. For ceramic crowns, the

cusp angles can influence the prosthesis's resistance and the stress concentration [6,7]. However the occlusal geometry and and fissure radius are still inconclusive [7]. Basically, crowns with thicker margins, smaller convergence angle and fully bonded are recommended for increasing fracture resistance final restorations [8]. This can be justified because a greater crown thickness and cusp angle resulted in a higher crack initiation load [9]. However, these information were not available for acrylic resin CAD/CAM crowns. Based on this, the aim of the current study was to investigate the influence of different occlusal anatomy patterns on the fracture behavior of acrylic resin full-crown restorations. The null hypothesis was that there would be no difference between the provisional crowns fracture load and stress according to different occlusal anatomy.

Methods

Twenty (20) crown preparations were machined in epoxy resin (G10, Protec, São Paulo, Brazil) using CAD/CAM (Computer Aided Design/Computer Aided Machine) technology. The use of this dentin analogue has been previous validated in literature [10,11], and its usage allows the samples standardization with a homogeneous substrate, reducing the bias associated with the complexity of mechanical properties in natural human teeth. The occlusal and axial walls were uniformly reduced (1.5 mm). The preparations presented rounded internal angles, chamfer preparation, and total occlusal convergence of 20°. The abutments were cleaned in an ultrasonic bath with distilled water for 5 min and embedded in self-cured polyurethane resin (25 mm Ø x 20 mm height) up to 1.5 mm bellow the chamfer [10]. Polyether (Impregum F, 3M ESPE) was used

to simulate the periodontal ligament [12]. According to the literature, the root embedment using polyether material as periodontal ligament simulator have a significant effect on fracture resistance and can modify the root fracture modes [13]. While the present study was not expecting to observe root fractures before the provisional crown fracture, the periodontal ligament simulation was performed to allow a proper load dissipation.

A thin layer of titanium dioxide-based powder was sprayed onto each abutment for scanning (inEos Blue, inLab SW4.2, Sirona, Benshein, Germany) and subsequent crown design. For that, the Cerec inLab (Sirona for Dental Systems, Benshelm, Germany) database was used to provide the restoration anatomy information , and two shapes of crowns were obtained: ''Adult''
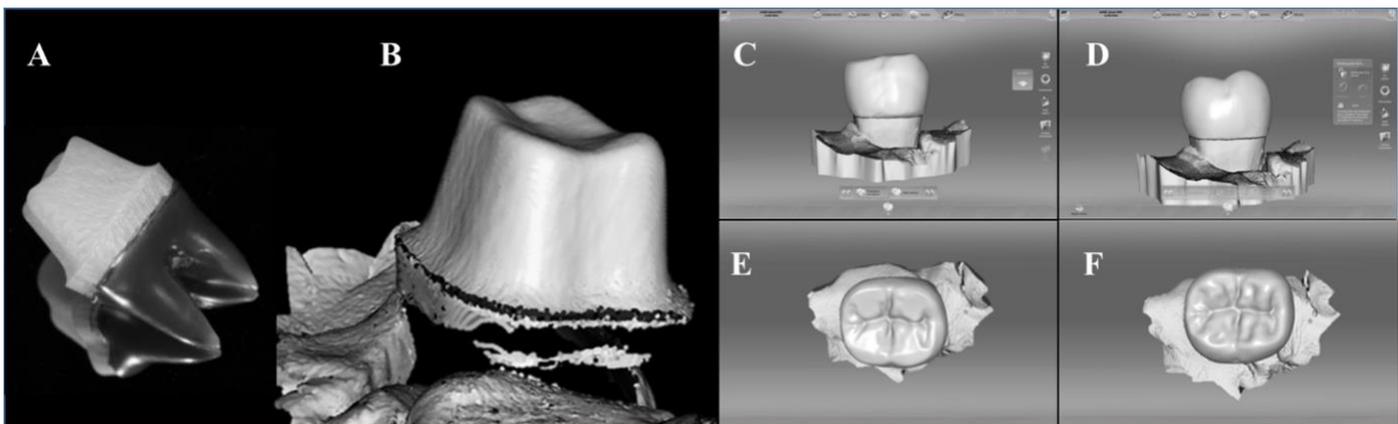

Figure 1. Sample preparation. A) Prepared abutment tooth, B) Digital impression in CAD software, C) Buccal view from Adult design crown, D) Buccal view from Young design crown, E) Occlusal view from Adult design crown and F) Occlusal view from Young design.

(AD - plane cusp) and ''Young'' (Y-high cusp heights) (Figure. 1).

The CAD/CAM temporary acrylic crowns (Vita Zahnfabrick, Bad Säckingen, Germany) were randomly allocated in groups according to the anatomy shape (n=10).

The G10 preparations were etched with 10% hydrofluoric acid (HF) for 60 s, washed with air/water jet for 30 s, and then dried [14]. The intaglio surface of each crown was air-abraded with 50 μm alumina particles at a pressure of 20 bar from a 10 mm distance for 50 s in each face with a constant particle incidence angle at 45º.

The cement (Temp-bond, NE Kerr Dental, Brea, CA, USA) was manipulated in 1:1 ratio and applied onto the intaglio surface of the crowns, which were then placed on the respective abutment and kept in a 750g weight for 5 min. After the working time, the excess cement was carefully removed (Figure 2). The cemented restorations were stored in 37 °C distilled water for 24 h before the fracture test.

Each crown was submitted to single load to fracture test (load cell of 1000 kgf and 0.5 mm/min of cross-head speed) in a universal testing machine (DL-1000, EMIC, São José dos Pinhais, Brazil). The data was recorded as the mean load value (in N) of both groups. The maximum load to fracture data were statistically analyzed using one-way analysis of variance (ANOVA) and the post-hoc Tukey multiple range tests (α=0.05) [15].

Finite Element Analysis

A three-dimensional (3D) model of an upper first molar was used to evaluate the tensile stress of the resin crown. The model containing root, pulp chamber, periodontal ligament, medullary and cortical bones was imported to Rhinoceros CAD software (version 5.0 SR8, McNeel North America, Seattle, USA). For each group (Young and Adult), the anatomy previous provided by the database during the sample preparations was exported as STL file to the CAD software and converted to NURBS using a reverse engineering plugin.

The volumetric solids were imported to the analysis software (ANSYS 16.0, ANSYS Inc., Houston, USA) in STEP (STandard for the Exchange of Product model data) format. A mesh convergence test (10%) determined 331538 nodes and 223955 tetrahedral elements for the Young design; and 3252248 nodes and 197852 elements for the Adult design preparation (Figure 3).

The contacts were considered perfectly bonded. The static structural mechanical analysis was performed loading the groups with 300 N distributed at contact areas and the base constrained
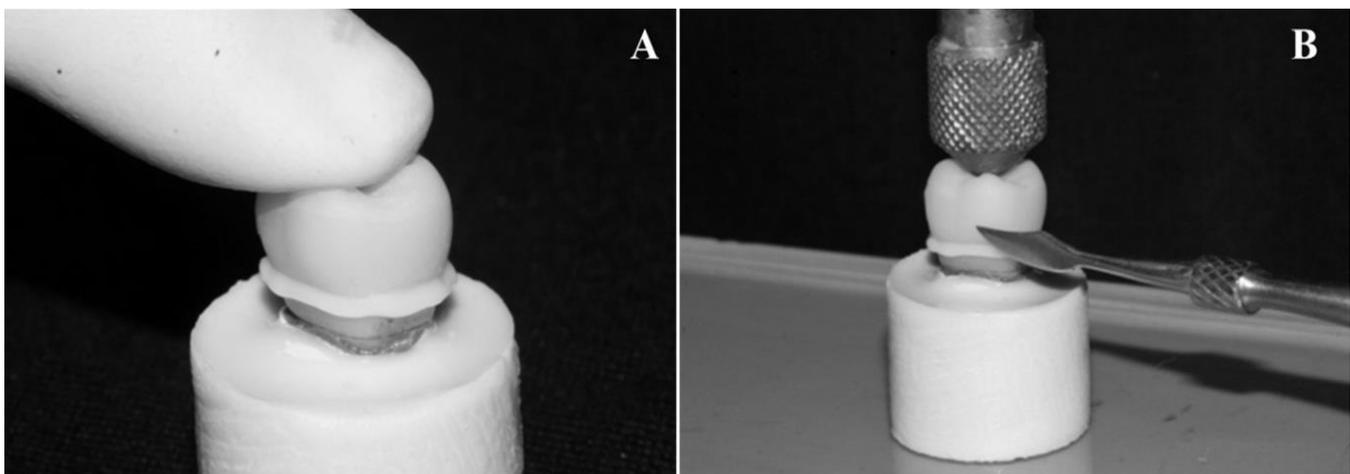

Figure 2. Luting procedure in A) Crown sitting with digital pressure and B) Excess cement removal.
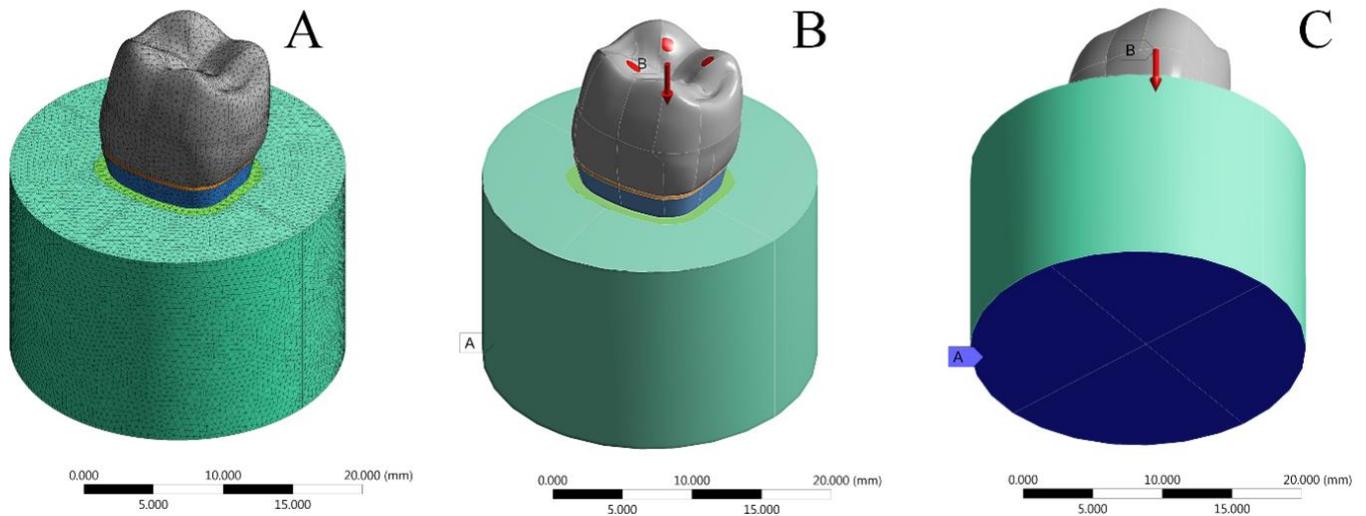
Figure 3. Boundary conditions simulated in finite element analysis. A) Mesh division, B) occlusal load contact points and C) fixed support.

following the experimental setup [16]. The Maximum Principal Stress criterion was used for analysis of the tensile stress concentration. Results were plotted in stress maps and the peaks recorded for quantitative comparison. Table 1 shows the material properties used for the finite element analysis.

Results

One-way ANOVA showed that crown design influenced on the fracture load (F = 55.19, p < 0.001). For adult design the load to fracture average was 2007±345 N and for Young design the load to fracture average was 1139±132 N.

The Young design concentrated more stress compared to Adult design restorations (Figure 4). The higher the cusp angle, the higher the stress concentration in the crown's intaglio surface and occlusal surface. The tensile stress peak values are 76 MPa for Young design and 35 MPa for Adult design. The stress concentration regions for both groups suggest that the failure origin will be located in the occlusal sulcus.

Discussion

The goal of this study was to evaluate the effect of CAD/CAM acrylic crowns occlusal anatomy on the fracture behavior; it was observed that the design influenced the crowns' fracture load and stress concentration, leading to rejection of the study's hypothesis.

Table 1. Material properties used for the finite element analysis.

Materials	Elastic Modulus (GPa)*	Poisson ratio*
Polyurethane	3.60	0.30
Polyether	0.05	0.45
Dentin analogue	17.90	0.32
Cement	5.50	0.30
Acrylic resin	6.00	0.30

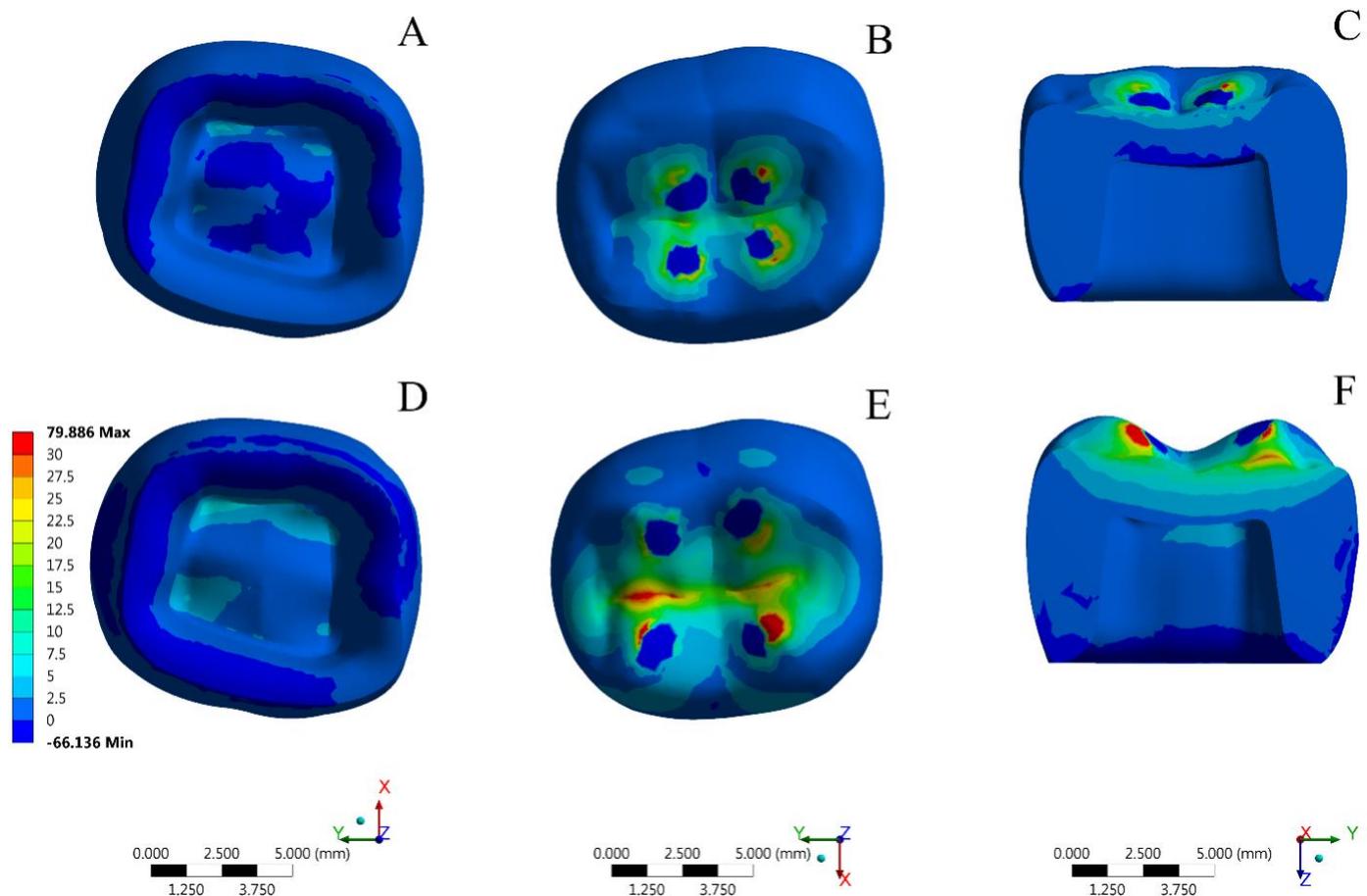*Characterization done by an acoustic excitation pulse.

Figure 4. Maximum principal stress maps results for the restoration with A-C) Adult design and D-F) Young design.

Provisional crowns are expected to have sufficient resistance against bite forces. A previous study [17] investigated the maximum human bite forces; for female they found a bite force ranging from 108.9 N to 834.6 N (mean of 424.2) and from 262.8 N to 999.3 N (mean of 587.2) for male. In our study, the fracture load of the acrylic crown had a value above the average bite strength values for both genders.

A previous study [18] reported that there is no significant difference for the fracture resistance between provisional crowns using the chamfer preparation with a width ranging from 0.6 mm to 1 mm. The present study complements this information suggesting that the failure will start in the occlusal surface and the anatomy should be more relevant for the maximum fracture load on acrylic resin CAD/CAM crowns.

The most important role that a provisional restoration plays is to stabilize and protect the existing tooth structure after tooth preparation. Besides, temporary crowns also act as interim prosthesis in cases where

treatment gets delayed as in orthodontics or implants. Therefore, temporary materials are required to be tough and fracture resistant [19]. Based on this, the present study suggests that the use of Young design should be careful indicated since it presents higher stress concentration and lower load to fracture values, suggesting a higher failure possibility.

Despite the fitting accuracy of CAD-CAM restorations, an ideal occlusal surface is difficult to design, since it demands determining the dynamic relation

between the dental arches, even if the CAD database already present a generic restoration anatomy [20]. In this sense, the use of Young or Adult morphology can be used as a predominant factor to create the occlusal shape, however the contact points should be based in the antagonist tooth and individualized for each case.

A previous report [21], found that full-crowns made using dental database with the antagonist design technique had a significantly smaller occlusal vertical discrepancy than those made with only correlation design technique; and that the use of the dental database with antagonist design provides the most accurate technique. The present study complements this report suggesting that the acrylic crown anatomy should be based in the patient`s occlusion also and not only in database anatomy.

The major difference between both crown's design simulated in the present study was the cusp angle and occlusal sulcus. Despite both designs share the same clinical indication and can be manufactured for the same clinical case, the Young design presents a more detailed anatomy. The explanation for the worst biomechanical behavior for the Young design is because the cusps of posterior teeth substantial

increased the bending and flexural loads during functional and parafunctional occlusal movements. These applied loads can theoretically generate a horizontal force component which tends to open up the principal sulcus space increasing the tensile stress concentration and subsequent creating cracks at the bottom of the fissure [22,23]. The present study corroborates with this statement since the numerical simulation showed an increased stress magnitude when the Young anatomy was used.

A previous finite element study suggest that the cusp angle can modify the loads incidence for provisional endocrowns restored molars [23]. The same indication can be performed for the present study considering only the fracture load and stress concentration for acrylic resin crowns. A 3D computer model can be used to simulate various conditions with numerous simulation parameters [24], however destructive mechanical tests, such as fracture load tests, are important for biomechanical analysis of tooth and   dental   restorative materials,   as   they enhance understanding of the behavior of teeth in high loading situations [25]. Usually, areas of high stress concentration eventual failures are more   expected to   occur [26]

and both methodologies can be associated to perform a properly investigation from the fracture mechanics [27].

In conventional acrylic resin restorations, the cross-linking agent may lead to variation in the material performance [28]. The results of the present study support the use of CAD/CAM, which may reduce voids in the composite, allowing for controlled polymerization and a more homogeneous matrix.

According to an in vitro study [9] any surface irregularity including the sharp occlusal notch can be considered as a discontinuity in the microstructure of the material which can predispose the crown to crack initiation. Factor that can be reduced using an Adult design tooth anatomy.

However, reducing the cusp angle and simplifying the tooth anatomy, can negatively affect the patient's masticatory efficiency and muscular activity when used for artificial tooth in removable partial dentures [24,29]. The present study suggests, however that the use of simplified anatomical tooth can be positive for temporary crowns, in a short-term period of use until the final restoration can be cemented.

As strengths of the present methodologies, the fracture load is an important method employed to evaluate the ultimate strength of restored posterior teeth during compressive load fracture test [30]. This mechanical test is usually performed associating the influence of different factors that can affect simultaneously the restoration success [30,31]. In addition, the finite element method is extensively applied in dental materials mechanical assessment, allowing the simulation of different structures that compose the dental restoration [2,6,10,16,22-27]. This numerical approach allows the stress maps visualization and quantitative measurements of stress peaks, indicating with acceptable precision the failure area of possible fracture origin [23,32].

As study's limitations is important to relate that a single compressive load to failure not replicate all of the clinical loads to which the restoration is exposed. The thermocycling also can reduce the bond strength between a cemented restoration increase the failure susceptibility [32,33]. The isotropic material simulated in the finite element study cannot be found in the clinics and patient's occlusion can modify the load application pattern [32]. It is also important to note that, for acrylic resin, incomplete polymerization with residual monomer unreacted promotes high degree of water absorption, deterioration of intrinsic pigments and dissolution of material components [29,33] and further studies with mechanical aging simulation should also be performed.

Conclusion

Chairside digital workflow should be performed aiming to improve the indirect restoration mechanical response, however an anatomy design with higher cusp angulation and more evident occlusal sulcus can increase the stress concentration and reduce the fracture load for acrylic resin CAD/CAM crowns.

Acknowledgments

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