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Effect of repeated pressing on the fracture resistance of heat-pressed glass ceramic crowns

Efeito da re-prensagem na resistência à fratura de coroas de cerâmica de vidro injetadas

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ABSTRACT

Objective: This study examines the impact of re-pressing four different glass ceramic materials on the fracture resistance (FR) of single crowns. **Material and Methods:** Fifty-six heat-pressed crowns were fabricated from four glass ceramic materials. Crowns were divided into 4 groups (n=14): lithium disilicate IPS Emax press LDS1, lithium disilicate LiSi press LDS2, zirconia reinforced lithium silicate Celtra press ZLS, and zirconia reinforced lithium disilicate Vita Ambria ZLDS. Two subgroups (n=7) were created for each group. Group (P) crowns were made from fresh ingots. Group (R) crowns were made from re-pressed buttons. Samples were then subjected to fracture resistance (FR). Failure load was indicated by an audible crack and verified by a dramatic decline in the load-deflection curve, as recorded using computer software. The load under which crowns fractured was ultimately recorded in Newtons (N). The properties of the glass ceramic crowns were characterized before and after re-pressing by scanning electron microscope (SEM), X-ray diffraction (XRD), and energy dispersive X-ray (EDAX). **Results:** Numerical data were tested for normality using the Kolmogorov-Smirnov and Shapiro-Wilk statistical tests. The results indicated that ceramic type had a significant effect on FR (p-value < 0.001). The thermal technique used also had a significant effect on FR (p-value $= 0.036$). Group LDS1 showed the highest FR (1765.8N), while Group ZLDS showed the lowest FR (1247N). When comparing (P) to (R) groups, XRD revealed no variation in the primary crystalline structure. EDAX revealed no difference in chemical makeup between groups. **Conclusion:** Re-pressing improves the studied glass ceramics crowns' resistance to fracture.

KEYWORDS

Flexural strength; Glass ceramics; Lithium disilicate; Recycling; Zirconium oxide.

RESUMO

Objetivo: Este estudo examina o impacto da re-prensagem de quatro diferentes materiais de cerâmica de vidro na resistência à fratura (RF) de coroas unitárias. **Material e Métodos:** Cinquenta e seis coroas injetadas foram fabricadas a partir de quatro materiais de cerâmica de vidro. As coroas foram divididas em 4 grupos (n=14): dissilicato de lítio IPS e.max Press LDS1, dissilicato de lítio LiSi press LDS2, silicato de lítio reforçado com zircônia Celtra press ZLS e dissilicato de lítio reforçado com zircônia Vita Ambria ZLDS. Dois subgrupos (n=7) foram criados para cada grupo. As coroas do grupo (P) foram feitas a partir de lingotes novos. As coroas do grupo (R) foram feitas a partir de lingotes re-prensados. As amostras foram então submetidas a testes de resistência à fratura (RF). A carga de falha foi indicada por um estalo audível e verificada por uma queda dramática na curva de carga-deflexão, conforme registrado por software de computador. A carga sob a qual as coroas fraturaram foi registrada em Newtons (N). As propriedades das coroas de cerâmica de vidro foram caracterizadas antes e depois da re-prensagem por microscópio eletrônico de varredura (MEV), difração de raios X (DRX) e espectroscopia de raios X por dispersão de energia (EDAX). **Resultados:** Os dados numéricos foram testados quanto à normalidade

usando os testes estatísticos de Kolmogorov-Smirnov e Shapiro-Wilk. Os resultados indicaram que o tipo de cerâmica teve um efeito significativo na RF (valor p < 0,001). A técnica térmica utilizada também teve um efeito significativo na RF (valor p = 0,036). O grupo LDS1 apresentou a maior RF (1765,8N), enquanto o grupo ZLDS apresentou a menor RF (1247N). Ao comparar os grupos (P) e (R), a DRX não revelou variação na estrutura cristalina primária. A EDAX não revelou diferença na composição química entre os grupos. **Conclusão:** A re-prensagem melhora a resistência à fratura das coroas de cerâmica de vidro estudadas.

PALAVRAS-CHAVE

Resistência à flexual; Cerâmicas de vidro; Dissilicato de lítio; Reciclar; Óxido de zircônio.

INTRODUCTION

The most prevalent dental ceramics include glass ceramics, densely sintered alumina, and zirconia-based ceramics. Heat pressing is a method for processing glass ceramic restorations that, unlike other techniques such as sintering, has a wide range of applications in dental restoration due to its simplicity and its ability to produce decreased porosity, reduced shrinkage, increased flexural strength, and better marginal fit and crystalline distribution within the glassy matrix. During the manufacturing of glass ceramics, the glassy phase is converted into the crystalline phase, resulting in a glassy matrix with numerous crystalline phases [1]. The ultimate crystalline form is determined by the glass composition, nucleating agent, and manner of heating. The form and size of the crystals have a substantial impact on mechanical properties [2].

Lithium disilicate glass ceramics exhibit greater flexural strength and fracture toughness than other glass ceramics [3]. They also offer excellent aesthetic restoration due to their intrinsic translucency. IPS e.max Press is an aesthetically pleasing, translucent, heat-pressed lithium disilicate ceramic with a flexural strength of 400 MPa and a 70% volume of needle-shaped lithium disilicate crystals, making it suitable for short-span fixed partial dentures [2]. Initial LiSi Press is another high-strength lithium disilicate glass-ceramic manufactured with unique High-Density Micronization (HDM) technology that equally distributes micro-crystals, rather than larger crystals that fill the entire glass matrix [4]. Ohashi et al. [5] reported that Lisi and IPS e.max press have relatively similar strengths.

Heat-pressed ceramics use the lost wax technique, in which ceramic ingots are pressure-pressed into a mold in a pneumatic press furnace [6]. When the lithium disilicate-pressed restoration is removed, the sprue and button portions are discarded, leaving a substantial amount of ceramics unused. Using the same ingot to press multiple restorations at once can save money but may not always be practicable. In some dental labs, it is found to be more beneficial to use residual materials (leftover sprues and buttons) to produce new restorations, rather than squandering the residual sprue and button components. Recycling ceramic material is an economical way to reduce the expense of restoration [7].

A variety of studies have investigated the effect of re-pressing residual material on the biaxial flexural strength of heat-pressed glass ceramics. Gorman et al. and AlBakry et al. reported no significant difference in biaxial flexural strength or fracture toughness after re-pressing lithium disilicate ceramic [1,7]. X-ray diffraction was utilized to characterize the crystalline phase and scanning electron microscopy was used to examine the microstructure. Repeated pressing revealed no difference in crystalline composition. Chung et al. was determined that lithium disilicate glass-ceramic may be re-pressed while retaining good mechanical qualities and not considerably affecting the crystalline composition of the material [8].

In contrast to Chung et al., who concluded that re-pressing produced a statistically significant increase in the flexural strength of re-pressed lithium disilicate-reinforced glass-ceramic material (Empress®2) [8], Tang et al. [6] detected significant differences in three-point fracture toughness, flexural strength, and hardness after re-pressing of IPS e.max press. The density of lithium disilicate ceramics (IPS e.max Press) reduced and porosity increased after two heat pressing events. Flexural strength, Vickers hardness, and fracture toughness all dropped dramatically.

Recently, different companies have added different percentages of ZrO_2 to develop zirconia-toughened glass-ceramics, reinforcing ceramic

structures through crack interruption [9,10]. Celtra® Press is a newly released zirconia-reinforced lithium silicate (ZLS) containing 10% ZrO_2 as a nucleating agent that shows flexural strengths of more than 500 MPa following power firing at 760°C. A study by Yehia et al. demonstrated that re-pressing enhanced the flexural strength of Celtra [11].

Ambria is another ZLS with a biaxial strength of 450 MPa after pressing at 890°C; this increases after annealing to 600 MPa [12]. Heat tempering is a widely used technique for strengthening glass ceramics by enhancing the size of lithium disilicate crystals [10,13-15]. The crystal's microstructure becomes more interlocking and closely packed, with the result that crack propagation must follow a more tortuous path [16-18]; this significantly increases flexural strength [13]. Heat tempering is a technique whereby a heat-pressed ceramic crown is heated to a temperature just above the glass transition region, yet below its softening point [19]. Abo-Elezz et al. [12] reported that heat tempering with a temperature 5% below pressing temperature increased the biaxial flexural strength of IPS e.max Press, initial LiSi Press, Celtra Press, and VITA Ambria crowns.

According to previous studies, Celtra® Press and Vita Ambria have mechanical properties that are comparable to commonly used lithium disilicate glass ceramics [12]. However, there is a dearth of information in the literature about the effect of re-pressing on the microstructure and mechanical characteristics of recently released ZLS and ZLDS glass ceramics, as well as their comparison to other LDS glass ceramics. The null hypothesis of this study was that re-pressing has no influence on the fracture resistance or microstructure of four studied glass ceramic materials, and that ceramic type has no effect on fracture resistance.

The present study aims to assess the impact of repeated heat-pressing on the fracture resistance of four glass-ceramics, and describe the microstructural characteristics of freshly-pressed and re-pressed materials using X-ray diffraction (XRD), energy dispersive X-ray analysis (EDAX), and scanning electron microscopy (SEM).

MATERIALS AND METHODS

This study employs a power analysis based on a previous work [20] to test the null hypothesis, which stated that there would be no significant difference in fracture resistance for tested groups. Using G*Power version 3.1.9.7 [21], we determined an alpha (α) level of 0.05, beta (β) level of 0.2, and effect size (f) of 0.595. The anticipated total sample size (n) was 48, with 12 samples in each group and 6 samples in each subgroup. In this investigation, 56 samples were used, with 14 in each group and 7 in each subgroup.

Specimen preparation

A computerized numerical control lathe-cut milling machine (CNC premium 4820, imes-icore, Eiterfeld, Germany) was used to prepare an acrylic resin lower first molar prototype for a lithium disilicate crown (1.5 mm occlusal and axial reduction, 1 mm shoulder finish line). It was subsequently duplicated using silicon duplicating material (Replisil 22N, Dentecon, Germany), then chemical cure epoxy resin (Chemapoxy 150, MBC) was poured into the silicon mold and allowed to set for 24 h. Each die was then magnified using loops to look for flaws.

A total of 56 heat pressed glass ceramic crowns were fabricated using the heat press technique. The crowns were divided based on the material used into four groups (n=14). These comprised Group (LDS1): Lithium disilicate glass ceramic (IPS e.max Press, Ivoclar), Group (LDS2): High Density Micronization (HDM) Lithium disilicate glass ceramic (GC initial LiSi Press, GC), Group (ZLS): Zirconia reinforced lithium silicate glass ceramic (Celtra Press, Dentsply Sirona), and Group (ZLDS): Zirconia reinforced lithium disilicate glass ceramic (VITA Ambria, VITA Zahnfabrik). Each group was then subdivided into two subgroups (n=7) based on the ingot used. These subgroups comprised Subgroup (P): Samples fabricated from new ceramic ingots, and Subgroup (R): Samples fabricated from the button material remaining from all the pressing group samples.

Exocad computer software version 2017 (Exocad GmbH) was used to design wax patterns for glass ceramic crowns, which were then milled using a 5-axis milling machine (VHF CAM 5-S1, VHF) to standardize the anatomy, thickness, and contour of the crowns while eliminating all operator variables involved in the fabrication process.

The tooth to be restored was chosen at the beginning of the production process (Figure 1A), and the suggested design was picked. The die was scanned, and a 3D image (virtual model) was produced on a screen (Figure 1B), using a desktop Identica blue scanner (MEDIT Corp., Seoul, Korea). The proposed design was subsequently modified, and a 5-axis milling machine (Dima Mill Wax, KULZAR, Germany) was used to mill the crown wax pattern (Figure 1C). Under 2.5x magnification, the wax patterns were evaluated for fit, accuracy, and marginal adaptation (Figure 1D). Patterns that were flawed were eliminated. The IPS Press VEST (Ivoclar Vivadent, Zurich, Switzerland) was then used to invest the patterns after they had been sprued. After 30 minutes, the wax was removed using a wax burn-out furnace.

Ingots of Groups (LDS1), (LDS2), (ZLS) and (ZLDS) were pressed in a heat press furnace EP 3000 (Ivoclar Vivadent AG, Schaan/Liechtenstein) (Figure 1E). The thermal cycle used for each material is shown in (Table I). Crowns for (P) groups were extracted from the investment ring through air abrasion with 110 μm alumina particles (Cobra, Renfert) under 4 and 2 bar pressure (representing rough and soft divesting, respectively). The pressed LDS1 crowns were then separately submerged in 1% hydrofluoric acid Invex liquid (Ivoclar Vivadent AG, Zurich, Switzerland) and cleaned in an ultrasonic cleaner for 10 minutes, in accordance with the manufacturer's instructions, to remove the investment's reaction layer. To fabricate the subgroup (R) specimens, the remaining buttons from the pressing process were trimmed, and all the previously mentioned steps were repeated using the trimmed leftover buttons to produce re-pressed crowns (Figure 1F, G). Both groups' crowns were examined on the die (Figure 1H) and glazed using IPS Ivoclar Glaze Paste (Ivoclar AG, Zurich, Switzerland).

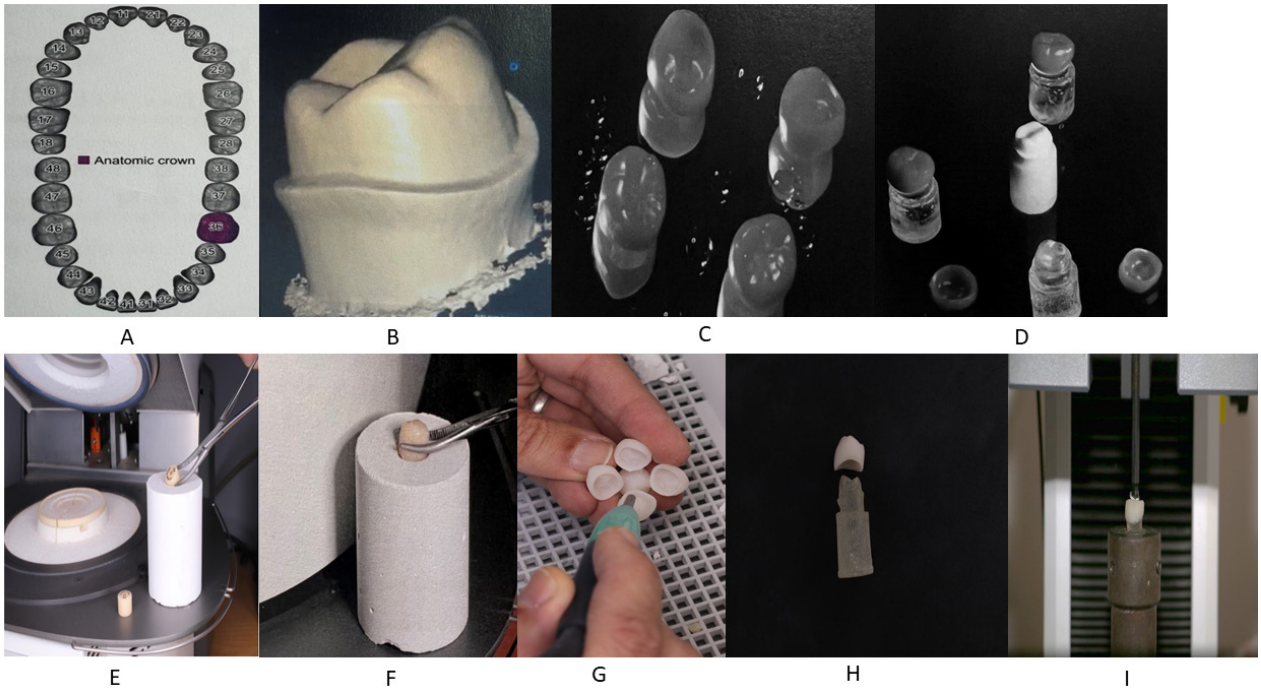


Figure 1 - Graphic Diagram Of Specimen Preparation. A: Selection Of Tooth To Be Restored On Exocad. B: Virtual Model. C: Milled Wax Pattern. D: Wax Pattern Try-in On The Corresponding Dies. E: Ingot Placement Inside Investment. F: Re-pressing Of Finished Buttons. G: Divesting And Sprue Cutting. H: Restoration Was Checked For Its Adaptation. I: Sample Undergoing Fracture Resistance Testing.

Table I - Pressing parameters of the four ceramic materials

Materials	Start temperature (°C)	Heating rate (°C/min)	Maximum temperature (°C)	Holding time (min)	Press time (min)	Pressing pressure (bar)
IPS e.max Press Group (LDS1)	700	60	917	25	3	3
LiSi Press Group (LDS2)	700	50	910	30	3	3
Celtra Press Group (ZLS)	700	40	865	30	3	3
VITA Ambria Group (ZLDS)	700	60	890	25	3	3

The interior surface of each crown was etched for 20 seconds using a 9.5% hydrofluoric acid gel (Porcelain Etchant, BISCO, USA). It was then rinsed with water and dried with oil-free, moisture-free air. The internal surface of each restoration was treated with a silane coupling agent (Prehydrolyzed Silane, BISCO, USA) for one minute, and each was then allowed to air dry for five seconds.

Fifty-six (56) epoxy resin substrates were acid-etched for 15 seconds using 37% phosphoric acid. The surfaces were then rinsed with water and allowed to air dry for 20 seconds. Transparent dual-cured self-adhesive resin cement (Breeze, Pentron Clinical) was used to cement the crowns. Next, the crowns were installed on the appropriate dies using light finger pressure. For the 56 samples, an axial load of 5 kg was applied for 10 minutes after any excess luting material was removed with a brush. The luting substance was light-cured for 20 seconds on each surface. The specimens were left for 24 hours before the fracture test to ensure complete setting of dual-cured self-adhesive resin cement.

Fracture resistance

The 56 samples underwent a fracture resistance test using a universal testing machine (Instron 3345, Instron, USA) with a 5 kg load cell. Using a metallic rod, a compressive load was applied to the occlusal surface's midpoint (Figure 1I). Only the inclined planes of the buccal and lingual cusps were contacted by the rod, at a crosshead speed of 1 mm/min. A tin foil sheet was placed between the crown's occlusal surface and the applicator tip for stress distribution. Failure load (detected via an audible cracking sound with a sharp drop at the load-deflection curve) and fracture values were recorded in Newtons (N).

Mode of failure of fractured samples

Failure modes were inspected and classified into 3 groups (Table II): Cracking, Chipping or partial fracture, and Catastrophic fracture [20].

Scanning electron microscopy (SEM)

The fitting surface of a representative cracked or fractured crown from each group was etched for 90 seconds with 9.8% hydrofluoric acid, then cleaned, steamed, dried, and coated with sputter gold. A 10000x magnification scanning electron microscope (Leo Supra 55, Jena, Germany) was used to investigate the fractured samples.

X-ray diffraction analysis (XRD)

Representative powder samples were scanned using 20-40 degrees Cu Kα **X**-ray angle,

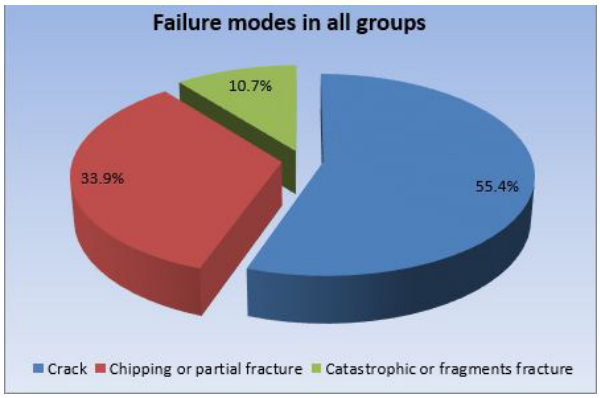


Figure 2 - Pie chart representing percentage distributions of failure modes in all groups.

Table II - Frequency distribution of failure modes

Group	Crack		Chipping or partial fracture		Catastrophic or fragments fracture		*P*-value	Effect size *(v)*
	n	%	n	%	n	%		
LDS1P	3	42.9	4	57.1	0	0	0.531	0.389
LDS2P	3	42.9	2	28.6	2	28.6		
ZLSP	4	57.1	3	42.9	0	0		
ZLDSP	5	71.4	2	28.6	0	0		
LDS1R	3	42.9	1	14.3	3	42.9		
LDS2R	3	42.9	3	42.9	1	14.3		
ZLSR	5	71.4	2	28.6	0	0		
ZLDSR	5	71.4	2	28.6	0	0		
Total	31	55.4	19	33.9	6	10.7		

2θ with a step size of 0.04 degrees and 5 sec-step intervals (X'pert PRO; PW 3040/60, Almelo, Netherlands).

Energy dispersive X-ray analysis (EDAX)

EDAX was carried out for one sample from each group to quantify elements by X-ray microanalysis (FEI Czech SEM, Brno, Czech Republic).

Statistical analysis

Statistical analysis was carried out using IBM SPSS Statistics, Version 23.0. (Armonk, NY: IBM Corp). The normality of the numerical data was explored using Kolmogorov-Smirnov and Shapiro-Wilk tests. Data were presented as mean ±standard deviation (SD). To study the effect on fracture resistance of ceramic type, thermal procedure and their interactions, a two-way analysis of variance (ANOVA) test was used followed by Bonferroni's *post-hoc* test for pair-wise comparisons. Fisher's exact test was used to compare failure modes in different groups. The significance level was set at $P < 0.05$.

RESULTS

Regardless of ceramic type, pressing showed significantly lower mean fracture resistance than re-pressing (p-value = 0.036, v = 0.094). Regardless of heat pressing treatment, whether with pressing or re-pressing, different ceramic types showed a significant difference in mean fracture resistance. Pair-wise comparisons of ceramic types revealed that LDS1 showed statistically higher mean fracture resistance than LDS2, and ZLS showed statistically lower mean values. ZLDS showed the lowest mean fracture resistance with a non-significant mean fracture resistance difference from ZLS (Table III).

Results of Fisher's exact test for comparison between failure modes in different groups showed that there was no significant difference between failure modes in different groups (p-value = 0.531, v = 0.389). Percentage distributions of failure modes in all groups are presented in Figure 2.

Scanning electron microscopy (SEM)

The 10000x magnification SEM image observation revealed multilayered rod-shaped lithium disilicate crystals in the LDS1P group (Figure 3A). On the other hand, the LDS1R group's lithium disilicate crystals seemed better oriented, aligned parallel to the direction of pressing with an increase in both width and length. The crystals this time arranged themselves in an interconnecting pattern (Figure 3B). LDS2 specimens differed significantly from LDS1 specimens in terms of microstructure. An interlocking microstructure created by multilayered platelet-shaped crystals is depicted in (Figure 3C). After re-pressing, a more interconnected microstructure is exhibited (Figure 3D).

Lath-like crystals with randomly oriented regular and irregular forms were visible in SEM images of ZLSP specimens (Figure 3E). These crystals grew longer and wider after being re-pressed. Additionally, they came to resemble belts (Figure 3F). In both the pressed (Figure 3G) and re-pressed (Figure 3H) specimens, needle-shaped particles were visible in the ZLD SEM images. The particles' size increased after re-pressing.

X-ray diffraction analysis

XRD analysis of both pressed and re-pressed samples revealed crystalline phases, with lithium disilicate being the primary crystalline phase for LDS1, ZLDS and LDS2 groups, and lithium silicate being the primary crystalline phase for ZLS (Figure 4).

Table III - The mean, standard deviation (SD) values and results of a two-way ANOVA test for comparison between the fracture resistance (N) values of ceramic types: IPS e.max Press Group (LDS1),LiSi Press Group (LDS2),Celtra Press Group (ZLS) and VITA Ambria Group (ZLDS) with each thermal procedure.

Thermal procedure	LDS1 (n = 7)		LDS2 (n = 7)		ZLS (n = 7)		ZLDS (n = 7)		*p*-value	Effect size *(Partial eta squared)**
	Mean	SD	Mean	SD	Mean	SD	Mean	SD		
Pressing	1780.9 ^{A}	127.4	1370.3 ^{B}	116.8	1274.5 ^{BC}	109.9	1177.8 ^{C}	125.4	<0.001*	0.547
Re-pressing	1750.7 ^{A}	172	1520.3 ^{B}	158.8	1408.7 ^{BC}	152.8	1306.4 ^{C}	255.6	<0.001*	0.396

*Eta squared measures the proportion of the total variance in a dependent variable that is associated with the membership of different groups defined by an independent variable. Partial eta squared is a similar measure in which the effects of other independent variables and interactions are partialled out [22].

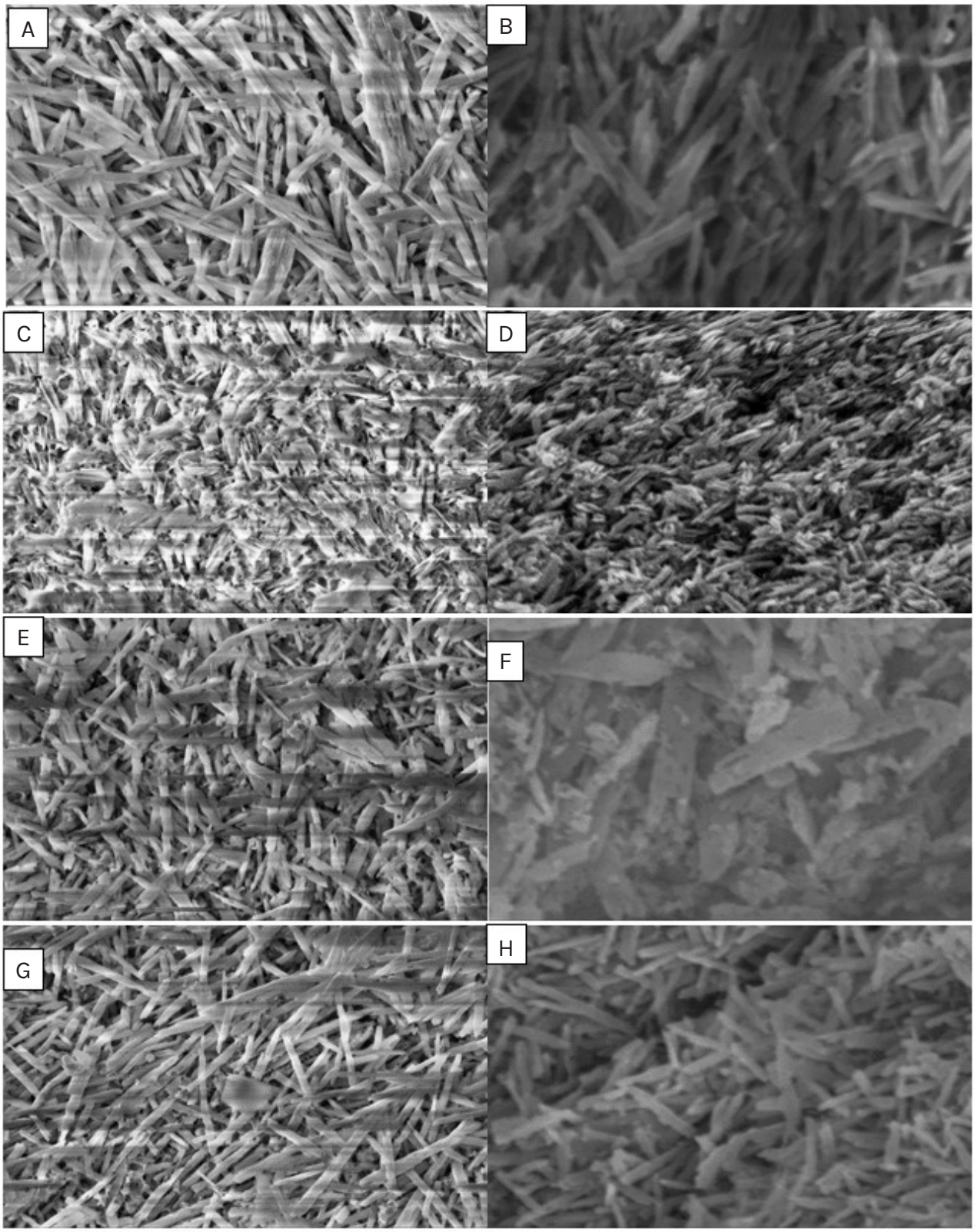


Figure 3 - Representative SEM Of The Sample Surface At X10000 Magnification. A: LDS1P, B: LDS1R, C: LDS2P, D: LDS2R, E: ZLSP, F: ZLSR, G: ZLDSR,H: ZLDSP.

EDAX analysis

EDAX system is attached to a scanning electron microscopy instrument that allows the microscope's imaging capabilities to identify the specimen of interest. The information produced by the EDAX analysis consists of spectra with peaks that represent the constituent elements of

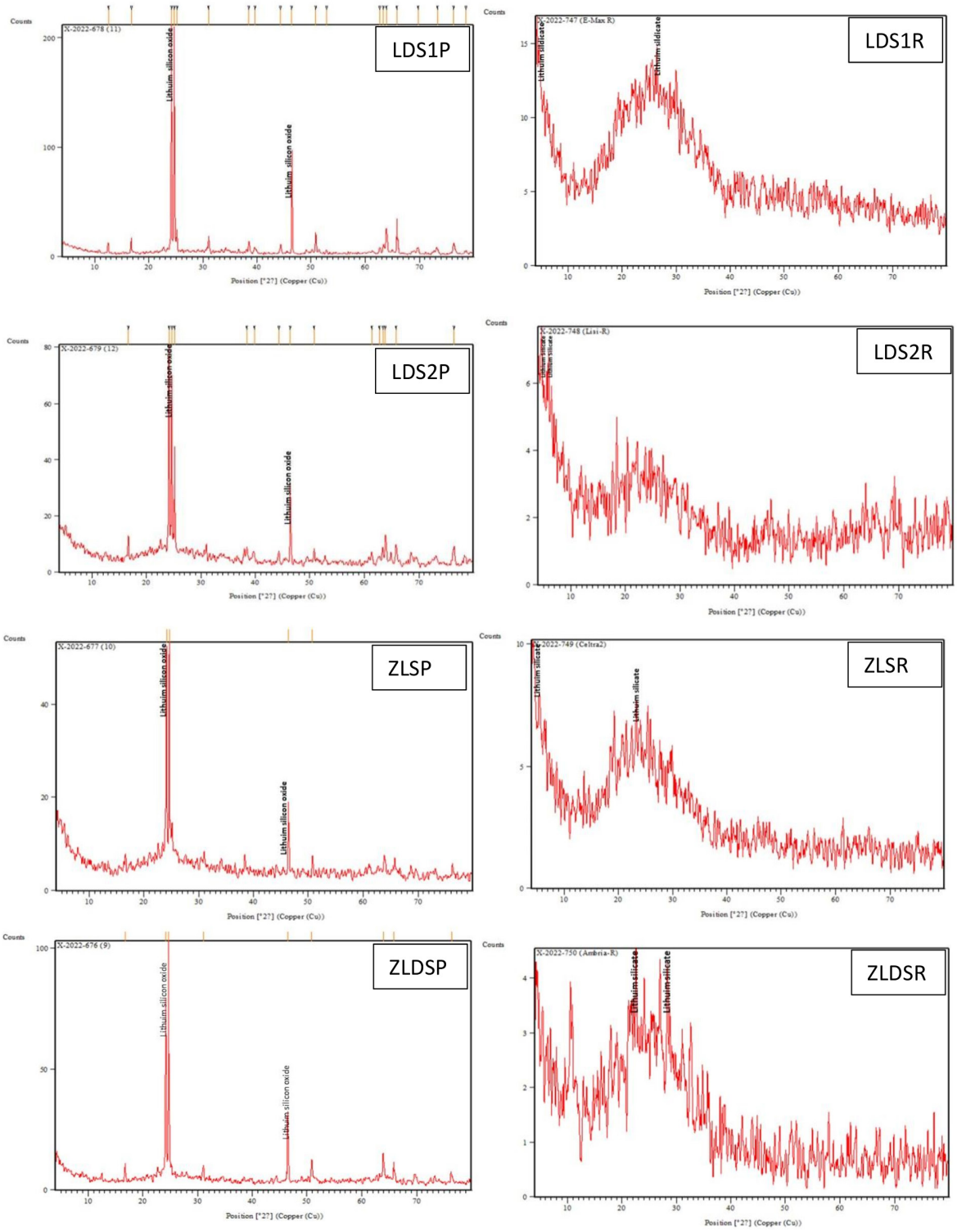
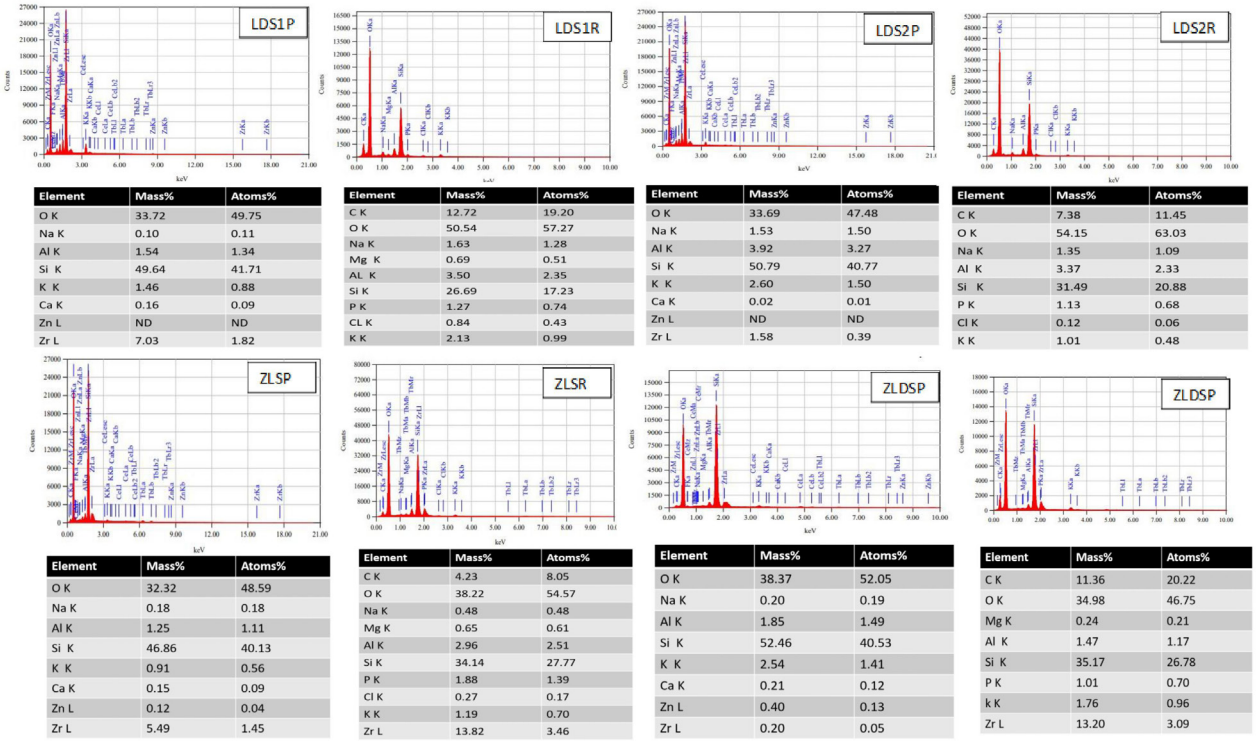


Figure 4 - XRD peaks for all groups showing the main crystalline phases.

the sample under study. It also permits image analysis and elemental mapping of a sample. It can be quantitative, semi-quantitative, or qualitative. Through mapping, it also shows the spatial distribution of the elements. Pressed and re-pressed samples showed no difference in composition (Figure 5).

DISCUSSION

The re-pressing of lithium disilicate and leucite glass-ceramics has been documented in the literature. However, findings differ regarding how re-pressing affects the mechanical and physical characteristics of these glass-ceramic materials.



Element	Mass%	Atoms%
O K	33.72	49.75
Na K	0.10	0.11
Al K	1.54	1.34
Si K	49.64	41.71
K K	1.46	0.88
Ca K	0.16	0.09
Zn L	ND	ND
Zr L	7.03	1.82

Element	Mass%	Atoms%
C K	12.72	19.20
O K	50.54	57.27
Na K	1.63	1.28
Mg K	0.69	0.51
AL K	3.50	2.35
Si K	26.69	17.23
P K	1.27	0.74
CL K	0.84	0.43
K K	2.13	0.99

Element	Mass%	Atoms%
O K	33.69	47.48
Na K	1.53	1.50
Al K	3.92	3.27
Si K	50.79	40.77
K K	2.60	1.50
Ca K	0.02	0.01
Zn L	ND	ND
Zr L	1.58	0.39

Element	Mass%	Atoms%
C K	7.38	11.45
O K	54.15	63.03
Na K	1.35	1.09
Al K	3.37	2.33
Si K	31.49	20.88
P K	1.13	0.68
Cl K	0.12	0.06
K K	1.01	0.48

Element	Mass%	Atoms%
O K	32.32	48.59
Na K	0.18	0.18
Al K	1.25	1.11
Si K	46.86	40.13
K K	0.91	0.56
Ca K	0.15	0.09
Zn L	0.12	0.04
Zr L	5.49	1.45

Element	Mass%	Atoms%
C K	4.23	8.05
O K	38.22	54.57
Na K	0.48	0.48
Mg K	0.65	0.61
Al K	2.96	2.51
Si K	34.14	27.77
P K	1.88	1.39
Cl K	0.27	0.17
K K	1.19	0.70
Zr L	13.82	3.46

Element	Mass%	Atoms%
O K	38.37	52.05
Na K	0.20	0.19
Al K	1.85	1.49
Si K	52.46	40.53
K K	2.54	1.41
Ca K	0.21	0.12
Zn L	0.40	0.13
Zr L	0.20	0.05

Element	Mass%	Atoms%
C K	11.36	20.22
O K	34.98	46.75
Mg K	0.24	0.21
Al K	1.47	1.17
Si K	35.17	26.78
P K	1.01	0.70
k K	1.76	0.96
Zr L	13.20	3.09

Figure 5 - EDAX analysis of pressed and repressed samples.

Furthermore, the existing literature contains little information regarding how re-pressing affects the mechanical and physical characteristics of ZrO_2 lithium silicate glass-ceramics.

The results of the present study allow the null hypothesis to be rejected, as the re-pressing and different types of glass ceramics was found to have a significant impact on fracture resistance. Different types of ceramic had statistically significant differences regardless of the heating process used, with LDS1 (1765.8 N) exhibiting the highest mean fracture resistance. ZLDS (1247N) exhibited the lowest mean fracture resistance, differing from ZLS in a way that was not significant. The microstructural characteristics (as measured by SEM) of the LDS1 specimens, which showed pore-free multilayered rod-shaped lithium disilicate crystals producing a high interlocking microstructure, may correspond to this finding. Moreover, LDS1's higher pressing temperature may promote greater crystal development and interlocking.

These findings are consistent with research conducted by Wang et al. [23] on the effect of heat-pressing temperature on the microstructure and flexural strength of lithium disilicate glass-ceramic, which found that the IPS e.max press at the highest temperature produced the most pore-free structure. Furthermore, heat-tempering lithium disilicate glass ceramics enhances its flexural strength, as reported by Sun et al. [24]; this was explained by a shift in crystal morphology from spherical to rod-shaped.

Another important factor that significantly affects ceramic material strength is the number of crystal fillers in the material. Glass ceramics are made by melting glass and carefully heating it with nucleating chemicals until the desired degree of crystallinity is reached. During these processes, the glassy phase transforms into the crystalline phase, and the materials that remain are composed of a glassy matrix with several embedded crystalline phases [25]. In glass ceramics, nucleation is the main controlling process for crystallization. The prevailing mechanism is determined by the chemical composition of the nucleating chemicals and the parent glass [26]. ZrO_2 was used as a nucleating agent, which aided in volume crystallization. of glasses while impeding crystal development. This could explain why ZLS and ZLDS have lower flexural strengths than LDS1, because ZrO_2 increases the viscosity of the heat-pressed ceramic and inhibits the growth of lithium metasilicate and lithium disilicate crystals during heat tempering [2,27].

Hallmann et al. [2] found that after heat tempering at 860 °C, the Celtra press exhibited the lowest biaxial flexural strength values when compared to the IPS Emax press and the Initial LiSi press. This result is consistent with that of Radwan et al. [28], who assessed the biaxial flexure strength of several pressable lithium silicate ceramics and concluded that Celtra press had the lowest strength and IPS e.max press the greatest. In contrast, zirconia-reinforced lithium silicate crowns have a greater mean fracture resistance value than lithium disilicate crowns, according to a study by Hamza et al. [29]. This finding may have been due to the composition of the material, as adding 10% zirconia may have boosted its strength. In the present study, examination of broken samples indicated that ZLDS had the most frequent failure mode, which was cracking. Microstructural analysis (SEM) of ZLDS revealed nanoclusters that were well aggregated and fused together to form bigger clusters, which may be responsible for this finding.

The mean fracture resistance of pressed samples was found to be much lower than that of re-pressed samples, regardless of the type of ceramic. SEM examination showed a pore-free microstructure with an increase in grain size in LDS1, LDS2, ZLS, and ZLDS following repressing, which may be accountable for this result. The increase in grain size signifies the continued existence of the crystallization. process during the re-pressing process, resulting in the precipitation of more crystals of lithium silicates. This behavior is called Ostwald ripening [30], and is common for all precipitated materials. The microstructure coarsens, releasing excess surface energy due to small particle solubility, causing larger grains to grow at the expense of smaller particles [31]. This finding is in line with Albakry et al. [1] and El-Etreby et al. [3,20] who evaluated the impact of re-pressing on glass ceramics and discovered that re-pressing led to substantial growth of the crystals, but it is at odds with Tang et al.'s [6] investigation into the impact of repressing on the mechanical characteristics and microstructure of lithium disilicate ceramics, which led to the conclusion that re-pressing changed the microstructure by noticeably increasing porosity. Along with a significant decline in hardness, fracture toughness, flexural strength, and density. According to Gorman et al. [7], the mechanical qualities of lithium disilicate ceramics after repressing remained constant even after multiple pressings, with the first pressing offering the best results.

CONCLUSION

Within the limitations of this *in vitro* study, the following can be concluded:

1. Re-pressing improves the studied glass ceramics crowns' resistance to fracture.
2. Recycling the investigated glass ceramics may reduce failure and extend their service life.

Limitations

Neither the impact of intra-oral stresses nor the effect of several pressing cycles were studied in this research. Further research on additional mechanical and physical qualities is needed. The findings of this study may lend support to the cost-effective reuse of pressed glass ceramics; however, additional clinical research is necessary to validate these results.

Author's Contributions

MMES, AEE, FAM: Conceptualization. MMES, AEE: Methodlogy. MMES: Writing – Original Draft Preparation. AEE: Formal Analysis, Validation. AEE, FAM: Supervision. FAM: Writing – Review & Editing, Visulalization.

Conflict of Interest

The authors have no conflicts of interest to declare.

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Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of: Faculty of Dentistry, Ain Shams University, Cairo, Egypt (FDASU-REC).

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