The Effect of Modified Framework Design on the Fracture Resistance of IPS e.max Press Crown after Thermocycling and Cyclic Loading

Mahnaz Golrezaei1, Hossein Ali Mahgoli2, Negin Yaghoobi3, Somayeh Niakan4

Received on: 15 December 2023; Accepted on: 16 January 2024; Published on: 17 February 2024

Abstract
Aim: This study aimed to investigate the effect of modified framework (MF) design on the fracture resistance of IPS e.max Press anterior single crown after thermocycling and cyclic loading.

Materials and methods: Two types of IPS e.max Press frameworks were designed (n = 10); standard framework (SF) with a 0.5 mm uniform thickness and MF with a lingual margin of 1 mm in thickness and 2 mm in height connected to a proximal strut of 4 mm height and a 0.3 mm wide facial collar. The crowns were cemented to resin dies, subjected to 5,000 cycles of thermocycling, and loaded 10,000 cycles at 100 N. A universal testing machine was used to load specimens to fracture, and the modes of failure were determined.

Results: The mean and standard deviation (SD) of fracture resistance were 219.24 ± 110.00 N and 216.54 ± 120.02 N in the SF and MF groups. Thus, there was no significant difference (p = 0.96). Mixed fracture was the most common failure mode in both groups. We found no statistically significant difference between the groups (p = 0.58).

Conclusion: The MF design did not increase the fracture resistance of IPS e.max Press crown.

Clinical significance: Framework design is an essential factor for the success of all-ceramic restorations and its modification might be regarded as an approach to increase fracture resistance. Furthermore, the modified design was evaluated in metal–ceramic or zirconia crowns while less attention was paid to the IPS e.max Press crowns.

Keywords: Dental porcelain, Dental prosthesis design, Incisor.

The Journal of Contemporary Dental Practice (2024): 10.5005/jp-journals-10024-3621

Introduction
Over recent decades, lithium disilicate restorations such as IPS e.max Press are regarded as an ideal choice for anterior restorations compared to metal–ceramic, alumina, and zirconia, due to the growing patient esthetic demands and considering the effect of the smile on self-confidence and mental health. In particular, esthetic, translucency, marginal accuracy, biocompatibility, and mechanical features of IPS e.max Press have made it popular in esthetic dentistry.1–3 In addition, clinical studies have shown that lithium disilicate single crowns present the highest survival rate (96%) in five years, compared to zirconia and alumina.4 Despite all these advantages, the chipping of porcelain veneer is still a problem for single-unit lithium disilicate restorations.4,5

The framework design is a significant factor influencing the fracture of all-ceramic restorations.6–8 Clinical fractography analysis revealed that due to the predominance of circumferential stress, the margin of the crown is considered a vulnerable point to the development of cracks. By the occurrence of cracks in the margin, functional or parafunctional forces will increase the tension and subsequently cause crack propagation.6 Hence, the conventional design of a uniform thickness framework can be considered as a weakness of all-ceramic systems.9

So far, many attempts have been made to prevent the fracture of porcelain veneer associated with framework design.10 As previous studies show that the chipping rate is reduced by adding a cervical collar in the proximal and lingual areas of the core.11 Modified framework (MF) designs have been studied for years to improve mechanical properties and increase the fracture resistance of restorations.12 Notwithstanding, the effect of framework designs on all-ceramic systems is not sufficiently understood.13 One of the commonly proposed framework design modifications is the addition of a reinforcing collar, proximal strut, and lingual shoulder in the framework design, which has been evaluated in metal–ceramic and zirconia restorations.14,15 Nevertheless, the effect of using this design in IPS e.max Press restorations has not been assessed yet. Furthermore, fractures during clinical function have been described as the main problem of all-ceramic restoration.16 Simulating clinical situations in fracture-resistance studies, including cyclic loading and thermocycling under humid conditions, can provide some indication of the load-bearing conditions.
Core Design’s Effect on Fracture Resistance

According to previous reports, after several cyclic loads, an abrupt strength degradation and transition into damage mode occurred. For these reasons, it is necessary to consider the fatigue and the impact of the environment on dental restorations to avoid creating unrealistically high fracture loads.

Modified framework design was assessed in zirconia or metal–ceramic crowns, whereas IPS e.max Press crowns received less consideration. As a result, this study aimed to investigate the effect of the MF design on IPS e.max Press anterior single crown after thermocycling and cyclic loading. The null hypothesis was that the framework design does not influence the fracture resistance of IPS e.max Press anterior single crown.

Materials and Methods

This original in vitro study was conducted at the Department of Prosthodontics, Tehran, Iran from October 2022 to Jun 2023. The ethical committee at Tehran University of Medical Sciences has approved the study (IR.TUMS.DENTISTRY.REC.1399.141).

Sample Preparation

The left central tooth of a standard maxillary model (M8011 Standard Dental Tooth Model, Zhengzhou Smile CC Industrial Co. Ltd, Henan, China) was prepared to achieve a 2 mm incisal reduction, a 1 mm axial reduction, a finish line of 1 mm and 6° taper on each side. The finish line design was the radial shoulder, and all sharp angles were rounded. A putty index (Speedex Putty, Coltene Whaledent, Switzerland) was used as an aid to ensure correct preparation (Fig. 1).

The prepared tooth was scanned with the Ceramill Map 400 scanner (Amann Girrbach, Koblach, Austria), and 22 resin dies (Asiga DentaMODEL 3D printer resin, Sydney, Australia) were fabricated with a 3D printer (Asiga MAX 3D printer, Sydney, Australia).

Twenty-two IPS e.max Press copings (Ivoclar Vivadent, Schaan, Liechtenstein) with two different designs using the Exocad software (Exocad GmbH, Darmstadt, Germany) were planned. The cement space was 30 μm covering 86% of the prepared die surface.

Study Subgroups

The IPS e.max Press copings were divided into the following two groups based on their designs: A standard framework (SF) design (n = 11) with a 0.5 mm uniform thickness, and an MF design (n = 11) with a labial collar (0.3 mm in thickness and 0.3 mm in height) and a buttressing shoulder of 1 mm thickness and 2 mm height at the lingual surface, which was increased to 4 mm of height in the proximal half to form a proximal strut. Other areas of the coping were 0.5 mm thick (Fig. 2).

Fabrication of Crowns

The data from the software was transferred to the 3D printer (Asiga MAX 3D printer, Sydney, Australia) and designed frameworks were fabricated with Super wax Resin (SuperWAX™ Resin, Asiga, Sydney, Australia). Then, the specimens were heat-pressed according to the manufacturer’s instructions.

Veneering ceramic (Ivoclar Vivadent, Schaan, Liechtenstein) was applied to the frameworks using the conventional manual layering technique according to the manufacturer’s instruction. To achieve a standardized contour and thickness, a transparent index and metal gauge were used for porcelain build-up.

Cementation of Specimen

Thereafter, the dies and crowns were separately cleaned in an ultrasonic bath (digital ultrasonic cleaner machine, Centro Star Technology, Shenzhen, China). Upon completion, the internal surfaces of the copings were cleaned with a steam cleaner and were dried. Panavia F 2.0 luting cement (Kuraray Dental, Tokyo, Japan) was used for the cementation of all restoration according to the manufacturer’s recommendations, after two to three seconds.
of light-curing with a gentle finger pressure, excess cement was removed. Then a constant load of 15 N was applied for a duration of 60 seconds, using a 0.5 kg weight via an acrylic medium fabricated equally to the size of the crowns.

Aging Process
Following cementation, all samples were thermocycling (Vafaei Industrial, Iran) for 5,000 cycles between water baths at temperatures of 5 and 55°C. Each cycle lasted 60 seconds with a residence time of 20 seconds and a transfer time of 10 seconds.

Subsequently, all samples were stored in artificial saliva at 37°C for a period of 40 days. Afterward, all restorations with the aid of a navigator at an angle of 135° (IMPLA 3D Theta System, Schütz Dental GmbH, Rosbach, Germany) were mounted in a self-polymerizing acrylic resin (Acropars; Marlic Company, Karaj, Iran) (Fig. 3).

To complete the aging procedure, the crowns underwent cyclic loading at 100-N loads, comprising 10,000 cycles at 1 Hz (Chewing simulator CS-4, SD Mechatronic, Feldkirchen, Westerham, Germany). The load was transferred through a stainless-steel conical ball of 4 mm in diameter. The loading point was on the palatal surface, 2.5 mm below the incisal edge (Fig. 4).

Measuring Fracture Resistance
The fracture resistance test was carried out by a universal testing machine (ZwickRoell Z050, Ulm, Germany) at a crosshead speed of 1 mm/minute. The load was applied with a round stainless-steel indenter of 4 mm in diameter as the same location in cyclic loading. Two layers of thin foil were placed between the indenter and the restoration as stress breakers which were changed for each specimen.

Statistical Methods
Failure loads were measured, and detailed data entry was performed with the Statistical Package for Social Sciences (SPSS) statistical software (Version 20.0 for Windows, Chicago, IL, USA). Statistical analysis was performed using an independent samples t-test.

Mode of Failure
The specimens were evaluated under a stereomicroscope at 10× magnification (Euromex stereo Microscope Holland, model ST.1740, Japan) to determine the mode of failure: Adhesive failure (failure at the veneer-core or core-cement interfaces), cohesive failure (failure within the cement layer, core layer or veneer layer) and mixed failure (a combination of both adhesive and cohesive failures in different areas) (Fig. 5).

Results
The mean ± standard deviation (SD) of failure resistance in the standard group was 219.24 ± 110.00 N and in the modified group was 216.54 ± 120.02 N (Table 1). Conclusively, the Independent
Core Design’s Effect on Fracture Resistance

The mechanical characteristics of restorations are influenced by a number of factors, including framework design. 6,7 Modified design is not evaluated in glass–ceramic restorations, but it is reviewed in zirconia or metal–ceramic restorations.

Our study is inspired by the recommended metal–ceramic framework design by Miller,14 which includes reinforcing collar, buttressing shoulder, and proximal strut. Silva et al.,20 investigated the influence of a similar framework design on the reliability of the zirconia crown, which includes a 2.5-mm lingual shoulder that extends to the proximal area. They concluded that the MF design improved the reliability and fracture resistance of the porcelain veneer. Using a different material (zirconia crown) may be the cause for different results. Additionally, their framework design differed slightly from that of the current study. Seyyedan et al.,9 evaluated the effect of a zirconia coping design with a 1 mm thick labial collar and a 2 mm lingual shoulder on the fracture load of the mandibular first molar crown. Based on the results, the new framework design increased the fracture resistance of restorations. Different core materials, evaluating posterior crowns, and lack of aging process are some factors responsible for the inconsistency of results. A similar design to the present study by Bonfante et al.,27 with a cervical margin of 2 mm and a lingual margin of 1 mm attached to a proximal strut of 3.5 mm, showed a significant impact on the fracture resistance of the In-Ceram premolars crowns. It is reported that the Proximal Strut plays an important role in supporting porcelain veneer, especially in the proximal area, and can therefore prevent crack propagation. Cracks propagate through the glass matrix in glass–ceramic restorations, which is different from in-ceramic restorations and can account for various fracture resistance mechanisms.21 Additionally, Nikzadjamnini et al.15 and Lorenzoni et al.22 assessed fracture resistance of zirconia crowns in standard and MF. There was no significant difference between the two groups in both studies. Such conflicting results of different studies may be attributed to the ceramic type, loading point, core thickness, preparation design, luting cement, die material, tests, and pretesting procedures.23,24

In the present study, in recognition of the increased exposure to functional and parafunctional loads on the lingual portion of anterior crowns in clinical situation and the importance of the proximal strut in supporting porcelain veneers, the collar height increased in the proximal and lingual portion, and a buttressing shoulder was created.8,17 The buttressing shoulder with increased height acts as a shock absorber in the margin area and presents excellent support for the porcelain veneer.25 Many researchers in comparable studies, emphasized the posterior teeth (mainly the mandibular first molar) while less attention was paid to the anterior teeth. In addition, the focus of these studies is on zirconia-based ceramics. Therefore, we decided to investigate the effect of the MF design on IPS e.max Press anterior single crown. As a result, we found that this change did not improve ceramic crown strength. In this way, our null hypothesis was confirmed.

The clinical performance of dental restorations is evaluated in a humid environment with thermal oscillation and different ranges of load through the years.19 The fracture resistance studies with simulating clinical conditions may provide a baseline to estimate the actual load-bearing capacity.24 The pretesting procedure in the current disposition has been used and discussed in several studies.14,18 According to the previous studies, artificial aging which includes thermocycling and cyclic loading has a significant effect on ceramic materials.18,19 In the absence of the preloading procedure, Sawada et al.26 found that the supporting structure of the zirconia/alumina-based crowns had a minor effect on the fracture resistance or failure properties. In an aqueous environment, the aging process leads to fatigue and stresses, like mechanical stresses, by increasing the growth of small cracks through thermal oscillation.18 On the contrary, without artificial aging, unrealistically high fracture loads can result.19

In the present study, insistence emphasis was placed on the stages of the aging procedures. For the purpose of applying thermal stress, restoration was subjected to thermocycling. Anusavice et al.27 stated in their study that thermocycling has a significant effect on the degradation of ceramics, especially glass–ceramics used for veneers. In addition, the storage of the cemented restoration in artificial saliva for 40 days played an essential role in the implementation of the aging process. Mohammed and Alwahab28 study showed that the artificial saliva reduced the shear bond strength of zirconia and metal–ceramic restorations. In general, the presence of water can weaken the glass–ceramic and hydraulic fracture of Si–O–Si bonds.22

Based on the study by Wang et al., cyclic loading can reduce the load-bearing capacity of IPS e.max Press.28,29 Chewing Simulation with slow crack propagation leads to an accumulation of tension, fatigue, and consequent mechanical destruction. Over time, this fatigue significantly reduces the strength of the ceramic, resulting in failure at much lower forces than the original fracture resistance.19

The elastic modulus of the die has a significant effect on the fracture resistance of all-ceramic crowns. The use of a supporting die with a low elastic modulus may be proper for fracture strength tests, in an attempt to appropriately reflect clinical conditions.30 According to Scherrer and de Rijk,31 the fracture load increased significantly by using dies with a higher elastic modulus. The elastic modulus of metallic dies is much higher than the dentin, such as titanium, stainless steel, and chromium-nickel alloys.8 In 2012,

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### Table 1: The mean (±standard deviation) of failure resistance covered by the study

<table>
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<th>Mean (N)</th>
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MF, modified framework; SF, standard framework

### Table 2: Mode of failures (%)

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<tbody>
<tr>
<td>SF</td>
<td>10</td>
<td>90</td>
<td>70</td>
</tr>
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samples *t*-test revealed no statistically significant difference between the two coping designs (*p* = 0.96). Furthermore, resin die fractures were reported in all specimens. As three crowns in the modified group and one crown in the standard group did not show any crack in the universal testing machine, their resin died instead of fracturing. There was fracture through both the core and veneer in all fractured crowns. In the standard group, nine mixed failures, and in the modified group seven mixed failures were observed (Table 2). Fisher’s exact test revealed no statistically significant difference between the groups (*p* = 0.58).

**Discussion**

The mechanical characteristics of restorations are influenced by a number of factors, including framework design. Modified design is not evaluated in glass–ceramic restorations, but it is reviewed in zirconia or metal–ceramic restorations.

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Core Design’s Effect on Fracture Resistance

Larsson et al.\(^9\) pointed out that abutment’s support significantly affects fracture load and failure mode of the zirconia crowns, which was consonant with the results of previous studies. Due to the difference in the elastic modulus of titanium and dentin, the stress distribution during loading on the titanium abutment should show different patterns on the natural teeth.\(^1,10\) Chen et al.\(^11\) reported that fracture resistance of minimal thickness IPS e.max computer-aided design (CAD) crowns may be influenced by the elastic modulus of the abutments. Several researchers use resin dies to standardize the preparations and obtain crowns with identical physical qualities.\(^12\)

These are the reasons for the choice of the resin die in the present study, despite the fact that the unusual die failure in all specimens during the aging process and the uncertain water absorption rate of the resin can be considered as disadvantages of this material.

Based on previous studies, the load was applied at a crosshead speed of 1 mm/minute to provide sufficient time for the distribution of forces across the porcelain. The high speed of the universal testing machine may overestimate the strength of the crowns.\(^14\) The loading point plays a significant role in the concentration and distribution of tension.\(^1,10\) Loading was applied axially at an angle of 135° on the palatal surface (2.5 mm below the incisal edge) to simulate the approximate anterior relationship during mastication.\(^20,34\) Two layers of tin foil as a shock absorber were placed centrally between the sample and the indenter to prevent the Hertzian cone crack. This crack takes place when a conical indenter is compressed into the surface of brittle or cryptocrystalline material which is rare in clinical settings.\(^23,35,36\)

Whilst specimens of the modified group remained intact in the pretesting procedure, visible cracks were reported in three samples of the standard group. Three crowns of the modified group did not show any crack in the universal testing machine and their resin dies have been fractured instead. This may be attributed to the positive effect of the MF design and the high susceptibility of resin dies to aging. Overall, the modified group outperforms our standard group in terms of their failure modes, although the two groups had similar mean fracture resistance.

Øilo et al.\(^37\) in a similar study, evaluated the failure mode and fracture load of IPS e.max Press central crowns, with the difference that an anatomical framework design was used, and the aging process only included storing the samples in 37°C distilled water for 24 hours. Additionally, loading was applied on the incisal edge by a steel cylinder with a diameter of 30 mm. Fracture in all specimens started from the margin of the proximal region and was considered the weakest part of the crown. The mean fracture load of IPS e.max Press crowns was 750 N; while in the present study, the mean fracture load was 218 N. This discrepancy can be explained by the difference in the aging process, type of die and its elastic modulus, and methods of load application.

It is worth noticing that the average fracture load of the present study is greater than the shear forces normally applied to the anterior region of the oral cavity; assuming the average force in this area is from 89 to 111, with an added safety margin of 200 N.\(^17\)

Limitations of this in vitro study included that only one material and two types of frameworks were tested. More clinical studies can be conducted on novel CAD/CAM materials such as polymer-infiltrated ceramic networks (PICN) and zirconia-reinforced lithium silicate (ZLS) in the future. Furthermore, different types of cement can be assessed in different framework designs and other mechanical properties can be examined.

**Conclusion**

There were no statistically significant differences in fracture resistance between the modified and standard groups. Mixed fracture was the most common failure mode in both groups. Thus, based on the aforementioned results, the MF design did not increase the fracture resistance of IPS e.max Press crown. However, the difference in the failure mode of the two groups might indicate the positive impact of the MF design.

**Data Availability**

Data of this article is available on request from corresponding author.

**References**

Core Design’s Effect on Fracture Resistance


