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Effect of Finishing and Polishing on Biaxial Flexural Strength of Different Ceramic Materials (In vitro study)

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Abstract:
Background: *The increased popularity of all-ceramic materials as an alternative to metal-ceramic restorations is attributable to their excellent matching with natural tooth structure in terms of physical and mechanical properties, beside their biocompatibility. IPS e.max is a type of lithium disilicate which delivers high strength and high esthetic material for the press and the CAD/CAM technologies.CeraMotion® LiSi press ceramic is another type of lithium disilicate ceramics which characterizes by low-reaction pressable ingots, homogeneous with high strength edges that remain stable during grinding. Celtra Press is ZLS which consisting of a glass matrix and lithium silicate crystals having a crystal length of about 1.5 µm beside nano-scale lithium phosphate and about 10% zirconia (ZrO2), which is dissolved completely in the glass phase.Microstructure, surface cracks, and porosity are important factors affecting the flexural strength and clinical longevity of all-ceramic materials. Biaxial flexural strength is one property to help selection of material for restorations. It is usually representing the ability to tolerate chewing force. It is an important factor for the success of any fixed restorations.*
Materials and Methods: *In this in vitro study,sixty-three discs with standard dimensions of 2mm thickness and 10 mm diameter were prepared from ceramic materials. The discs divided into three groups according to the type of ceramic material (n=21); group A: IPS e.max press, group B: CeraMotion LiSi and group C: Celtra press. Each group divided into 3 subgroups according to finishing protocol (n=7); subgroup G: Glazing, subgroup F: Glazing then finishing and subgroup P: Glazing then finishing & polishing. 3D printed castable resin specimens were fabricated. Spruing, investing and pressing were done for each specimen. The finishing protocols had been done for each specimen using the dental standardizing apparatus. The biaxial flexural strength was measured using Instron testing machine (piston-on-three ball). Two-way ANOVA followed by Tukey's post hoc test was used to study the effect of different tested variables and their interaction. The significance level was set at P ≤0.05.*
Results: *There was a significant difference between different groups (p<0.001). IPS e.max press group showed the highest mean value (339.12±38.40) followed by CeraMotion® LiSi press group (233.34±29.03) while Celtra press group showed the lowest mean value(209.53±24.57).*
Conclusion: *Within the limitations of the present study, IPS e.max press showed the highest values of biaxial flexural strength with different finishing protocols, while Celtra press was the lowest.High values of surface roughness had an impact on flexural strength. The higher the values of surface roughness, the lower the values of flexural strength.Glazingof different ceramic materials had pronounced thehighest flexural strength.*
Key Word: *Biaxial Flexural strength, IPS e.max press, CeraMotion LiSi press, Celtra press, Glazing, Polishing, Finishing.*

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I. Introduction

Ceramic restorations are widely used due to their natural appearance seeking patients' high esthetic demand(1). The goal of a restorative dentist is to restore tooth structure to its natural form, function, and appearance which positively impact the patient's self-esteem. The increased popularity of all-ceramic materials as an alternative to metal-ceramic restorations isattributable to their excellent matching with natural tooth structure in terms of physical and mechanical properties, beside their biocompatibility (2). The use of all-ceramic restorations becomes widespread in recent years. For that, there is a wide range of ceramic materials and systems are available in the market for use in dentistry (3).

Lithium disilicate glass ceramic is all-ceramic system which covers the wide range of ceramic's indication range as thin veneers to 3 units FPDs(4). IPS e.max(Ivoclar Vivadent) is a type of lithium disilicate which delivers high strength and high esthetic material for the press and the CAD/CAM technologies. IPs e.max press consists of a lithium disilicate pressed glass ceramic, but its physical and mechanicalproperties are improved through different firing processes. The lithium disilicate crystals prevent the propagation of micro cracks of the IPS e.max press restorations[5].

CeraMotion® LiSi press (Dentaurum GmbH & Co, Ispringen, Deutschland) is another type of lithium disilicate ceramics which characterizes by low-reaction pressable ingots, homogeneous with high strength edges that remain stable during grinding[6].

The introduction of zirconia reinforced lithium silicate glass-ceramics (ZLS) was as the result of the excellent esthetic appearance and high mechanical properties of glass ceramics which stimulates the progressive improvement of glass ceramics to enhance their properties by refining their crystal structure with 10% zirconium oxide fillers which acts as nucleating agent to interrupt propagation of crack[7]. Celtra Press (Dentsply, Sirona) is ZLS which consisting of a glass matrix and lithium silicate crystals having a crystal length of about 1.5 μm beside nano-scale lithium phosphate and about 10% zirconia (ZrO2), which is dissolved completely in the glass phase. It is characterized by a high strength of about 500 MPa (after power firing) and excellent flow properties during pressing[8]. Zirconia particles in ZLS glass-ceramics provide good surface finishing and reinforce the ceramic structure by providing crack interruption through its small grains and homogeneously distributed structure[7].

Finished ceramic restorations from the technical laboratory ideally should not require any changes when fitted to the patient's mouth. Although, it is many times required to adjust the occlusion for patient's acceptance[3]. This occlusal adjustments of the ceramic restoration with abrasive rotary instruments had to be made after cementation of restoration which creates a rough surface, so can facilitate biofilm accumulation producing gingival inflammation and affect the mechanical properties of such restorations[4]. Beside that it can increase the wear of the opposing dentition or other restorative material. These adjustments will require chair side polishing to reduce the incidence of porcelain fracture, opposing tooth wear and bacterial accumulation[9].

Surface roughness is a factor that affects the flexural strength of ceramic restorations if existed in the critical defect range of values. Increasing the size of defect will decrease the flexural strength[10, 11]. Beside that, flexural strength of ceramics is also affected by heating during pressing of ceramic material due to increase the crystalline size in addition to porosity which acts as stress concentration which will decrease the flexural strength of ceramic material[12]. The higher the flexural strength, the higher the priority of ceramic material to be used in areas of high masticatory forces. Biaxial flexural strength is one property to help selection of material for restorations. It is usually representing the ability to tolerate chewing force. It is an important factor for the success of any fixed restorations. Microstructure, surface cracks, and porosity are important factors affecting the flexural strength and clinical longevity of all-ceramic materials[4, 13–15]. As flexural strength directly affects the durability of ceramic restorations, however data in literature are insufficient regarding the new ceramic formulations. Therefore, this study was conducted to evaluate the effect of different finishing protocols on biaxial flexural strength of different glass ceramic materials. The null hypothesis was that the ceramic material and finishing protocols had no effect on biaxial flexural strength.

II. Materials and Methods

This in vitro study was carried ceramics samples of 2 mm in thickness and 10 mm in diameter then prepared to receive different finishing protocols, the samples were divided into three groups according to the type of ceramic material used:

Group A: IPS e.max press.(Ivoclar Vivadent, Amherst, NY)
Group B:CeraMotion® LiSi press.(Dentaurum GmbH & Co, Ispringen, Deutschland)
Group C: Celtra press.(DeguDent GmbH, Dentsply Sirona)
Each group divided into 3 subgroups according to finishing protocol (n=7);
Subgroup G: Glazing.
Subgroup F: Glazing then finishing
Subgroup P: Glazing then finishing & polishing.

Study Design: in vitro comparative study
Study Location: This was a study done in Department of Fixed Prosthodontics, at Ain shams University, Cairo, Egypt.
Sample size: 63 ceramic samples.
Sample size calculation: To determine the number of specimens that would be required for each test group, power analysis was conducted, according to the results of Maroulakos et al. [16], the predicted sample size was found to be a total of 63 samples. A power analysis was designed to have adequate power to apply a statistical test of the null hypothesis that there is no difference would be found between tested groups. By adopting an alpha (α) level of (0.05), a beta (β) of (0.2) (i.e. power=80%), and an effect size (f) of (0.810) calculated based

on the results of a previous study; the predicted sample size (n) was found to be (63) samples (i.e. 7 samples per subSgroup). Sample size calculation was performed using G*Power version 3.1.9.7.

III. Procedure Methodology

Samples fabrication:

Digital 3D builder software system (Microsoft) was used in order to accurately design specimens of 2mm thickness and 10 mm diameter as follows: the required shape was selected using (insert object tool), then dimension of 2mm thickness and 10 mm diameter was adjusted. The design was saved as STL file. The STL file was exported to photon S (3D printer ANYCUBIC, Shenzhen Anycubic Technology Co., Ltd, China) to fabricate 3D printed castable resin specimens (Savoy Castable LCD Green, MAKTech 3d). The 3D printed specimens washed and cured using wash and cure machine for 6 minutes. All specimens were checked using digital caliber. After fabrication of castable resin discs, spruing, investing and pressing done for each ceramic material according to its manufacturer instructions. Sprue of diameter 2.5-3.5 mm was attached to the edge of resin disc and attached it to the ring (100g) then pouring each ceramic material with its investment material according to manufacturer instructions using vacuum mixer (4.5-9 min) and left to set (5.5-12min) then remove ring former. The investment placed upside down in burnout furnace for 45 minutes at 850°C to preheat the investment and allow gases to escape with no residue. The ceramic samples were pressed in Programat ep3010 furnace (Ivoclar Vivadent, Schaan, Liechtenstein) following manufacturer instructions. After cooling down divesting was done and remnants were cleaned by using airborne particle abrasion (50μm Al_2O_3 at 1 bar, 30 PSI).

Finishing protocols:

A- Glazing:

After divesting, all specimens had been polished and glazed according to manufacturer instructions of each material. All samples glazed on only one surface and the other surface kept only polished. Checking of all specimens after glazing using digital caliber to ensure that there were no dimensional changes had been done.

B- Finishing:

Finishing procedure was done for subgroups F and P of each group. The Dental Standardizing apparatus is a specially designed apparatus for simulating the dental handpiece movements at the Dentistry research center in the Faculty of Dentistry, British university in Egypt[17–19]. The stone and polishing tips were angled 0 degrees relative to the surface of the sample. A standardized 10 mm horizontal movement at a speed of 2 Hz was achieved and operated by the control box was designed and fabricated to standardize the finishing and polishing procedure. The samples were mounted onto pane balance and attached in place using screws. Finishing procedure was carried out using fine and extra fine parallel sided diamond stones for 5 seconds each (Intensiv, Viganello-Lugano, Switzerland) with high-speed contra angle handpiece under sufficient water coolant at intermediate power setting. The diamond stone was parallel to the surface of sample to ensure full contact between them for adequate finishing procedure. The ceramic specimens were fixed to the device byusing condensation silicon material (Zetaplus, Zhermack S.p.A, ITALY).

C- Polishing:

For subgroup p of each group, polishing procedure was done using low speed contra angle handpiece with adaptor mounted on the same apparatus as mentioned before. Polishing protocol was done using Diapro rubber polishing cups with two grits medium and fine (EVE Ernst Vetter GmbH, Pforzheim, Germany) 40 seconds for each one. Then using nylon brush and Unigloss polishing paste (Intensiv, Viganello-Lugano, Switzerland) for 50 seconds.

Measurements:

Biaxial flexural strength (BFS):

The biaxial flexural strength was measured using piston-on-three ball technique[20] in an Instron testing machine model 3365 England according to the ISO 9001 specifications for testing ceramic materials and data recorded using computer software Bluehill. Each disc was placed on the steal balls and load was applied by a piston of 1.5mm diameter and 1mm/min crosshead speed. The fracture load for each specimen was recorded and the biaxial flexural strength was calculated using the following equation:

$$\sigma = [-0.2387P\,(X - Y)]/d2$$

Where: σ = biaxial flexural strength (MPa), P: fracture load (N), d: specimen disk thickness(mm), X: $(1 + \upsilon)\ln(r2/r3)2 + [(1 - \upsilon)/2](r2/r3)2$, Y: $(1 + \upsilon)[1 + \ln(r1/r3)2] + (1 - \upsilon)(r1/r3)2$.

υ is Poisson's ratio (0.25). r1 is the radius of the support circle. r2 is the radius of the loaded area. r3 is the radius of the specimen. The results for the specimens in MPa were later recorded.

Statistical analysis

Two-way ANOVA followed by Tukey's post hoc test was used to study the effect of different tested variables and their interaction on biaxial flexural strength. Comparison of main and simple effects were done utilizing Bonferroni correction. The significance level was set at $P \leq 0.05$ within all tests. Statistical analysis was performed with R statistical analysis software version 4.1.2 for Windows (Core Team (2022, A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria).

IV. Results

Flexural strength:

Mean and standard deviation (SD) values of flexural strength (MPa) for different materials with different finishing protocols were presented in table (1) and figure (1). Two-way ANOVA showed that the materials and finishing protocols have statistically significant effect on biaxial flexural strength. There was a significant difference between different groups ($p<0.001$). The highest value was found in IPS e.max press followed by CeraMotion LiSi press while the lowest value was found in Celtra press for glazing, finishing and polishing.

Post hoc pairwise comparisons showed for all ceramic materials there was a significant difference as the highest value was found in glazing, followed by polishing while the lowest value was found in finishing ($p<0.001$).

Table (1): Mean ± standard deviation (SD) of flexural strength (MPa) for different materials with different finishing protocols

Finishing protocol	Flexural strength (MPa) (mean±SD)			p-value
	Celtra press	CeraMotion LiSi press	IPS e.max press	
Glazing	235.10 ± 2.92^{C}	265.60 ± 9.83^{B}	377.17 ± 5.43^{A}	**<0.001***
Finishing	181.02 ± 8.57^{C}	199.00 ± 4.76^{B}	290.89 ± 17.92^{A}	**<0.001***
Polishing	212.46 ± 14.47^{C}	235.42 ± 9.76^{B}	349.30 ± 6.35^{A}	**<0.001***

Means with different upper and lower superscript letters within the same horizontal row and vertical column respectively are statistically significantly * significant ($p \leq 0.05$)

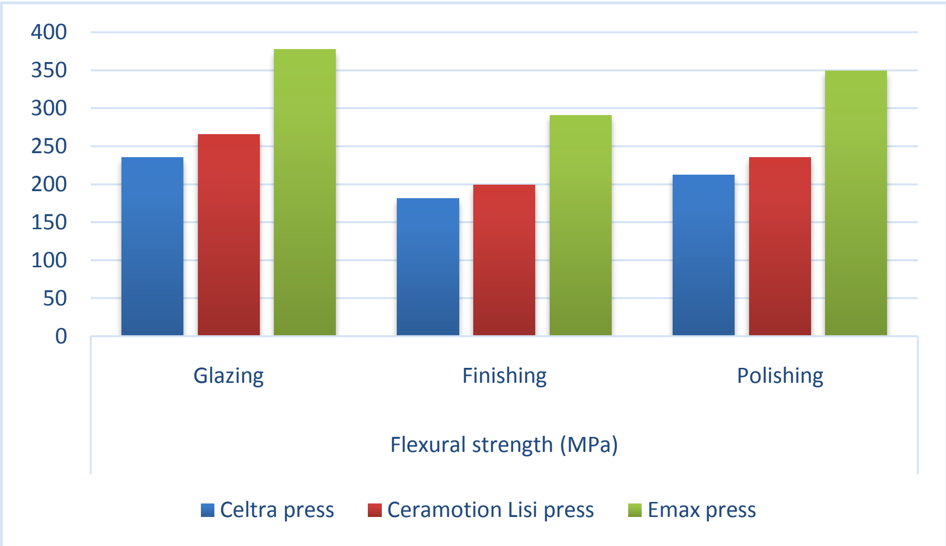

Figure (1): Bar chart showing average flexural strength (MPa) for different materials within each protocol

V. Discussion

Ceramics are increasingly used in aesthetic and restorative dentistry. They account for a high percentage of dental restorations because they have resembled texture and colour to natural teeth. Biocompatibility and polishability are some other favourable characteristics of dental ceramics[21]. Moreover, monolithic ceramic restorations have gained increasing popularity due to their enhanced fabrication process and lower frequency of complications. Besides that, good optical and mechanical properties increase indications in different types of restorations either posterior or anterior restoration[7, 22]. Monolithic ceramic restorations can be obtained in their final form using a hot-pressing technique, or by using CAD-CAM technologies. One of the benefits of pressing technique is the lower shrinkage during the process, which leads to less surface porosity and higher strength [23, 24]. Occlusal adjustment at the time of delivering a ceramic restoration is important to be concerned because a rough surface may abrade opposing tooth or restorative materials and affects the mechanical properties. Many studies have evaluated the effects of different finishing and polishing techniques on the surface roughness of restorative materials. Increasing the surface roughness led to decrease the biaxial flexural strength [25, 26].

Lately, lithium disilicate systems have brought attention to extensive investigations and a quantity of such glass-ceramics have been clinically used broadly[27–29]. Therefore, two of these ceramics used in this study were IPS e.max press and CeraMotion LiSi press as types of lithium disilicate ceramics. Another glass ceramic material used in this study was Celtra press to examine the role of ZrO2 in resulting properties such as strength in the multi-component system. A standardized sequential minimal finishing and polishing protocol using a specially designed apparatus for simulating the dental handpiece movements at the Dentistry research centre in the Faculty of Dentistry, British university in Egypt used to standardize the finishing and polishing procedures with equal pressure, speed and time among all specimens[17-19].

The biaxial flexure strength test (Piston-on-three-ball test) had been used which has the following advantages; point contact between the three stainless steel balls and the specimen disk prevents any undesirable stresses when the specimen is not flat, and the 5mm diameter formed by the three stainless steel balls is smaller than the specimen disk diameter of 10mm, therefore preventing edge fracture from direct loading, and simulating pure bending[30].

The aim of the present study was to compare the effect of finishing, finishing & polishing, and glazing on biaxial flexural strength of lithium disilicate ceramic materials and zirconia reinforced lithium silicate.The results of our study showed that finishing protocols had significant effect on biaxial flexural strength as glazed samples of different ceramic materials had the highest biaxial flexural strength followed by polished samples and the lowest values were for finished samples. Glazing is considered as a mean for strengthening brittle glass. The production of an outer surface layer having lower thermal expansion, this will serve two functions. First, it is placing the surface into a compressive state, and second it will also reduce the depth and width of surface flaws and will strengthen the material theoretically[9]. Previous studies reported that glazing increases the overall mechanical strength of all-ceramic restorations, and the results in this study agree with these findings[15, 31]. That agreed with results of Bukahri et al.2020[32] that surface treatment of different materials had an impact on their mechanical properties and founded that glazing of e.max press and celtra press had the highest values of flexural strength, and there was significant difference between flexural strength results of glazed samples and other samples with different finishing protocols. Moreover, finishing and polishing of ceramic restoration may lead to a rough surface that may affect the strength of ceramic and that was approved by Ahmed et al. 2018[33] who concluded that grinding procedure with no finishing showed lowest flexural strength followed by grinding and finishing with rubber tips followed by grinding and finishing with rubber tips & diamond paste that was the same result we found in this study.

Lithium disilicate ceramics in this study showed higher flexural strength values than Zirconia reinforced lithium silicate regardless finishing protocol used and there was significant difference between them. This finding might be attributed to IPS e.max high crystalline content and its homogeneity[34]. While the addition of zirconium dioxide (ZrO2) in the glass matrix does not enhance the flexural strength. However, the high ZrO2 content in the glass ceramics results in increasing the viscosity and is associated with a reduction in the crystal growth. These results was matched with Bukhri et al. 2020[32] and founded that IPS e.max press has the highest values of flexural strength followed by IPS e.max CAD, Celtra press then Celtra Dou showed the lowest values of flexural strength.

These approved by Wendler et al. 2017[34] when founded that IPS e.max CAD had higher flexural strength than Celtra Duo and Vita Suprinity. Hallmann et al.2019[35] reported that the biaxial flexural strength of IPS e.max press was higher than Celtra press, which agrees with our findings.

From a clinical perspective, manual polishing system has privilege of completing the in-office restoration occlusal adjustment in a single session with comparable performance to glazing system[36]. The manual polishing allows the clinician to finish the occlusal adjustment of restoration in-office without any thermal treatment which speeding up and simplifying the overall workflow; this is particularly relevant increase the use of monolithic restorations.

The limitations of this study were that using one type of polishing system and it may not be an actual reproduction of what may happen in the oral cavity.

VI. Conclusions

Within the limitations of this in vitro study the following conclusions could be drawn:

- IPS e.max press has the highest values of biaxial flexural strength then CeraMotion LiSi press while Celtra press showed the lowest values.
- High values of surface roughness had an impact on flexural strength. The higher the values of surface roughness, the lower the values of flexural strength.
- Glazed samples of all ceramic materials used in this study showed the highest values of flexural strength and finished samples had the lowest.

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