

# The Influence of Aging on the Fracture Load of Monolithic Crowns

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## Research Article

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# Abstract

**Background:** This in-vitro study was conducted to assess the fracture load of molar crowns fabricated with monolithic CAD/CAM materials.

**Methods:** The crown restorations were produced from Cerasmart, Vita Enamic, and IPS e.max CAD blocks. Dual-axis chewing simulator (50 N, 1.1 Hz, lateral movement: 1 mm, mouth opening: 2 mm, 1,200,000 cycles) and thermocycling ( $\pm$  5-55 °C, 6000 cycles) were applied as an aging procedure to half of the samples. Aging was not applied to the other half of the specimens. Then, all samples were evaluated in a universal testing machine to determine the fracture loading values'. Repeated measures of Variance analysis were used for statistical analysis of the data ( $p < 0.05$ ).

**Results:** The aging applied Vita Enamic crowns ( $1978,71 \pm 364,05$  N) were exhibited the lowest fracture load value. No aging process applied IPS e. max CAD crowns ( $3098,4 \pm 667,09$  N) were exhibited the highest fracture load value. According to the fracture load values after the aging process, statistically significantly different was found Vita Enamic crowns from all the others.

**Conclusions:** Cerasmart, Vita Enamic, and IPS e.max CAD monolithic crowns used in the study were found resistant to the 5-years aging process via chewing simulator. Cerasmart, a hybrid ceramic material may be used as an alternative to IPS e.max CAD when considering the behavior against fracture load.

## Background

Increased interest and demand for biocompatible restorations that contain no metals have encouraged researchers to search for new materials. All of the ceramic restorations became promising with the help of soft tissue biocompatibility [1], improved color stability, improved abrasion resistance as well as superior light transmittance [2]. In recent years, computer-aided design (CAD) /computer-aided manufacturing (CAM) technologies have been extensive in dentistry. Standardized production processes of CAD/CAM-produced restorations have enabled uniform material quality, reproducibility of restorations, and reduced production costs. Thus, a new generation of ceramic and composite materials for bi-layered and monolithic applications was developed. However, chipping in bi-layered all-ceramic restorations still represents the most widely recorded laboratory and clinical problems [3, 4]. Another way to avoid veneer fractures is to use monolithic restorations [5–9]. Monolithic crowns have significant advantages, such as reduced production times and economic. Also, the elimination of the veneer layer makes a more conservative preparation possible. Another advantage of monolithic ceramics is that they significantly reduce the risk of cohesive failure compared with conventional veneering techniques [8, 10–12]. Lithium disilicate glass-ceramics are usually used for monolithic restorations because of their high fracture resistance [11, 13]. Recently, CAD-CAM blocks of interpenetrating ceramic and polymer networks have been introduced [14–16]. This dual-network provides reduced brittleness and surface hardness, and elastic modulus closer to that of dentin, faster milling, better marginal quality, and easier polishing [6, 16].

However, inadequate data exist regarding the fatigue resistance of posterior resin-ceramic dual network restorations [14, 15, 17].

The primary criterion in determining the restorative material used is that it has sufficient mechanical properties against the chewing forces and can protect the remaining tooth structure. Nevertheless, all-ceramic restorations are subjected to complex intra-oral forces during clinical service. To determine the durability of all-ceramic restorations similar to the oral conditions, loading them under similar thermal and mechanical conditions is beneficial. Restorations are loaded repeatedly in the presence of water with masticatory loads reaching an average of 240.000-250.000 cycles/year [18–20]. However, there is little information on the long-lasting mechanical load properties of monolithic CAD/CAM polymer-based resin composite materials [9, 21]. Also, there is a need for long-term work on fatigue behavior, and fracture resistance of new hybrid ceramic materials.

This in-vitro study was conducted to assess the fracture load of monolithic CAD/CAM molar crown restorations after aging. The first null hypothesis of the study was that the fracture load values would reveal no significant difference before and after aging between the monolithic CAD/CAM crown restoration materials. The second null hypothesis of the study was that there would be no decrease in the fracture load values of the monolithic crown restorations after the aging process.

## Methods

### Preparation of Specimens

Sixty freshly-extracted and caries-free left mandibular first human molar teeth were collected, cleaned, and stored in 0.1 % thymol solution [22]. The dimensions of the collected teeth were measured is  $11 \pm 1$  mm in mesiodistal direction,  $10 \pm 1$  mm in labio-lingual direction, and  $7 \pm 1$  mm in cervical-occlusal direction. Then, the teeth were prepared according to the accepted tooth preparation principles using a chamfer diamond rotary instrument (879 014 10 Diatech Dental AG, Heerbrugg, Switzerland) by adjusting for a 1 mm circumferential chamfer margin, 1.5 mm occlusal reduction, 1 mm axial preparation, and  $6^\circ$  convergence angle. After preparation, the master casts were evaluated using a surveyor to detect undercuts [23].

Subsequently, the teeth were divided into three test groups ( $n = 20$ ). For each test group, full crown restorations were fabricated with Cerasmart (GC, Tokyo, Japan), Vita Enamic (Vita Zahnfabrik, Bad Sackingen, Germany) and IPS e.max CAD (Ivoclar Vivadent, Liechtenstein) monolithic blocks in Cerec System (Cerec inLab MC XL, Sirona, Bensheim, Germany). Sintering and glazing were applied to IPS e.max CAD crowns at  $850^\circ\text{C}$  in inLab Fire (Sirona, Bensheim, Germany) for 25 min. Ceramic Primer II (GC, Tokyo, Japan), and Optiglaze Color (Optiglaze Color, GC, Tokyo, Japan) were applied after sandblasted with  $25\text{-}50\ \mu\text{m Al}_2\text{O}_3$ , and then air-dried to the Cerasmart and Vita Enamic specimens.

### Luting of the Crowns

All the crown restorations were adhesively luted on prepared molar teeth using a dual-cure composite material (Panavia F 2.0, Kuraray Noritake Dental Inc., Japan). Equal amounts of Panavia Paste A and B (Panavia F 2.0, Kuraray Noritake Dental Inc., Japan) were mixed and applied to the inner surfaces of the crowns according to the manufacturer's instructions. The restorations were seated onto the teeth and held in place by the application of finger pressure. The excess cement was removed with sponge pellets, and an air-blocking gel (Oxiguard II, Kuraray Noritake Dental Inc., Japan) was applied. Then they were cured using a curing light for 20 sec. The specimens were stored for 24 h at 37 °C before being subjected to aging [23].

## Aging

All the root surfaces of the teeth were coated with a 1 mm-thick polyether layer (Impregum Soft, 3M Espe, Seefeld, Germany) from the marginal finish line of the restorations to 2-mm apical direction to simulate the physiologic mobility of teeth [24,25]. The teeth were immersed in a wax bath, which was replaced by polyether in a second fabrication process, as previously described. Later, restorations on teeth were fixed in a resin mold, which acts as the sample holder for the chewing simulator, using a self-curing acrylic resin material (Meliodent, Heraeus Kulzer, Hanau, Germany). Thermal and aging were not applied to half of the specimens (n=10). The other half of the specimens underwent thermocycling (SD Mechatronik Thermocycler, SD Mechatronik GmbH, München, Germany) for 6,000 cycles between 5° and 55 °C, over a dwell time of 60 sec, and a transfer time of 10 sec (n=10) [26,27]. After thermocycling, the specimens were subjected to a 2-body wear test in a dual-axis chewing simulator in distilled water solution (CS 4.2, SD Mechatronic GmbH, München, Germany). Steatite balls (Hoechst Ceram Tec., Wunsiedel, Germany) of 6 mm diameter were used as the opposing occlusal surface. The balls were fixed to the upper sample holders of the chewing simulator using a light-curing composite resin (GC Pattern Resin, GC, Tokyo, Japan). The chewing simulation parameters used are summarized in Table 1. The load was transferred to the center of the central fossa of the mandibular first crowns by antagonistic steatite balls. To simulate 5-years of clinical service, a total of 1,200,000 cycles were performed [23,28-30].

## Fracture Load Test

Following the aging procedure, the specimens were tested on a universal testing machine (AGS-X, Shimadzu, Tokyo, Japan) until fracture. They were subjected to a compressive force at a crosshead speed of 0,5 mm/min with a round-shaped modified bur of 4 mm diameter. A metal bar was positioned parallel to the long axes of the crown specimens and the buccal and lingual cusps of the crowns were used to apply the force. The maximum load necessary to fracture each specimen was recorded in newtons (N) [23].

## SEM

To characterize the surface wear patterns, one specimen of each monolithic CAD-CAM crown-group was evaluated by a scanning electron microscopy (SEM, JEOL JSM-7001F, Jeol Ltd., Tokyo, Japan), for which the sample surfaces were initially coated (Quorum SC7620, Quorum Tech. Ltd., Newhaven, UK) with a thin layer of gold. The surfaces were then examined at a magnification of 10-200 x at 25 keV.

## Statistical Analysis

Statistical analysis was performed using SPSS 20.0 (IBM SPSS Statistics 20, IBM Co., Somers, NY, USA) for Windows. Having assessed that, all the obtained results were normally distributed and the differences of the measures in terms of groups were evaluated using repeated measures of Variance analysis. The results are expressed as mean  $\pm$  standard deviation and the level of significance is set at 5 % ( $p < 0.05$ ).

## Results

None of the samples fractured during aging. The mean and standard deviation of the Fracture Load values are shown in Table 2. Two-way ANOVA showed statistically significant differences when the fracture load values of IPS e.max CAD, Cerasmart, and Incoris TZI crowns after 1,200,000 chewing cycles were analyzed ( $p < 0.05$ ). While load value for the highest fracture was observed in IPS e.max CAD (3098,4  $\pm$  667,09 N) crowns that aging was not applied, the lowest fracture load value was observed in aging applied-Vita Enamic (1978,71  $\pm$  364,05 N) crowns. The mean and standard deviation of the Fracture Load values of all specimens to which aging was not applied are shown in Table 3. The average fracture load value of Cerasmart crowns without aging was 2731,81  $\pm$  488,51 N while the mean fracture load value of Vita Enamic crowns without aging was 2195,46  $\pm$  387,83 N. There was not a statistically significant difference between the fracture load values of specimens of IPS e.max CAD and Cerasmart crowns that aging was not applied ( $p > 0.05$ ). Likewise, there was not a statistically significant difference between the fracture load values of specimens of Cerasmart and Vita Enamic crowns to which aging was not applied ( $p > 0.05$ ). However, it was found that there existed a statistically significant difference between the fracture load values of specimens of IPS e.max CAD and Vita Enamic crowns to which aging was not applied ( $p = 0.02$ ). The mean and standard deviation of the Fracture Load values of all specimens that aging was applied are shown in Table 4. According to the fracture load values after the aging process, there was not a statistically significant difference between the fracture load values of IPS e.max CAD crowns (2781,51  $\pm$  559,45 N) and Cerasmart (2578,99  $\pm$  575,9 N) crowns to which aging was applied ( $p > 0.05$ ). The fracture load values of Vita Enamic crowns (1978,71  $\pm$  364,05 N) were statistically significantly different from both of the fracture load values of IPS e.max CAD ( $p = 0.005$ ) and Cerasmart crowns ( $p = 0.04$ ). The mean values of the fracture load of all samples with aging treatment with a chewing simulator and thermal cycling were not statistically significant among the three materials ( $p > 0.05$ ).

Representative SEM images of the surface patterns of IPS e.max CAD, Cerasmart, and Vita Enamic crowns are shown in Fig. 1-3 (a,b).

## Discussion

To overcome the chipping behavior of the newly developed esthetic ceramics, the use of monolithic materials has become widespread. In this study, the fracture load of monolithic molar crown restorations fabricated with lithium disilicate reinforced glass-ceramic and hybrid ceramic blocks after aging was investigated in vitro conditions. According to the average fracture load values without the aging process, there was not a statistically significant difference between IPS e.max CAD crowns, and Cerasmart crowns ( $p > 0.05$ ). It was also determined that there was not a statistically significant difference between Cerasmart crowns, and Vita Enamic crowns ( $p > 0.05$ ). But according to the average fracture load values without aging process, there was a statistically significant difference between IPS e.max CAD crowns, and Vita Enamic crowns ( $p < 0.05$ ). Similarly, according to the average fracture load values with the aging process, IPS e.max CAD crowns, and Cerasmart crowns were statistically significantly different from Vita Enamic crowns ( $p < 0.05$ ). For this reason, the first null hypothesis of the study - the fracture load values would reveal no significant difference before and after aging between the monolithic CAD/CAM crown restoration materials - was rejected. In the light of the results of this study, crown specimens' fracture load values with and without aging were not significantly different from each other. So, the second null hypothesis of the study -there would be no decrease in the fracture load values of the monolithic crown restorations after the aging process- was accepted.

Lithium disilicate blocks with high flexural strength (360 MPa) and modulus of elasticity (95 GPa) have been shown the highest values of fracture load and were confirmed by the results of previous studies [31, 32]. In a study, resin-based CAD/CAM materials were found to have higher fatigue resistance to occlusal loads than CAD/CAM ceramic materials [33]. In addition to fatigue loading, artificial aging with a thermal cycle is a well-established method to imitate the clinical situation [34]. There are many problems with restoration due to temperature changes in the oral cavity caused by eating, drinking, and breathing [2]. In these in vitro studies, different thermal cycle temperatures were used and most of these temperatures range from + 5°C to + 55°C [29, 30, 35]. In addition, various cycles ranging from 1 to 1,000,000 and retention times ranging from 4 seconds to 20 minutes have been observed [36]. In the present study, thermal cycling applications were performed with water temperatures of 5 °C and 55°C over a dwell time of 60 sec, a transfer time of 10 sec, and a cycle number of 6000 cycles [26]. According to the literature, an average of 250,000 chewing cycles in a chewing simulator corresponds to use in a one-year clinical setting [37]. For this reason, 1,200,000 cycles were conducted in this study for the chewing function to correspond to five years [38, 39]. The chewing force 50 N at a frequency of 1-1.6 Hz has been commonly applied to simulate intraoral conditions in in-vitro studies [23, 24, 34, 39, 40].

Güngör and Nemli [41] have investigated the effect of aging on fracture resistance of monolithic ceramics and veneered zirconia crowns. The Vita Enamic crowns were catastrophically broken during the aging process. The highest fracture resistance values were found in the monolithic zirconia crowns,

followed by IPS e.max CAD crowns, which were monolithic lithium disilicate. In this study, it is important to note that the application of aging with a force of 100 N, and the only polishing application instead of glazing on the specimens exhibit the fracture load values of tested ceramic blocks. This study is the first one advocating the use of resin ceramics as a veneer on the core. Contrary to this work, aging and deterioration can occur without visible catastrophic failures. In these cases, the next static fracture test can help detect weak spots. For this purpose, no fracture was observed in the present study during the dynamic loading with the chewing simulator. All surviving samples were placed in a universal test machine for static loading so that the fracture load values could be determined. Fracture load data cannot be directly related to clinical survival but may provide information on the suitability of new ceramics for the requirements of clinically proven systems.

In another study, the fracture resistances of six different restoration materials produced by CAD/CAM were compared [42]. Cerasmart, Lava Ultimate, and Paradigm MZ100 were found to be significantly more successful than the new hybrid blocks. Ceramic materials are less flexible and more fragile than blocks containing resin. This difference in the elastic property is caused by the resin component which helps to reduce the fragility. Materials that perform well in flexural testing should be investigated for other properties, such as cyclic fatigue, color stability, and material and antagonist wear. Yet, the materials which were used in these tests do not show the clinical setting [43]. For this reason, it is aimed to compare the effect of aging processes applied with using full-crown restorations on fracture load in the present study.

Aboushelib et al. [16], investigated the effect of cyclic fatigue on resin infiltrated ceramics and reinforced glass-ceramic blocks and reported that dynamic fatigue significantly reduced initial fracture strength. Among the resin infiltrated ceramics, Lava Ultimate and Vita Enamic were less affected by fatigue and fracture strength while the incidence of fracture during fatigue was highest in resin infiltrated ceramics. According to the results of the present study, it was found that there was not a significant difference between the mean fracture load values of the samples with and without aging. However, the reduction in the fracture strength of the lithium disilicate-reinforced ceramic samples was observed more than the resin-containing ceramics as similar to the study of Aboushelib et al. [16].

Seydler et al. [22], investigated fracture load of IPS e.max CAD crowns prepared at different thicknesses in the 10,000 thermal cycles and 1,200,000 chewing cycles. It was found that, during the aging process with the chewing simulator, no fracture was observed in specimens with thicknesses of 1 mm and 1.5 mm, and better resistance against fracture compared to specimens with a thickness of 0.5 mm. Fracture resistance values for lithium disilicate restoration are lower than those in the present study, which may be related to the load difference applied during the chewing simulator. Sieper et al. [43], reported no significant effect on the fracture strength of occlusal thicknesses of lithium disilicate and PICN crowns after the chewing simulator in studying fracture strength of PICN, zirconia-reinforced lithium disilicate, and lithium disilicate crowns.

In the present study, fracture load revealed for all the crowns have a consistent crack pattern. Although there was no chipping, the monolithic crowns were massively (catastrophically) broken up to the surface of the prepared tooth. One limitation of this study is that the ceramic material does not have a uniform thickness. One of the reasons for the non-uniform thickness of the crown is the production of anatomically contoured crowns on standard preparations. Another limiting factor of this study may be the use of steatite antagonists instead of human tooth antagonists for dynamic loading.

## Conclusions

In the light of the data obtained from the study that contributed to the literature by aging monolithic crowns in the posterior region, it was seen that the durability of the crown restorations with three different materials was resistant to the 5-year aging process. But the long-term biological, mechanical and abrasive effects of these new CAD/CAM materials should be confirmed by future in-vitro and in-vivo investigations.

## Abbreviations

**CAD:** Computer-aided design, **CAM:** Computer-aided manufacturing, **%:** Percent, **°:** Degree, **°C:** Centigrade degrees, **h:** Hour, **min:** Minute, **sec:** Second, **mm:** Millimeter, **µm:** Micrometer, **N:** Newton, **MPa:** Megapascal, **GPa:** Gigapascal, **keV:** Kiloelectron volt, **Hz:** Hertz, **Al<sub>2</sub>O<sub>3</sub>:** Aluminum, **PICN:** Polymer infiltrated the ceramic network.

## Declarations

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## Ethics approval and consent to participate

All procedures performed in this study involving human teeth were following the ethical standards (with the 1964 Helsinki declaration and its later amendments) and approved by the Clinical Research Ethics Committee of the University of Tokat Gaziosmanpaşa with the number of 15-KAEK-170/2015. Informed consent was obtained from all individual participants included in the study.

## Consent for publication

Not applicable

## Availability of data and materials

The datasets generated and/or analyzed during the current study are not publicly available due to “The study was carried out as a specialization thesis in the field of prosthodontics” but are available from the corresponding author on reasonable request”.

## Competing interests

The authors declare that “they have no competing interests”.

## Authors Contribution

C.G. Study conception and design, acquisition of data, analysis, and interpretation of data, drafting of the manuscript.

I.S. Study conception and design, acquisition of data, analysis, and interpretation of data, critical revision. Both authors read and approved the final manuscript.

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## Tables

**Table 1**

Configuration of parameters set for aging.

<b>Parameter</b>	<b>Data</b>
Number of cycles	1.200.000
Force	49 N
Height	2 mm
Lateral movement	1 mm
Descendent speed	55 mm/s
Lifting speed	55 mm/s
Feed speed	50 mm/s
Return speed	50 mm/s
Frequency	1.1 Hz

**Table 2**

Mean values and standard deviations (SD) for Fracture Load (N) of the specimens.

Material	Without aging	With aging
IPS e.max CAD	3098.4 ± 667.09 (a,x)	2781.51 ± 559.45 (a,x)
Cerasmart	2731.81 ± 488.51 (ab,x)	2578.99 ± 575.9 (a,x)
Vita Enamic	2195.46 ± 387.83 (b,x)	1978.71 ± 364.05 (b,x)

\*Different letters indicate a statistically significant difference between groups ( $p < 0.05$ ).

\*a,b intra-group comparisons.

\*\*x,y between-group comparisons.

**Table 3**

Mean values and SD for Fracture Load (N) of all specimens that aging was not applied.

	(I) Material	(J) Material	Average difference (I-J)	SD	$p^{**}$	95 % confidence interval for the difference	
						Lower limit	Upper limit
<b>Aging was not applied</b>	IPS e.max	Cerasmart	366.590	235.806	.395	-235.296	968.476
		Enamic	902.941*		.002	301.055	1504.827
	Cerasmart	IPS e.max	-366.590		.395	-968.476	235.296
		Enamic	536.351		.093	-65.535	1138.237
	Enamic	IPS e.max	-902.941*		.002	-1504.827	-301.055
		Cerasmart	-536.351		.093	-1138.237	65.535

\* 0.05 level of significance

\*\* Bonferroni correction for multiple comparison

**Table 4**

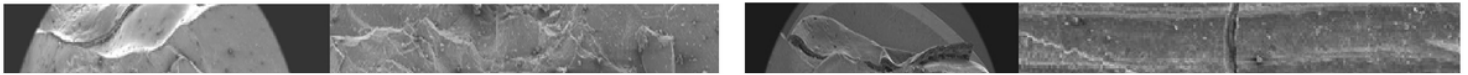
Mean values and SD for Fracture Load (N) of all specimens that aging was applied.

	(I) Material	(J) Material	Average difference (I-J)	SD	$p^{**}$	95 % confidence interval for the difference	
						Lower limit	Upper limit
<b>Aging was applied</b>	IPS e.max	Cerasmart	202.519	227.624	1.000	-378.481	783.519
		Enamic	802.798*		.005	221.798	1383.798
	Cerasmart	IPS e.max	-202.519		1.000	-783.519	378.481
		Enamic	600.279*		.041	19.279	1181.279
	Enamic	IPS e.max	-802.798*		.005	-1383.798	-221.798
		Cerasmart	-600.279*		.041	-1181.279	-19.279

\* 0.05 level of significance

\*\* Bonferroni correction for multiple comparisons

## Figures



**Figure 1**

**a:** SEM picture (50x) of the IPS e.max CAD specimens without aging.

**b:** SEM picture (100x) of the IPS e.max CAD specimens with aging.

## **Figure 2**

**a:** SEM picture (200x) of the Cerasmart specimens without aging,

**b:** SEM picture (25x) of the Cerasmart specimens with aging.

## **Figure 3**

**a:** SEM picture (50x) of the Vita Enamic specimens without aging,

**b:** SEM picture (50x) of the Vita Enamic specimens with aging.