# Effect of Zirconia Thickness on the Tensile Stress of Zirconia Based All-Ceramic Restorations

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**Abstract**

**Introduction:** The purpose of the presented study was to evaluate the effect of zirconia thickness on the tensile stress of zirconia based all-ceramic restorations. **Methods:** Twenty zirconia disks with 10mm diameter were prepared in two groups using CAD/CAM system. The thickness of zirconia was 0.5mm in first group and 0.3mm in second group. After sintering, 0.4mm glass ceramic porcelain was applied to each disk. Then, sintering and glazing of porcelain carried out. Instron testing machine with 1mm/min crosshead speed used to evaluate the failure load of the samples. Biaxial Flexural strength standard formula employed to calculate tensile stress of specimens. Statistical analysis performed using SPSS software. **Results:** Although data analysis showed more maximum tensile stress in 1st group, no significant differences were found between two groups. **Conclusion:** Zirconia with 0.5mm and 0.3mm thicknesses cause similar tensile stress in all-ceramic restorations and thickness of these laminates could be reduced to 0.7mm.

**Key words:** Zirconia, Tensile stress, Laminate.

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## Introduction

Nowadays, the desire for beautiful smile with shiny teeth in order of higher personal self-steam has increased patients' demands for getting their inelegant anterior teeth restored. Although porcelain fused to metal crowns was the most common treatment for these purposes, all-ceramic restorations need more conservative tooth preparation. On the other hand, laminate veneers are prepared at the same level of enamel to protect dentin and pulp. Furthermore, metal-free restorations are more pleasant; make natural tooth brightness and present more natural soft tissue color than PFMs (1).

Despite all positive aspects of all-ceramic veneers to substitute PFMs, restricted depth limits laminate thickness, which makes it sensitive to masticatory loads. Recently, most of the scientists and dental researchers are working on improving the mechanical features such as, failure load and marginal integrity of all-ceramic laminates. One of these efforts was combining the strength of ceramic cores like alumina and zirconia, and superior aesthetics of a weaker veneer ceramic (2).

Zirconia is a crystalline dioxide of zirconium (3) with metallic mechanical properties and tooth like color (4). Its special qualities such as strength, transformation toughening, white color, chemical and structural stability make it a good choice for a core material (5). Application of 0.5mm zirconia core to porcelain laminates has increased the strength of all-ceramic restorations (6). Zirconia based restorations presented 755 N average load capacity (7) and fracture resistance of 1mm thickness monolithic zirconia crowns was as same as PMFs (8). In addition, zirconia based laminate veneers presented more fracture resistance in comparison with glass-ceramic ones (9).

Ceramic chipping is the second reason of laminate veneer's failure after aesthetic ones (10). It depends on tooth preparation method, core thickness, finish line position and bonding procedure (11-13). Some studies showed different preparation methods could not affect laminate veneers failure load with several core (9).

Zirconia opacity helps dentists to cover unsightly discolored teeth by thin restorations (9).Aesthetic aims require at least 0.4 mm thickness of veneer porcelain on zirconia core. Thus, through 0.7 mm thickness of laminate veneers, 0.3 mm remains for core materials. So, the purpose of this study was to compare the tensile stress of all-ceramic restoration with 0.3 mm and 0.5mm zirconia core. The null theory was that these two zirconia thicknesses lead similar tensile stress in zirconia based all-ceramic restorations.

## Materials and Methods

Twenty Cercon zirconia based all-ceramic disks were prepared as below:

1. Ceramill® mind software (CAD construction software, AmannGirrbach America, Inc. , USA) used for designing disks with 10mm diameter and 0.5mm thickness in 1st group (n=10) and 0.3mm thickness in 2nd group (n=10).
2. The designed model was sent by CORiTECicam (mes-icore GmbH, Germany), a highly reputable 5-axes Profi-CAM-System, to milling device (CORiTEC-550 imes-icore GmbH, Germany) in order to disk construction from zirconia blanks (Ceramic Zr blank,Jiaozuo Lifeng Industrial Co., China) by its 5 cutting axes.
3. Zirconia disks were placed in sintering furnace (iSINT HT Speed imes-icore GmbH, Germany). The furnace heated up to 1350 $^{o}$c in one hour and half and kept in this temperature for 2 hours. After that, cooling procedure was done for 2 hours and half.
4. 0.4 mm thickness glass ceramic porcelain (Cercon® Ceram Kiss, DeguDent Co., Germany) was applied on every 20 disks by manually aided method. So, in 1st and 2nd group, the thickness of final disks was 0.9mm and 0.7mm, respectively.
5. Samples were put in furnace and heated in 970$^{o}$c according to Table 1.
6. Glazer powder applied to each sample and then glazing carried out in 800$^{o}$c according to Table 1.

Before failure load examination, disks were evaluated under low magnification microscope to clarify any cracks or breaking and damaged samples were then excluded.

Clear surface (Zirconia part) of disks placed on a tripod pellet of universal testing machine (SANTAM STM-20, Santam, Iran) and loaded by one millimeter per minute crosshead speed (a piston with 1.6 mm diameter cylindrical indentor closed to the porcelain surface) and 50 kg to 200 kg load cell until fracture occurred. Force/Extension diagram was traced by Instron software for each sample. After disks breaking, the device was stopped and Peak and Break points which are equal for brittle materials such as zirconia were measured.

Because of different thickness of two groups, Biaxial Flexural strength standard formula used to calculate tensile stress of samples:

$S= -0.2387\ P(X-Y)/d^2$

S: Maximum tensile stress

P: load of fracture

d: specimen thickness

$X= (1+v)\ln (B/C)^2+[(1-v)/2](B/C)^2$

$Y= (1-v)[1+\ln(A/C)^2]+(1-v)(A/C)^2$

v: Poisson's ratio = 0.25 (for zirconia and dental porcelain)

A: radius of the support circle

B: radius of the tip of piston

C: samples' diameter

In statistical analysis, 2 independent samples test (Mann Whitney U Test) was used by SPSS version 11.0.0 (SPSS Inc., Chicago, IL, USA.)

## Results

Calculated maximum tensile stress of specimens is presented in Table2.

Diagram 1 & 2 containing Force/Extension diagram of one sample of each group, which was created by Instron device software.

Shapiro-Wilk test showed normal distribution of maximum tensile stress in 1st group and then 2 Independent sample test (Mann Whitney U Test) was performed and determined no significant difference between two study groups (P-value=0.063). (Table3)

**Table 1.** Cercon Ceram Kiss firing chart

| | Pre-heating (°c) | Drying time Pre-heating time (min) | Heating rate (°c/min) | Final temperature (°c) | Holding time (min) | Vacuum (hPa) | Long term cooling |
|---|---|---|---|---|---|---|---|
| Paste liner 1 | 575 | 8:00 | 55 | 970 | 1:00 | 50 | - |
| Paste liner 2 | 575 | 8:00 | 55 | 960 | 1:00 | 50 | - |
| Margin 1 | 450 | 6:00 | 55 | 850 | 1:00 | 50 | - |
| Margin 2 | 450 | 6:00 | 55 | 850 | 2:00 | 50 | - |
| Dentine 1 | 450 | 5:00 | 55 | 830 | 1:30 | 50 | - |
| Dentine 2 | 450 | 5:00 | 55 | 820 | 1:30 | 50 | - |
| Glaze | 450 | 3:00 | 55 | 800 | 1:00 | - | 6:00 |
| Correction (Final Kiss) | 450 | 5:00 | 55 | 680 | 1:00 | 50 | 6:00 |
| Final shoulder (F-SM) | 450 | 5:00 | 55 | 680 | 1:00 | 50 | 6:00 |

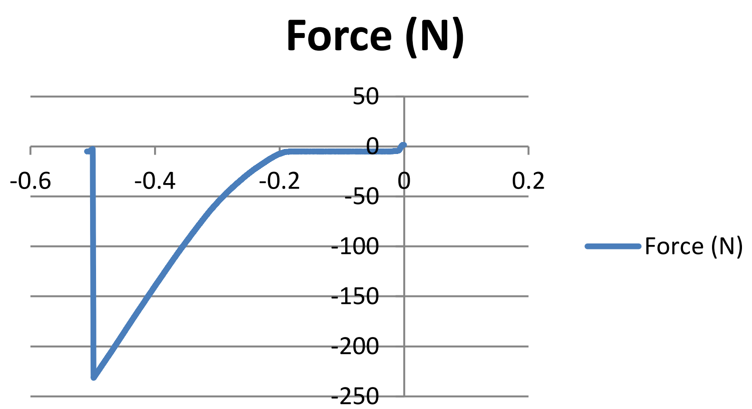


**Figure 1.** An example of Force/Extension diagram of 2nd group samples calculated by Instron special software. Disk breaking occurred at 231 N.

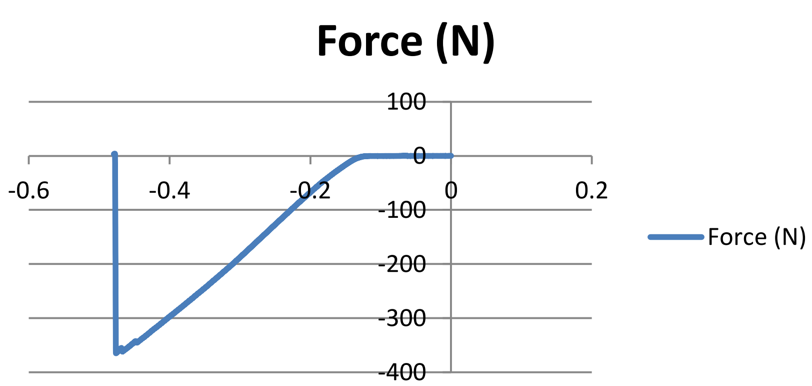


**Figure 2.** An example of Force/Extension diagram of 1st group samples calculated by Instron special software. Disk breaking occurred at 364.93 N.

**Table 2.** Calculated maximum tensile stress of specimens

| Number of samples | 10mm diameter and 0.9mm thickness | 10mm diameter and 0.7mm thickness |
|---|---|---|
| 1 | 830.50 | 711.99 |
| 2 | 642.21 | 742.22 |
| 3 | 963.54 | 611.77 |
| 4 | 852.68 | 726.13 |
| 5 | 816.54 | 681.98 |
| 6 | 876.46 | 733.95 |
| 7 | 829.85 | 794.99 |
| 8 | 830.64 | 902.87 |
| 9 | 826.88 | 679.03 |
| 10 | 829.20 | 898.25 |

**Table 3.** Statistical indices for both groups.

| Group | N | Mean | Standard deviation | Min | Max | *P*-value |
|---|---|---|---|---|---|---|
| 0.9mm thickness | 10 | 829.85 | 96.57 | 642.21 | 963.54 | 0.1 |
| 0.7mm thickness | 10 | 784.32 | 93.36 | 611.77 | 902.87 | |

## Discussion

Dentists are looking for the best materials to use in different clinical conditions. They have to rely on standard laboratory tests to choose appropriate substances they need. In clinical situation most of restoration's failures are chipping, breaking or deformation, which are the result of materials' properties. But, it should be considered the restoration success also depends on biophysical and physiological quality of supporting tissue.

Ceramic materials have an important role and situation in restorative dentistry. One of the advantages and also a disadvantage of the ceramics is their brittle nature causing friability of them when there is more than 1% deformity (14). This issue causes researchers efforts to find ways for increasing ceramic strength to prevent its fragility with preservation of other positive characteristics which has made it unique. Such material production has been accelerated during recent years mainly with the aim of increasing the materials power and appearance beauty. Metal core of fixed restoration prostheses is still one of the reliable solutions for ceramic enhancement. However, increasing needs for more beauty in ceramic restorations has led to the endeavors to find a replacement for opaque metal core. Based on the above reasons, all- ceramic systems were emerged that were totally different. zirconia ($ZrO2$) application is one of the most recent approaches. These materials are applied in industry specifically in electronics and medical fields like in orthopedics. Now, this material has a special place in dentistry that is mainly used as a core material of ceramic restorations and also as osteointegration substance in dental implants. Application of these materials has been initiated since 2000 and become more acceptable since 2010(15).

Although, different kinds of ceramic systems containing zirconium have been used in industry (16), three systems have been applied in dentistry. These systems include complete stabilized tetragonal zirconia, partial stabilized zirconia, and zirconia reinforced alumina.

In this cross sectional study, the failure load of all-ceramic restorations containing zirconia with 0.7 and 0.9 millimeters (mm) thickness was assessed and difference between tensile stress and failure load of two groups were not significant.

In previous studies, various characteristics with regard to the failure load of ceramic restorations have been compared and assessed. Sun et al. performed a research concerning the effect of thickness on failure load and showed that monolithic zirconia crowns had higher failure load in comparison to monolithic disilicate lithium crowns, layered zirconia crowns, and metal ceramic crowns. It has also been revealed that fracture load of monolithic zirconia crowns with 1mm thickness could be similar to PFMs. Furthermore, increasing core thickness from 0.6 mm to 1.5 mm multiplies fracture load of this restoration system by 3 (17). These results are not in consistent with our results; however, diversity of thicknesses and applied materials between Sun study and ours are different.

Kim et al. (6) conducted a study to assess failure load of zirconia crowns based on the thickness and marginal design of coping, showed thicker coping group (0.7 mm coping thickness including collar height) made high failure load, but coping group without facial collar (0.5 mm thickness) did not differ statistically with standard coping group (0.5 mm coping thickness and 0.2 mm facial collar height). This study was compatible with the present study.

Three other studies emphasized on the preparation design. Castelnuovo et al. (18) evaluated the effect of preparation design on the failure load of ceramic laminates. The results showed that after control group, preparation design without decreasing incisal edge height and preparation design with decreasing less than 2 mm of incisal edge height presented the most failure load, respectively. Stappert et al. (19) measured the failure load of ceramic veneers that prepared with various designs. They demonstrated no statistically significant difference between normal tooth failure load and tooth prepared with different designs which reconstructed with IPS Empress 1 laminate. Khatib et al.'s study (20) revealed that butt-joint preparation obtained considerably more failure load as compared with window and overlap incisal edge preparations. With regard to the laminate material, failure load of samples with IPS e-max CAD was considerably more than IPS Empress CAD.

The effects of materials on failure load have been investigated in some studies. Schmidt et al. reported preparation design and amount of existing tooth structure had a considerable effect on the failure load. A preparation design with a palatal chamfer margin for a non-worn tooth had significantlyhigher failure load than other groups (21).

Alghazzawi et al. (9) compared failure load of zirconia laminates produced to CAD/CAM method with conventional glass-ceramics laminates. They concluded preparation design of tooth will not affect failure load significantly. In addition, lowest fracture rate and highest debonding rate occurred in zirconia laminates; whilst, feldspathic laminates showed opposite results.

Altamimi et al. (8) compared fracture load of monolithic lithium disilicate heat-pressed crowns to zirconia/ fluorapatite. Results indicated that the monolithic lithium-disilicate crowns had more fracture load than other two groups. Fracture load of the anatomical design was also higher than standard design. Effect of different thicknesses has not been assessed in their article.

In our study, only the effect of zirconia thickness on the failure load of all-ceramic laminates were examined. But, according to the previous researches failure load of restorations are influenced by applied materials, preparation methods, finishing line and fabrication method which were not considered in our study. It should be suggested to test different zirconia systems, preparation methods and etc. and repeat the experiments in oral cavity conditions.

## Conclusion

The tensile stress of zirconia based all-ceramic restorations produced by CAD/CAM system with 0.7 and 0.9 mm thicknesses were not significantly different. Thus, in clinical situations 0.3mm zirconia core is enough for laminate veneers.

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