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Material Thickness Influence on Fracture Load of Polymer Infiltrated Ceramic Network CAD/CAM Restorations

LIANE AVRAM[1], LUCIANA GOGUTA[1,2*], SERGIU-VALENTIN GALATANU[3*], CARMEN OPRIS[3], CODRUTA ILLE[1,2], ANCA JIVANESCU[1,2]

[1] University of Medicine and Pharmacy Victor Babes Timisoara, 2 Eftimie Murgu Sq., 300041, Timisoara, Romania
[2] Centrul de Cercetare TADERP, 2 Eftimie Murgu Sq., 300041, Timisoara, Romania
[3] University Politehnica Timisoara, 1 Mihai Viteazul Blvd., 300222, Timisoara, Romania

Abstract: *Polymer infiltrated ceramics are hybrid materials that combine the strength of ceramics and the flexibility of polymers. The aim of this study was to compare the fracture load capacity of monolithic CAD/CAM crowns with different occlusal thicknesses, made from polymer infiltrated ceramic network. Fifteen full contour CAD/CAM crowns made of Vita Enamic with occlusal thicknesses of 0.5 mm, 1.0 mm and 1.5 mm were fabricated with a wet milling machine. Restorations were cemented on human molars with adhesive cement. Samples were loaded along the long axis until fracture, with a single static compressive force. A scanning electron microscope (SEM) was used to examine the fracture surface of specimens after the fracture. The results of this study reveals that the fracture load of the samples increased progressively with the occlusal thickness. The highest fracture value was recorded for1.5 mm occlusal thickness of the crown. No statistically significant difference was reported between the three experimental groups. It can be concluded that hybrid monolithic CAD-CAM crowns showed sufficient fracture strength to be used for single restorations in the posterior area, even with a reduced occlusal thickness.*

Keywords*: CAD/CAM, polymer infiltrated ceramic network, fracture load*

1. Introduction

CAD/CAM (Computer-Aided Design/ Computer-Aided Manufacturing) technology was used with success in dentistry for more than two decades. This has brought a lot of advantages, such as shorter treatment time, industrial fabrication of the materials [1,2], with improved characteristics and reduced failure rates [3,4]. Some of the CAD/CAM materials are ready to use immediately after the milling process. They do not need furnace firing, sintering or crystallization, providing patients restorations in a single visit session [5,6]. CAD-CAM chairside systems are designed to reduce laboratory procedures, allowing practitioners to follow all the steps of crown restoration, from preparation to cementation, in one single appointment. Therefore, there is no need for provisional restorations [7]. All the data are collected with an intraoral scanner, which eliminate the conventional impression. The digital design (CAD) of the prosthetic restoration is finalized with a specific software, and using a subtractive process, the milling machine (CAM) will deliver the final restoration in several minutes [6-9]. Ceramic blocks were the first CAD-CAM materials developed for in office use, showing superior mechanical properties, outstanding esthetic, color stability, and excellent biocompatibility [10,11].

Some of the disadvantages of these ceramics are that they are breakable, difficult to repair and will cause in time natural tooth wear [11-13]. New hybrid CAD/CAM materials are represented by either a ceramic network filled with polymer, or a polymer matrix infiltrated with ceramic particles [6]. The infiltrated ceramics and resins have better elasticity, are less brittle, with improved mechanical, optical, and esthetic properties [1,6,7].

Until present, Vita Enamic is the only example of hybrid ceramic with a three-dimensional matrix of feldspar ceramic filled with acrylate polymer under heat and pressure. It contains feldspar ceramic (86 wt%) infiltrated by polymers (14 wt%) such as urethane dimethacrylate (UDMA) and triethylene glycol dimethacrylate (TEGDMA) [7,14]. This combination of the ceramic and polymer gives the material the

*email:lucianagoguta@yahoo.co.uk; lucianag@umft.ro; sergiu.galatanu@upt.ro

flexibility of the resin and the strength of the ceramic [3,15,16]. The polymer component prevents the crack formation and propagation and determine pressure absorbing produced by the intraoral forces [1,17]. Compared to the ceramic materials, polymer-infiltrated-ceramic-network (PICN) have enhanced fracture toughness (30 GPa) and the modulus of elasticity is equal to the dentin (from 9 to 14 GPa). Disadvantages of this material consists in reduced flexural strength and reduced the wear resistance [7,12,13,15].

2. Materials and methods

2.1. Specimen Preparation

In the present study were used 15 natural sound extracted molars, selected from a pool of extracted 24 human third molars caries and restorations free and with similar dimensions. The teeth were carefully cleaned, the fragments of calculus and residue of periodontal ligament were removed with an ultrasonic scaler. Disinfection was made with 1.0% chloramine-T trihydrate bacteriostatic/bactericidal solution for seven days. The preservation was made in distilled water at 4°C according to ISO 3696:1987, grade 3, preceding the preparation of the specimen in conformity to ISO/TS 11405. Molars were prepared by the same operator for all ceramic crown, following the specific protocol. The samples were divided randomly into 3 groups, and preparation was made with three different occlusal thicknesses. The occlusal reduction for group A was 0.5 mm, for group B was 1 mm, and for group C was 1.5 mm. The axial reduction was 1.0 mm, with a round shoulder, placed at the cement-enamel junction, using round end cylinder diamond burs, under cooling water. All angles were rounded. Prepared teeth were mounted in silicone bar, and digitized with an intra-oral scanner (Planscan, Planmeca). 15 hybrid ceramic crowns, with three different thickness (0.5 mm, 1.0 mm, 1.5 mm), were designed with the software PlanCAD easy (Romexis, Planmeca) (Figure 1, 2) and then milled with the milling machine Planmill 40 (Planmeca).

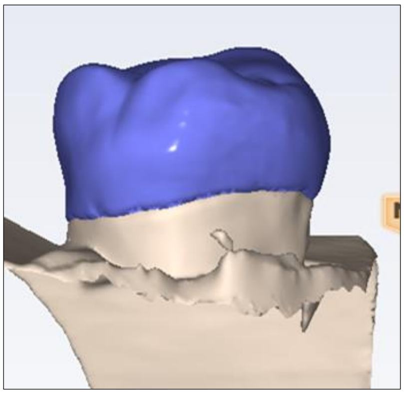

Figure 1. Digital design of the crown

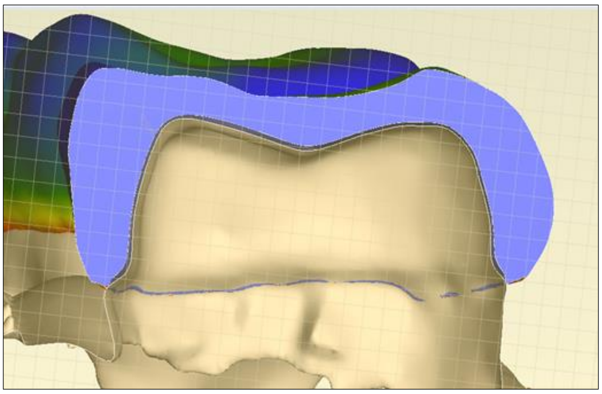

Figure 2. Crown section during design process

After removing the sprue, after finishing and glazing, the crowns were cemented on the prepared teeth. Cementation protocol was according to the manufacturer indications. Hybrid ceramic crowns were etched with 5% hydrofluoric acid for 60s, washed and dried, then brushed with a coat of silane (Monobond Plus) for 60s. Tooth structure was treated with a self-etch primer (Multilink, Ivoclar), scrubbed for 30 s, then air dried. The crowns were adhesively cemented using Multilink Automix dual-curing adhesive system resin cement, under a 1000 g load for 60s. A LED light-curing lamp (WoodPecker I LED Dental Wireless Curing Light) was used to polymerize the cement excess on the margins for 2s. Excess was removed with a probe. To finish the polymerization of the cement light-curing lamp was used 40 s on each side. Samples were inserted in polymethyl-methacrylate acrylic resin into a 25mm polyvinyl chloride cylinder (PVC) (Figure 3) mold exposing 1-2 mm of the root, with the occlusal table parallel to the base of the cylinder (Figure 4). Periodontal ligament was reproduced by coating the roots in a 0.3 mm layer of wax, replaced after the polymerization of the acrylic resin by a polyvinylsiloxane light body impression material.

Figure 3. Selected tooth prepared for the experiment (roots were then coated with polyvinylsiloxane)

Figure 4. Final result of embedded tooth

2.2. Compression tests

Specimens were loaded along the long axis until fracture with a single static compressive force on a Zwick Proline Z005 universal testing machine (Figure 5a), with a maximum force of 5 KN at 1 mm/min speed. The tests were carried out at room temperature of 22^{o}C. A preload of 0.1 N with a speed of 1 mm/min was set. The Zwick Proline Z005 machine has high (24-bit) measured-value resolution for maximum test-result accuracy and reproducibility. This means for example that even minimal force changes on the specimen can be recorded and displayed accurately. Load to fracture was applied to specimens using a stainless-steel bar with hemispherical head, attached to the upper movable compartment (Figure 5 b, c). The tests have been completed when specimens were fractured. During the test, the force in [N] and the displacement of the crosshead in [mm] were recorded by a computer.

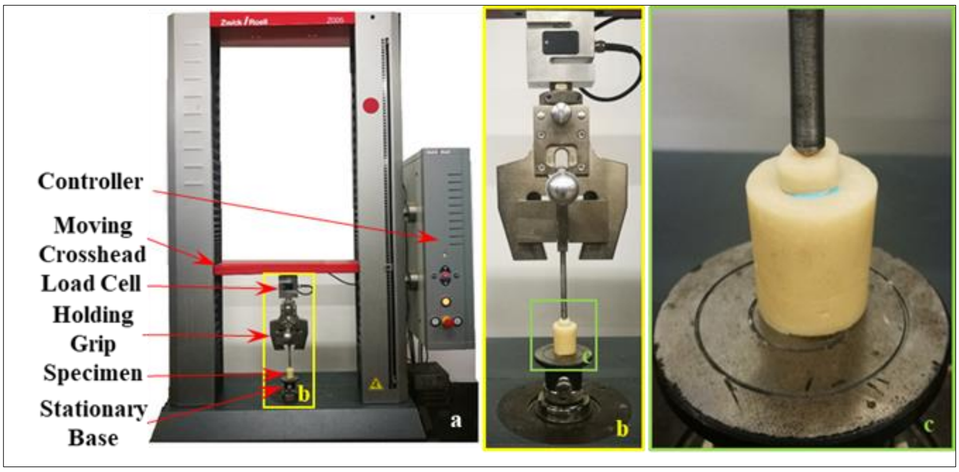

Figure 5. Zwick Proline Z005 universal testing machine (a), detail before the compression tests (b), and detail of the contact between specimen and grip before the tests (c)

3. Results and discussions

3.1. Results of the compression tests are showed in Figures 6, 7 and 8. In these figures the force – displacement curve obtained after compression tests for specimens with different thicknesses (0.5 mm, 1.0 mm, 1.5 mm) is represented.

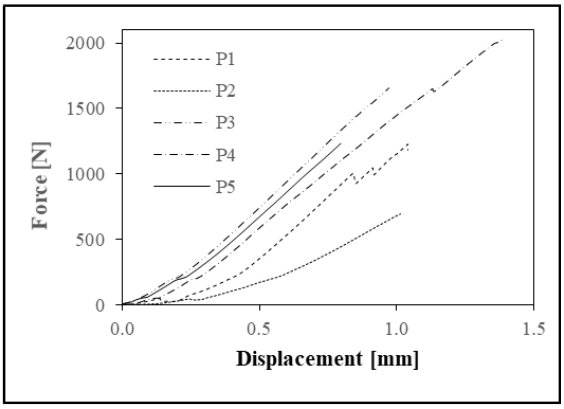

Figure 6. Force – displacement curve for specimens with 0.5 mm thickness

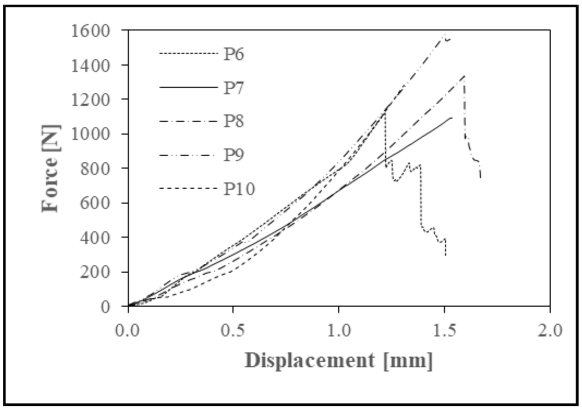

Figure 7. Force – displacement curve for specimens with 1 mm thickness

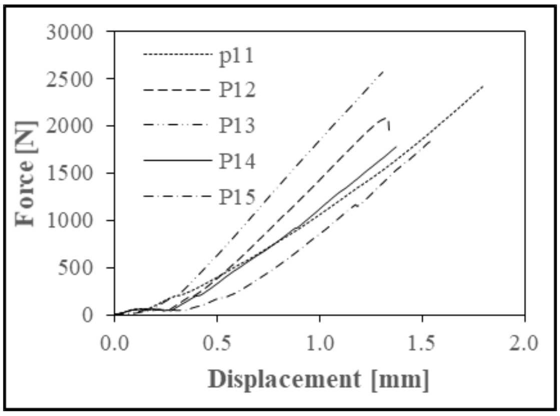

Figure 8. Force – displacement curve for specimens with 1.5 mm thickness

The disjunction of the restoration occurred under static axial load as a bulk fracture. The cracks were initiated on the occlusal surface under the contact point of the intender, usually from the central fossa. In some cases, the fracture has extended to the supporting structures resulting some chipping of the cusps or axial wall of the tooth. No fracture involved pulpal tissue.

Table 1. Compression tests results for specimens with 0.5 mm thickness

Sample	**Parameter**			
	Maximum Force F_{max} (N)	Displacement at the maximum force δ (mm)	Thickness of the crown (mm)	Test Speed (mm/min)
P1	1226.53	1.043	0.5	1
P2	696.49	1.015		
P3	**696.49**	0.971		
P4	**2033.22**	**1.394**		
P5	1233.03	**0.796**		
Average	**1177.15**	**1.044**		

Table 2. Compression tests results for specimens with 1 mm thickness

Sample	Parameter			
	Maximum Force F_{max} (N)	Displacement at the maximum force δ (mm)	Thickness of the crown (mm)	Test Speed (mm/min)
P6	1124.62	**1.21**	1	1
P7	**1092.76**	1.53		
P8	1337.63	**1.59**		
P9	**1579.67**	1.49		
10	1282.26	1.31		
Average	**1283.39**	**1.43**		

Table 3. Compression tests results for specimens with 1.5 mm thickness

Sample	Parameter			
	Maximum Force F_{max} (N)	Displacement at the maximum force δ (mm)	Thickness of the crown (mm)	Test Speed (mm/min)
P11	2417.34	**1.79**	1.5	1
P12	2080.69	1.32		
P13	**2565.9**	**1.31**		
P14	**1777.37**	1.37		
P15	1835.51	1.54		
Average	**2135.36**	**1.47**		

All restorations exhibited fracture at average loads ranging from 1177.15 N to 2135.36 N (Table 1, 2, 3). The minimum force was 696.49 N for group A (0.5 mm) (Table 1) and maximum force was 2565.9 N for group C (1.5 mm) (Table 3). There was a fracture of the acrylic resin base of one specimen in group B (1.0 mm). The value of the load of this samples went up to 1092.763 N which was slightly lower than the average of this group 1283.39 N. The fracture load values progressively increased with occlusal thickness.

3.2. Scanning electron microscopy

A scanning electron microscope (SEM) (Inspect S, FEI, Japan) was used to examine the fracture surface of specimens after the static loading forces were applied. The observations were made under magnification ranging from 40X to 200X. Six PICN samples were chosen (two representative specimens from each group) for SEM observation. SEM images display the fracture surfaces of specimens after the compression test. Fractured surfaces revealed fine hackle lines and cracks propagation. Cracks were initiated at the contact point of the loading tip. Crack lines are sinuous, radiating in all directions and some of them are incomplete due to the polymer bridge formation across the crack. Cohesive and adhesive displacement can be observed on few specimens.

In vitro studies on dental materials have an important contribution to the clinical applications, due to the significant amount of information related to their performance and behavior [18].

Results obtained during in vitro testing improve the procedures in restorative dentistry and all gathered information can be transferred to the stomatognathic system for a better understanding of fracture resistance of the dental materials [19].

Fracture tests evaluate the resistance of dental materials to higher forces than those developed in the oral cavity during the performance of masticatory function [20].

Chewing force in the oral cavity can range between 600 and 800 N. Restorative materials should present a greater compressive strength for appropriate clinical performance [21, 22].

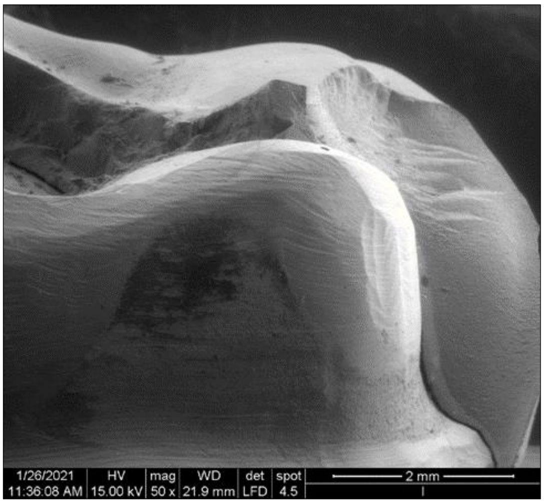

Figure 9. SEM image of the surface after the static loading forces - magnification 50X

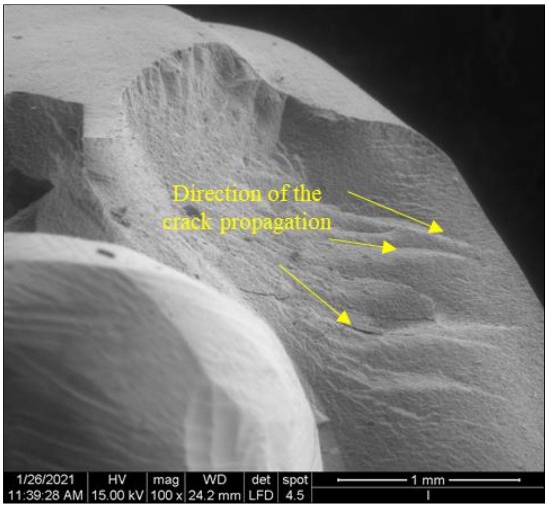

Figure 10. Analyze under SEM of the direction of the crack propagation - magnification 100X

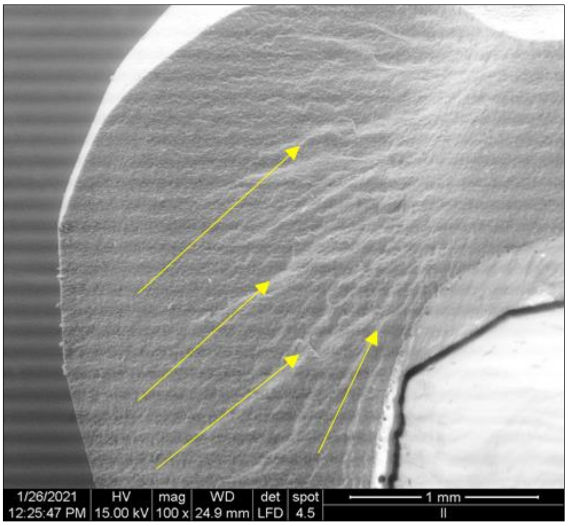

Figure 11. SEM micrographs of arrest lines - magnification 200X

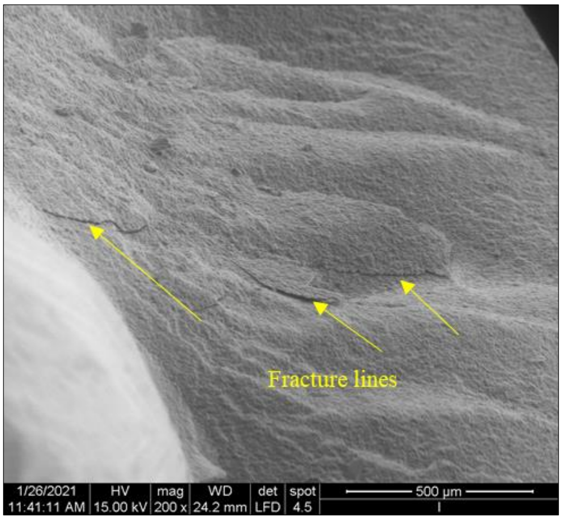

Figure 12. SEM image of radiating fracture lines - magnification 100X

Occlusal thickness is an essential characteristic of material resistance. For some materials, reducing the thickness represents a decreased load-bearing capacity or number of test cycles [15].

On the other hand, saving tooth natural structures as much as possible is important and nowadays this feature is achievable, due to the biomechanical characteristics of dental materials [23]. This new concept of combining ceramics and polymers to enhance their biological and mechanical characteristics, assure similarities with human enamel and dentin. PICN's elastic modulus and the hardness resemble to the dental tissues, and fracture resistance is higher compare to CAD/CAM leucite and feldspar glass ceramics [5,12]. Crack propagation in this material is blocked due to low Young's modulus, and the inter-penetrating components network behaves like impact-absorbing mechanism [10,20,24].

PICN has a dominant ceramic structure of porous sintered feldspar ceramic enriched with aluminum oxide and zirconia infiltrated with a monomer mixture of UDMA and TEGDMA followed by polymerization. The ceramic phase gives resilience and milling ease [25,26]. Adding UDMA (high molecular weight) and TEGDMA (low molecular weight) monomers into the material composition increase the elasticity values. However, addition of TEGDMA affects in general mechanical properties, raised water absorption and determine color instability. UDMA reduces the polymerization shrinkage and ensures flexural strength, elastic modulus and hardness of the material [27,28]. UDMA and TEGDMA have resembling modulus of elasticity, significantly higher than other monomers [25,29]. Methacrylate monomers produce extensive cross-link network resulting a resin matrix highly resisting to wearing and degradation [26].

This study aimed to evaluate fracture load of thin occlusal crowns fabricated of CAD/CAM PICN material under a static compressive load [27]. To evaluate the fracture resistance Engra & all recommends static load tests or flexural tests as best choice [20]. The maximum principal stress (MPS) principle shows that crack initiations occurs when occlusal loading exceeds the yield strength and the fracture line will propagate in a perpendicular direction to release the energy [30,31]. The greater the thickness of restoration the lower stress accumulation zones under a higher occlusal load. The material type and thickness can influence MPS, becoming a decisive factor of fracture resistance. A reduced thickness was demonstrated to expand cracking surface area under lower load values. The restorative material should be able to transfer the stress to the adjacent substrates [30].

Shahmoradi [30] and Ahmed [32] showed in their studies that multiple factors have to be taken into consideration to determine mechanical performance and resistance of a crown or fixed dental prostheses, such as material type and homogeneity of chairside CAD/CAM blocks, the thickness and configuration of the restoration, the characteristics of adhesive system and cement layer, the quality of supporting structure (vital or non-vital tooth), tooth elasticity, dentin and enamel quantity and preparation characteristics [30,32].

To increase the tooth endurance and fracture resistance of dental material especially for very thin restorations it is important to use an adequate resin cement so, the applied forces can be transmitted through the hybrid crown and dissipate in the abutment structures [14,19]. It was observed that the most vulnerable regions of the restoration are those that are allowing a greater stress concentration such as fissures and grooves [33].

The results of the present study exhibited a higher compression load for 1.5 mm-thick crowns compared to thicknesses of 0.5 mm or 1.0 mm. There were no significant differences of fracture load between groups with 0.5 mm and 1.0 mm occlusal thicknesses. Lowering material volume will determine a greater stress concentration. The 0.5 mm thickness crowns will be subject to accumulate more stress than thicker restorations [33,34]. Restorative materials that do not have the ability to transfer the accumulated forces to the supporting structures are more susceptible to fracture. PINC transmits more stress to the abutment compared to stiffer materials such as high translucency zirconia and zirconia-reinforced glass ceramic [17,33].

Sulki & all showed that PICN, due to crack stop mechanism and stress absorbing capacities, it can reproduce natural dentition biomimetics and deformation so the energy is dissipated from the crack and the catastrophic failure can be avoided [35]. Another study revealed that fracture load and tensile stress presented higher values when increasing the thickness due to a greater capacity of absorbing energy, and better performance can be achieved with restorations above 0.5 mm [36].

Clinical assessment of PICN indirect restorations has been reported as successful for minimally invasive restorations for anterior and posterior crowns (veneers, inlays, onlays) and for implant supported crowns [10].

Some authors found that an extensive tooth preparation will lead to weakened remaining tooth structure causing irreversible failure and other conclude that a thicker restorative material will enhance the fracture resistance of the restoration [37,38].

In the present study it was observed that the fracture line was initiated faster in those regions where the supporting structures were lacking even when the restauration material was thicker.

Vita Enamic was compared with many CAD/CAM aesthetic materials. It was demonstrated that lithium disilicate (e.max CAD) has superior mechanical properties [32] while other studies showed that between the lithium disiclicate and PICN there are no differences of load bearing [22]. Fracture properties are similar for Vita Enamic and IPS e.max CAD [37] and Vita Enamic and Lava Ultimate [32, 39], when these materials are used for occlusal onlays respective occlusal veneers 0.6-mm and 1.5 mm thick. Songa [10] reported that fracture toughness and damage resistance of PICN are higher than CAD/CAM machinable leucite and feldspar glass ceramics.

Ioannidis & all evaluated the fracture resistance of occlusal veneers fabricated of PICN, with 0.5-1.0 mm thicknesses, obtaining values of 2128 N for this material [22]. These results are similar with the results obtained in the present study.

In accordance with a recent study [40], the present research reported that displacement occurred under static axial load as a bulk fracture from the central notch or central fossa and in some cases the fracture has been extended to the supporting structures.

The results of this study demonstrate that restored teeth with PICN CAD/CAM crowns, regardless of the crowns thickness, can achieve values of compression load between 700 N and 2500 N. These values are above the human masticatory forces (600-800 N) even in patients with bruxism who are developing 780 N -1120 N during mastication. For conservative preparations, CAD/CAM single PICN restoration represents an excellent option to treat dental lesions on posterior teeth.

4. Conclusions

Within the limitations of this in vitro study, the load developed on polymer-infiltrated ceramic network restorations was higher than the force developed by the physiologic masticatory process. CAD/CAM hybrid ceramic materials can provide satisfactory fracture strength and load capacity for the posterior area restorations.

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