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Comparing Fracture Resistance of Monolithic Zirconia Crowns Designed with three Different Thicknesses: An In Vitro Study

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A limited available inter-occlusal space has always been a challenge for many dental practitioners, which hinders acquiring aesthetic restorations while conserving the remaining dental structure.

This research aims to analyze the relationship between the occlusal thickness of second-generation CAD/CAM monolithic zirconia restorations, and their fracture resistance, in order to determine the feasibility of reducing the occlusal thickness – particularly in the posterior oral area, where a limited inter-occlusal space is usually available, and high biting forces are usually applied.

Thirty monolithic zirconia crowns were made using second generation zirconia block with different design settings that divided them into 3 groups (n = 10) according to the occlusal thickness of the restorations: Group A: 2 mm, Group B: 1.5 mm, Group C: 1 mm.

Thirty designed crowns were cemented to extracted prepared natural upper premolars using glass ionomer cement, then they were tested.

Fracture resistance of the monolithic zirconia crowns was significantly influenced by the occlusal thickness, the resistance improved steadily as the thickness increased.

Nevertheless, the occlusal thickness could be reduced down to 1 mm and the monolithic zirconia restoration would still own sufficient resistance to tolerate the maximum natural human biting loads of the posterior oral regions.

Keywords: Fracture, Resistance, Monolithic, Zirconia, Crowns, Thickness

Introduction

Zirconia is a ceramic material that has a polycrystalline structure, which is suitable for dental applications due to its mechanical properties [1, 2], it is also a polymorph material that exists in three phases according to the temperature:

– Monoclinic (m) in room temperature up to 1170 °C,
– Tetragonal (t) between 1170 °C–2370 °C,
– Cubic (c) between 2370 °C–2716 °C (melting point) [3].

Currently, zirconia is classified into four generations according to its mechanical and aesthetic properties [4]. The first generation contained (0.25 wt%) of Al_2O_3, (3 mol%, 5 wt%) of Y_2O_3, ZrO_2 that (85–90%) of it in tetragonal phase, and (> 15%) cubic phase [5, 6].

In 2012, the second generation was introduced, the Al_2O_3 content was reduced from (0.25 wt%) to (0.05 wt%) which improved translucency [7].

In 2015 the third generation was introduced when the content of Y_2O_3 was increased to (5 mol%, 8.8 wt%), which had (50%) cubic phase of ZrO_2 [5, 6], this modification improved the aesthetic properties, but deteriorated the mechanical properties because its properties reduced the "Transformation Toughening" phenomenon [5].

In order to improve the practical usability of zirconia restorations, a fourth generation of zirconia blanks has been introduced in 2017 [4], which contained (4 mol%, 7.1 wt%) of Y_2O_3 [5].

Due to the recent developments of CAD/CAM techniques, it has recently become possible to make an entire "monolithic" or "full contour" zirconia restoration [8].

This research aims to analyze the relationship between the occlusal thickness of second-generation CAD/CAM monolithic zirconia crowns, and their fracture resistance, in order to determine the feasibility of reducing the occlusal thickness of a zirconia restoration, particularly in the posterior oral area, where a limited inter-occlusal space is usually available, and heavy biting forces are usually applied.

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Materials and Methods

This study included 30 extracted human teeth and 30 monolithic second-generation zirconia crowns, the hypothesis of the study was that fracture resistance of monolithic zirconia crowns depends on the restorative material thickness.

The G*power software (version 3.1.9.7) was used to calculate the sample size, with a 5% margin of error, 0.6 effect size and a power of 80%, the calculation provided a total sample size of 30 specimens with three subgroups (n = 10).

The thirty extracted human upper premolars were chosen according to 3 criteria: they had to be sound undamaged teeth, recently extracted for orthodontic or periodontal reasons.

All the 30 extracted human upper premolars had similar sizes (lingual-buccal dimension 8.12 ± 1.18 mm), any tooth with caries and/or previous restorations was excluded.

The root surfaces had been cleaned using periodontal curettes, then one by one, each premolar was examined with an optical light microscope (Olympus, USA) to investigate any minor crown fractures or root fractures, then the premolars were stored in sterilized water.

Later, each one of the 30 premolars was soaked into a resin block (Feiying, Anyang Yingpai Dental Material, China) 2 mm below cemento-enamel junction (CEJ) in order to simulate the alveolar bone level.

A dental surveyor (Emmevi, Dentaltix, Italy) with a turbine handpiece was installed, then the premolars were prepared to acquire heavy chamfer finish lines of 1 mm width, on a level of 1 mm above the cemento-enamel junction, using dental bur (TR-15, Mani, Japan).

During preparation, the total occlusal convergence was set at 6 degrees (TOC = 6 °C), then the preparation was finished using polishing bur (852F.FG.014, Jota, Switzerland).

According to previous studies [9], the determined height of the abutments was 5 mm, and the occlusal surface was prepared using the dental bur (EX-12, Mani, Japan), then the preparation was finally refined with (TR-26F, MANI, JAPAN) bur *(Figure 1)*.

A three-dimensional digital optical scan was applied on the prepared teeth using a dental scanner (3D Dental Scanner Swing, Dof Inc, Korea), then using (Exocad GMBH) software, three groups of zirconia crowns with three different occlusal thicknesses were designed:

2.0 mm (Group A),
1.5 mm (Group B),
and 1.0 mm (Group C). *(Figure 2)*

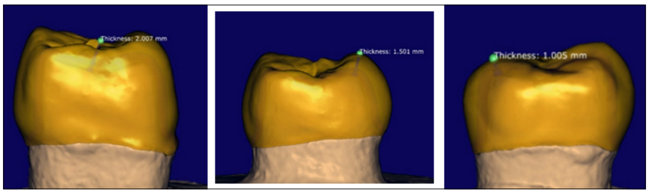

Figure 2: Monolithic CAD/CAM crowns designs: 2 mm, 1.5 mm, 1 mm (from left to right)

Cement thickness was set to be 30 microns, starting 1 mm above the finish line of preparation, then finally the 30 monolithic crowns were manufactured using a second-generation zirconia block (Bloomzir ST White, Blooden, China).

A total of 30 monolithic crowns were obtained, 10 crowns in each of the 3 mentioned groups.

The crowns had been dyed with A2 color liquid (Bloomzir A2, Bloomden, China), then inserted into a sintering furnace (Nabertherm Gmbh, Germany) at a temperature of 1550 °C for 8 hours.

Margin adjustment was conducted manually with a dental micromotor (Micro NX_201N, Denteeth, Spain) using suitable burs and finishing disks (ACTR006, ACTR007, ACTR004, Aidite Technology, China).

A glaze ceramic layer was applied on each monolithic crown (GCInitial Spectrum Stain, GC, Japan) then they have been inserted into a porcelain furnace (Vita-Vacumat 6000M, Vita_Zahn Fabrik, Germany) at a temperature of 820 °C.

All crowns were later cemented on their prepared abutments with glass ionomer cement (Vivaglass, Ivoclar Vivadent, Germany), and according to previous studies [10] a constant occlusal load of 15 N was applied to the occlusal surface for 6 minutes (according to the manufacturer's fixation guidelines) until the complete set of the cement, any extras were removed using a dental probe and a brush *(Figure 3)*.

Figure 1: Specimens after preparation

Figure 3: Specimens after crowns fixation

All specimens were put in an incubator (Incubator IS600, Yamato Scientific, Japan) for 24 ± 1 hours with a temperature of 37 ± 1 °C and 100% humidity.

Then finally, they underwent the main mechanical test in a universal testing machine (H50KS Tinius Olsen, Horsham, England) where a static force was applied in the center of the occlusal surface of the zirconia crown, using a semi-spherical head (4 mm), with a crosshead speed of 0.5 mm/min, until the occurrence of crown fracture, and the corresponding values with the fractures were recorded in newtons.

A tin foil was put between the spherical head and the occlusal surface of the restoration in order to dilute force concentrations [11] *(Figure 4)*.

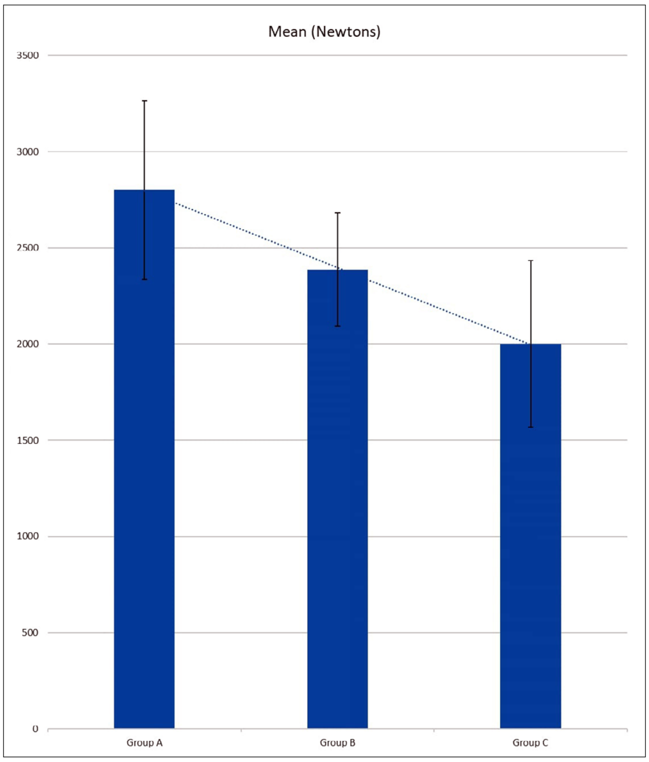

Figure 4: Results bar chart

After each zirconia crown fracture, each specimen was examined with a stereo-microscope (Smz800n, Nikon, Japan) at ×10 magnification to define the mode of failure *(Figures 5 and 6)*.

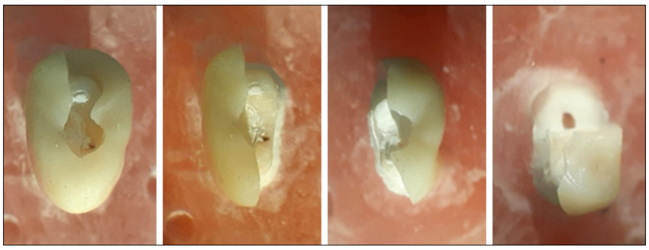

Figure 5: Failure modes examination

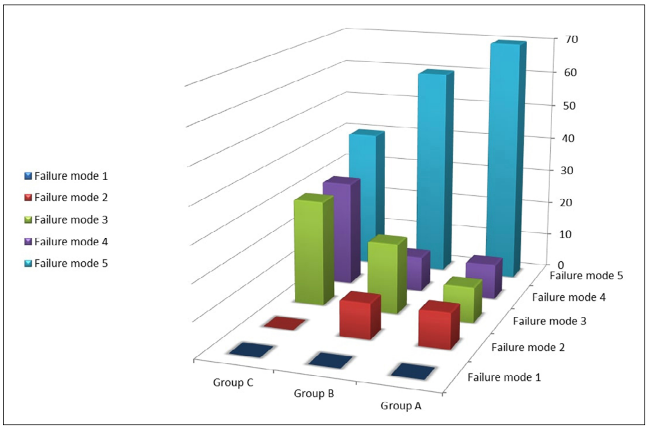

Figure 6: Failure Modes Diagram

Statistically, the fracture strength values were analyzed using the one-way ANOVA test.

Bonferroni post-hoc test was used for the multiple comparisons to determine the significance of differences between groups, Kruskal Wallis test was used to compare failure modes reoccurrence, and in all the analyses, the level of significance was set to be α = 5%.

Results

The mean of fracture strengths of group A (2800.20 N) was larger than the mean of group B (2387.60 N), which in turn was larger than the mean of group C (2002.30 N).

Table 1

Results table

Groups	*Mean (newtons)*	*Standard Deviation*	*Highest Value*	*Lowest Value*
A (2 mm)	2800.20	464.16	3788	2158
B (1.5 mm)	2387.60	293.76	2884	2105
C (1 mm)	2002.30	432.70	2668	1340

Table 2

Statistical analysis (One-way ANOVA)

Source	*Sum of squares*	*Df*	*Mean square*	*F*	*P*
Between Groups	3184464	2	1592232	9.769	0.001
Within Groups	4400710	27	162989		
Total	7585174	29			

There were no statistically significant differences between the three groups regarding failure mode recurrence, the predominant fracture modes in all three groups were catastrophic fractures.

Table 3

Failure modes index
(According to Burke FJ. 1999)

Failure Modes	–
Mode 1	Minimal fracture or crack in crown.
Mode 2	Less than half of crown is lost.
Mode 3	Crown fracture through midline: half of crown is lost.
Mode 4	More than half of crown is lost.
Mode 5	Severe fracture of crown and/or tooth.

Discussion

Materials and Methods discussion

This study investigated the fracture resistance of second generation 3Y-TZP zirconia monolithic crowns, and its relation to the occlusal thickness of the restoration.

The increase of restorative material thickness is widely believed to increase its fracture resistance strength, as the physical and mechanical properties are directly related to the thickness [12].

Natural teeth were chosen as abutments in order to make the experimental conditions closer to the clinical conditions, and the chosen technique for crowns manufacturing in this study was the "Monolithic CAD/CAM technique", this process usually uses high-quality materials with a minimum of flaws compared to the manual veneering process [13].

Usually, the cementation material for all-ceramic crowns could be either adhesive or conventional material, taking into consideration the type of restoration, the preparation design, tooth position, and geometry [4], all crowns in this study were cemented on their prepared abutments using glass ionomer cement.

3Y-TZP zirconia (1st & 2nd generations) is commonly indicated in the posterior oral region where the biting force is maximum because it has a better fracture resistance than 5Y-TZP zirconia (third generation) [14].

Results discussion

1) The results of this research have shown that an occlusal thickness of 1 mm was sufficient to tolerate the regular occlusal loads in the posterior dental areas. As the mean of the fracture resistance values of group C in this study (1 mm) was equal to (2002.3 N), this is obviously much higher than the average biting forces in the posterior area, which are estimated at (222–445 N) in premolars area [15], and 597–900 N in molars area [16].

This conclusion was consistent with some previous studies [16], however, other studies went even further to conclude that even a thickness of (0.5 mm) of 3Y-TZP Zirconia could be sufficient to tolerate the regular occlusal loads in the posterior dental areas [17, 18].

2) The results of this research had also shown a direct correlation between resistance and thickness, this conclusion was expected and consistent with some previous studies [9, 19].

However, and despite the accumulation of evidence, it cannot be asserted that there is a consensus about this issue, some researchers for instance indicated in a similar study that there was no clear direct correlation between fracture resistance and thickness [17], this kind of heterogeneity of results could be attributed to the variations of design parameters for such studies, regarding the chosen material for abutments, the abutment's topography, and the cementation technique.

It is worth mentioning that the high resistance of monolithic zirconia restorations documented in many studies may not be necessarily correlated with the nature of the material as much as with the monolithic manufacturing technique, a previous study indicated that even a monolithic lithium disilicate crown could have better resistance than a zirconia bi-layered one within the same experimental conditions [20].

Failure modes discussion

A detailed classification of failure modes was provided by Burke (1999) *(Table 3)* that classifies fracture failures into 5 modes [21[, and it became a commonly accepted reference among similar studies.

In our study, the predominant fracture modes in all three groups of monolithic crowns were catastrophic fractures (4 and 5 Burke modes) indicating their property of high resistance to fracture load, these results were supported by some previous studies where catastrophic fractures were also predominant [9, 10].

However, there were a variation between studies regarding this issue, for example, Sorrentino et al [17] found that the predominant failure mode was the "cohesive crack" (Burke mode 1), however, this inconsistency could be attributed to their utilization of resin cement under the crowns, which could have acted as an elastic stress absorber, or could be attributed to the different occlusal convergence angle they used, or their using polyvinylsiloxane as periodontal ligament stimulation layer.

Unfortunately, the results of our study might not represent the clinical situation due to the fact that only a static perpendicular force was applied, and since the clinical scenario is never totally simulated in experimental laboratory tests.

Several variables could affect the results of similar investigations such as sample storage, dye material, cementation technique, and crosshead speed, these variables may explain the heterogeneity of data reported in the literature.

However, this study provided some practical suggestions about the recommended thickness of monolithic zirconia crowns, further clinical investigations will be necessary to validate the results of the present study under functional loading.

Conclusions

Fracture resistance of monolithic zirconia crowns was significantly influenced by the occlusal thickness, the resistance improved steadily as the thickness increased.

While the occlusal thickness can be reduced down to 1 mm, the monolithic zirconia crown would still possess sufficient resistance to tolerate the regular natural loads even in the posterior oral regions where the biting forces are at their maximum.

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Eredeti cikk

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Három különböző vastagságú monolit cirkónium korona törési ellenállásnak in vitro összehasonlító vizsgálata

A beszűkült interokkluzális tér mindig komoly kihívást jelent a gyakorló fogorvosok számára, hogy esztétikailag kifogástalan restaurátumokat készítsenek, és ugyanakkor a lehető legnagyobb keményállományt is megőrizzék a fogakból. Jelen vizsgálat célja a második generációs CAD/CAM technikával készült monolitikus cirkónium-dioxid restaurátumok vastagsága és törési ellenállása közötti kapcsolat vizsgálata és annak meghatározása, hogy milyen mértékben lehet a korona vastagságát csökkenteni, elsősorban a moláris régióban, ott, ahol az interokkluzális tér csekély és a rágóerő a legnagyobb.

30 különböző tervezésű monolitikus cirkónium-dioxid koronát készítettek a második generációs CAD-CAM technológiával, amelyeket az okkluzális vastagság alapján három egyenlő számú [10] csoportra osztottak: A csoport 2 mm; B csoport 1,5 mm és C csoport 1 mm.

A tesztkoronákat előkészített, extrahált természetes fogakra (felső premolárisok) rögzítették üvegionomér cementtel, majd ezeket a koronákat mechanikai vizsgálatnak vetették alá. Megállapították, hogy a monolitikus cirkónium-dioxid koronák törésállóságát jelentősen befolyásolta a vastagságuk. A vastagság növekedésével a törési ellenállás folyamatosan javult. Arra a következtetésre jutottak, hogy még az 1 mm vastag monolitikus cirkónium-dioxid restaurátum is elég erős volt ahhoz, hogy a moláris régióban ellenálljon a fiziológiás körülmények között fellépő maximális okkluzális megterhelésnek. Következésképen a moláris régióban a monolitikus cirkónium-dioxid restaurátumok vastagsága megbízhatóan 1 mm-re csökkenthető.

Kulcsszavak: törés, ellenállás, monolit, cirkónium, koronák, vastagság