In Vitro Evaluation of Fracture Resistance of Zirconia Restorations Veneered by Two Different Systems: Rapid Layer Technique and Zir/CAD/CAM

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Received: 30 April, 2019   Accepted: 7 October, 2019

ARTICLE INFO

Abstract

Background: This study aimed to assess the fracture resistance of zirconia restorations fabricated with rapid layer (RL group) technique and zirconia computer-aided design/computer-aided manufacturing (zir/CAD/CAM) system (ZC group).

Methods: This study evaluated 30 all-ceramic crowns in two groups of 15. After fabricating the metal dies and scanning them by the CAD/CAM scanner, the crowns in RL group were anatomically designed and divided into two parts of the core and the veneering. Each part was milled separately by the machine. The core and the veneering were fabricated and cemented. An index was obtained from the restorations and used for the fabrication of samples in the ZC group. In the latter group, the metal dies were scanned and zirconia cores were milled by the machine. The veneering porcelain powder was then applied. Samples in both groups were cemented over metal dies using a glass ionomer cement. The fracture resistance of the complex was measured by a universal testing machine. Data were analyzed using SPSS software version 16.

Results: The mean fracture resistance of RL and ZC groups was not significantly different (P>0.05). The mode of failure was adhesive in all samples in RL group and cohesive in 85% of samples in ZC group. The remaining samples in ZC group showed a total fracture in the core and the veneering.

Conclusion: The fracture resistance of restorations fabricated by the zir/CAD/CAM and RL systems is not significantly different.

Citation: Radan P, Vafaee F, Firouz F, Soltanian A.R, Heidari B. In Vitro Evaluation of Fracture Resistance of Zirconia Restorations Veneered by Two Different Systems: Rapid Layer Technique and Zir/CAD/CAM. Jou*rnal of Kerman University of Medical Sciences*, 2019; 26 (5): 330-338.

Introduction

The increasing demand for esthetics has led to the growing popularity of all-ceramic restorations. Due to the inherent fragility of ceramics, these restorations have an unesthetic but strong core which are veneered by more esthetic but physically weaker translucent materials (1,2).

Porcelain fracture is the main drawback of these materials. Introduction of the computer aided design/computer aided

manufacturing (CAD/CAM) technique and the application of all-ceramic systems including zirconia enable the use of these restorations in extensive and complex fixed partial dentures (3). Despite numerous advantages of zirconia restorations such as their long-term stability, favorable esthetics, optimal mechanical properties and acceptable biocompatibility (4-6), porcelain chipping is a common occurrence in the clinical setting that decreases the success rate of zirconia-based restorations (7-10).

Rapid layer (RL) is a recently introduced CAD/CAM technique in which the core and the veneering are separately milled by the CAD/CAM machine and after sintering of the core, the two components are cemented using resin cement. Application of prefabricated ceramic blocks is among the advantages of CAD/CAM systems that enables the fabrication of more reliable restorations with fewer cohesive defects (11-15).

In addition, research studies show high bond strength for the conventional zir/CAD/CAM systems. The fracture resistance of this system has also been previously evaluated (16-20). However, literature review indicates a paucity of consistent studies on fracture resistance of restorations fabricated by the RL technique. Thus, this study aimed to compare the fracture resistance of restorations fabricated by the RL and zir/CAD/CAM techniques.

Materials and Methods

In this in vitro experimental study, the sample size was calculated to be 15 samples in each group according to a study by Choi et al. (12) assuming the standard deviation of fracture resistance to be 1110.8 N and 1759.5 N and the mean fracture resistance of 4263.8 N and 6242 N in the RL and ZC groups, respectively with type I error of %5 (α=0.05) and type II error of 10% (β=10%).

Thus, a total of 30 samples were evaluated in this study. Metal dies were used to fabricate the samples. The same dies were also used as a stub during load application.

An anatomical resin mandibular right molar tooth fixed on a model of the mandible was used to fabricate the die (Figure 1). The resin tooth was prepared and underwent 2 mm of occlusal reduction. It also received a 360° chamfer finish line with 1.2 mm width.

To control the magnitude of preparation, first, a silicon index (Panasil, Kettenbach GmbH., Germany) was obtained from the resin model. A mesiodistal section divided the index into buccal and lingual halves. The volume of preparation was frequently controlled using this index.

After preparation of the resin model, the prepared resin tooth was scanned by a laser scanner (3Shape D810; 3Shape, Denmark). The collected data were transferred to the respective device software (Sirona in Lab 2015, Sirona, Germany). The model was then processed in SolidWorks 2016 software (Dassault System solid works, Canada) and transferred to CNC machine (Maschinen-Wagner VMC 2040 - Maschinen-Wagner –Germany). Eventually, 30 metal dies were milled by the CNC machine using 316 steel alloy (UNS S31600 – AK Steel – USA) (Figure 2).

Metal dies were then randomly divided into two groups (n=15) of ZC (restorations fabricated by zir/CAD/CAM technology) and RL (restorations fabricated by the RL system). The ceramic crowns in each group were fabricated as follows:

RL group

First, a metal die was scanned by the laser scanner and a full-contour anatomical form was designed by the software. Next, the device automatically divided this complete form into a framework with 0.5 mm thickness with the geometry of the milled model without undercut and a veneer with maximum thickness possible. The framework was first milled out of a zirconia block (Vita In-Ceram; Zahnfabrik, USA) and sintered in a furnace (VITA ZYRCOMAT 6000 MS; Zahnfabrik, USA) at high temperature (1540°C). Next, the veneering was milled using VITABLOCS TriLuxe forte blocks (Zahnfabrik, USA). After fabrication of the cores and veneers, each veneering was tried on its respective core and its adaptation was evaluated. Also, the adaptation of zirconia cores on metal dies was evaluated (Figure 3).

Finally, the fabricated veneer was cemented on the fabricated framework using Panavia F2 (Kuraray, Japan) resin cement as follows: The internal surface of the veneering and the external surface of the cores were sandblasted with 50 μ alumina particles at a pressure of 2 bar (Basic mobil – Renfert – Germany). Next, the internal surface of the veneers was etched with 9% hydrofluoric acid (Ultradent, Germany) for 60 seconds. After rinsing with water, they were immersed in ethanol 100% (Wilmar, Australia) for 5 minutes and placed on a vibrator. After that, they were rinsed with water again and air was sprayed for 20 seconds.

Figure 1. Preparation of resin tooth

Figure 2. Steel die

Figure 3. Cores and veneers milled by the rapid layer system

After drying, silane (Ultradent, Germany) was applied on the internal surface of the veneering by a microbrush and it was placed in ambient air in order for the silane to dry. Zirconia cores were first sandblasted (in the same way) and were then cleaned by immersion in 100% ethanol (Wilmar, Australia). Also, they were placed on a vibrator for 5 minutes.

ED primer (Kuraray, Japan) was mixed according to the manufacturer's instructions and applied on the external surface of the veneering by a micro brush. Equal amounts of the two pastes of Panavia F2 were mixed on a glass slab and applied on the entire internal surface of the veneer. The core was then placed inside the veneer and compressed in order for the excess cement to leak out. After obtaining a primary fit prior to cementation, excess cement was removed by the sharp tip of an explorer and the samples were light-cured for 20 seconds.

A silicon index was obtained from the final sample in order to standardize all the samples in the conventional porcelain group.

ZC group

The die was first scanned and the zirconia core with the same thickness as mentioned for the RL group was milled by the CAD/CAM machine using Vita In-Ceram (Zahnfabrik, North America) blocks. Zirconia cores were then sintered in a furnace at 1540°C temperature. Porcelain in this group was applied by a technician using the index obtained of samples in RL group.

The core was first washed and the first opaque layer was applied on the core and sintered in a furnace at 960°C. Next, dentin and enamel layers of Vita VM 9 feldspathic porcelain (Zahnfabrik, North America) were applied on the underlying layers. The index obtained of samples in RL group was used to

standardize the samples. They were then sintered at 930°C and the porcelain was finally glazed.

All crowns were then cemented to metal dies using Fuji One glass ionomer cement (GC America, USA). The internal surface of the crown was steam-cleaned and impurities were removed using 100% ethanol. The steel die surface was sandblasted with 50 μ aluminum oxide particles at 0.5 bar pressure and cleaned with 100% ethanol prior to cementation.

The entire cementation process was performed by one operator. Glass ionomer cement was mixed with a plastic spatula for 20 seconds and spread on the internal crown surface using a disposable applicator. The crowns were placed over the dies and held in place by uniform finger pressure for 10 minutes. The assembly of the crown and metal die was stored in water at 37°C for 48 hours. Prior to load application, the samples were thermocycled for 1000 cycles between 5-55°C (TPO, Nemo, Iran). To stabilize the samples for fracture resistance testing, metal dies along with their restorations were mounted in polyethylene cylindrical rods based on their color (Figure 4) (12,21).

Figure 4. Fixing metal dies over cylindrical rods

Fracture resistance was measured using a universal testing machine (Z100/Z250; Zwick Roell, Ulm, Germany) (Figure 5).

A cylindrical rod with 6 mm diameter was used to obtain a three-point contact on the occlusal surface of restoration for load application until restoration fracture. The load was applied at a crosshead speed of 0.5 mm/minute. The load at failure was recorded as the fracture load. The mode of fracture was also determined visually and recorded.

Figure 5. Load application to samples

The mean, standard deviation, minimum and maximum fracture resistance of the two groups were recorded and compared using independent t-test. Level of significance was set at P<0.05. All statistical analyses were carried out using SPSS software version 16.

Results

The Kolmogorov-Smirnov test confirmed the normal distribution of fracture resistance data (P>0.05).

Independent t-test showed that although the mean fracture resistance in group 1 was higher by 187 units compared to

group 2, this difference was not statistically significant (Table 1). Diagram 1 depicts the distribution of the fracture load.

Table 1. Descriptive results of independent t-test for the comparison of mean fracture load in ZC and RL groups

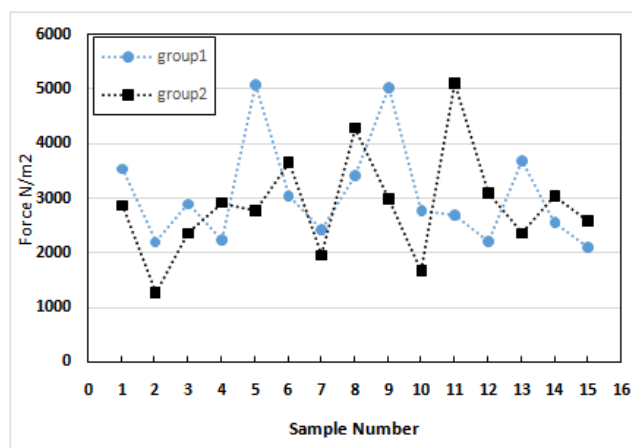| Group	Mean	Standard deviation	P-value
ZC	3056.3033	955.91335	0.599
RL	2869.4487	967.53476	0.599

Diagram 1. Fracture load in RL and ZC groups

Mode of failure

Mode of fracture was partial and occurred only in the veneering in all samples of the RL group. In ZL group, however, the fracture was partial in 13 samples (a thin layer of the veneering remained on the zirconia surface). Total fracture of the core and veneering was noted in two samples in this group. Fracture in RL group was in the form of the breaking of the veneering (Figure 6).
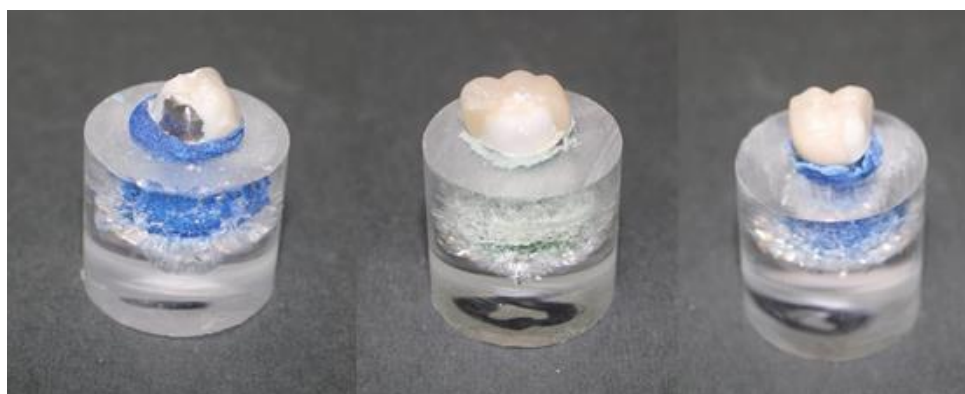
Figure 6. Fracture modes of all-ceramic restorations. From right to left: fracture in ZC sample, fracture in RL sample, total fracture in ZC sample

Discussion

The results showed that the mode of failure in RL samples was adhesive. In other words, fracture of the veneering occurred at the adhesive interface and the veneering layer broke. However, in ZC samples, the mode of fracture was cohesive within the veneering layer, which indicated higher susceptibility of the samples fabricated by the RL system to unfavorable fractures.

The mode of failure of restorations has been extensively studied. Ereifej et al. measured the shear bond strength of the core-veneering interface in bilayer ceramics. They veneered the IPS e.max ZirCAD and lithium disilicate cores by IPS e.max Ceram and subjected them to load application in a universal testing machine until fracture. The two groups showed different modes of failure. They reported adhesive mode of failure in zir/CAD group and cohesive failure within the veneering in LS/Ceram group (1). In the present study, the mode of failure was evaluated in zir/Cad and RL groups. The results showed different modes of fracture in the two groups in which the majority of samples in zir/CAD group indicated cohesive fracture as partial fracture of the veneering and porcelain chipping. Two samples in this group showed total fracture of the core and veneer which indicated strong core-veneer bond. In RL group, cohesive fracture within the veneering layer as well as adhesive fracture at the adhesive interface in the form of

breakage of the veneering was observed. This indicated poor bonding of the core-veneer (1,22). The majority of samples in ZC group showed cohesive fracture within the veneering in the form of porcelain chipping in only one point of the restoration. This form of fracture in zir/CAD systems allows restoration repair. In the RL group, adhesive fracture occurred in the cement layer in the form of breakage of the veneering which led to the separation of the veneering from the core. In RL samples, the veneering broke into pieces and was separated from the core which made the restoration repair impossible. This type of fracture in RL samples is due to the low bond strength of resin cement to zirconia core which has also been mentioned by Baltz et al. (23). Also, some other studies have evaluated the strategies to increase the bond strength of resin to zirconia (24,25).

Assessment of the mode of failure by Kanat B et al. revealed only adhesive failure in over cemented file-splitting group which was similar to the mode of failure observed in the RL group in our study. Failure was cohesive in over-pressing and layering groups. The mode of failure observed in the ZC group in our study was also cohesive. However, Kanat B et al. did not report total fracture of the core and veneering (26).

Choi et al. evaluated the shear bond strength of porcelain attached to zirconia core and metalcore. Assessment of the mode of failure by a scanning electron microscope revealed that

part of the veneering remained on the zirconia core (27). Their findings regarding the mode of failure in the all-ceramic groups (parts of porcelain remaining on the core) were similar to our results regarding the mode of failure in the ZC group.

Chen et al. evaluated the effect of restoration thickness on fracture resistance of resin nano-ceramic CAD/CAM systems (28). The results showed a linear correlation between fracture resistance and restoration thickness since by an increase in restoration thickness, the fracture resistance increased as well. In the present study, the thickness of the veneering was not evaluated as a variable. Instead, following the fabrication of RL samples (designed by the software and milled by the machine), an index was obtained from them and used for the fabrication of zir/CAD samples to standardize the samples in both groups.

One advantage of RL systems is that the occlusal surface of restoration is designed according to the opposing occlusion of the patient. In this system, the patients' function and biomechanics are taken into account to achieve an ideal occlusion for each patient. This technique saves time since the clinician no longer needs to adjust the occlusion chairside. The manual wax-up technique does not have such an advantage.

The mean fracture load (fracture resistance) was not significantly different in the two groups in our study. Considering the equal fracture resistance of the two groups, the simple strong bond created by resin cement in the RL group eliminates the need for porcelain sintering in the furnace and decreases the laboratory working time.

Choi et al. (12) evaluated the fracture resistance of all-ceramic restorations with zirconia cores. They veneered the zirconia cores by feldspathic porcelain (powdering technique) or glass-ceramic (heat press technique). In the third group, they scanned the zirconia cores by the CAD/CAM scanner and designed and milled the veneering layer. This layer was then sintered on the zirconia core. The load was applied to samples

until fracture. Data revealed maximum fracture resistance in the sintered group (12). In the RL group in the present study (designed by CAD/CAM system), first, the entire restoration was anatomically designed by the software and then the thickness calculated by the software was divided into core thickness and the veneering thickness. The veneering fabricated in this system does not require sintering in a furnace because pre-sintered blocks are used in this system. The two layers in this system are bonded to each other using resin cement. However, Choi et al. (12) sintered the veneering layer over a zirconia core. But, the sintered group in the study by Choi et al. (12) showed maximum fracture resistance, while in our study the RL group fabricated by the CAD/CAM system showed lower fracture resistance (12).

Beuer et al. evaluated zirconia cores in three groups depending on the method of veneering (21). Similar to the study by Choi et al. (12), Beuer et al. (21) applied veneering by three methods of layering, over-pressing of the veneering over the core and sintering method (fabrication of veneering by the CAD/CAM system and sintering it). The load was applied to samples until fracture using a universal testing machine. Analysis of the data revealed a significant difference in the fracture resistance of the groups in which the maximum fracture resistance was noted in the sintered group.

As mentioned earlier, the difference between groups fabricated with CAD/CAM system in studies by Beuer et al. (21) and Choi et al. (12) as well as the present study was attributed to the use of different blocks (pre-sintered and to be sintered). In studies by Beuer et al. (21) and Choi et al. (12), veneering was sintered over the core after milling, while in our study the veneering was cemented over the core.

In another study, Kanat B (26). measured the fracture resistance of single-unit restorations with zirconia frameworks. They also assessed the effect of different veneering techniques

on fracture resistance. The samples were veneered by the layering, over-pressing or over cemented file-splitting method (cementing the veneering and core to each other).

Restorations were fabricated, cemented on metal dies and subjected to load application in a universal testing machine until fracture. They reported minimum fracture resistance in over cemented file-splitting method which was in line with our findings. Although ZC and RL groups were not significantly different in terms of fracture resistance in our study, the mean fracture resistance of RL group (which is similar to over cemented file-splitting group in the study by Kanat B et al.) was numerically lower than that in ZC group (26).

We used metal dies in the form of a prepared natural tooth in this study. Thus, the fabricated restorations were similar to those fabricated in the clinical setting for natural teeth. Other studies have used different samples. For instance, Han et al. used zirconia blocks and Choi and Kanat B et al (12, 26) used

restorations with anatomical form. The samples in the latter study were the same as those used in our study.

Conclusion

Within the limitations of this study, the following results were obtained:

Fracture resistance of restorations fabricated by the zir/CAD and RL systems is not significantly different. Restorations fabricated by the zir/CAD method exhibit a more favorable mode of fracture compared to those fabricated by the RL technique.

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