AL-AZHAR
Dental Journal
For Girls

The Official Publication
of The Faculty of Dental
Medicine For Girls,
Al-Azhar University
Cairo, Egypt.

Print ISSN 2537-0308 • Online ISSN 2537-0316

ADJ-for Girls, Vol. 10, No. 1, January (2023) — PP. 53:62

Effect of Repeated Heat-Pressing on Marginal and Internal Fit of Lithium Disilicate Glass Ceramic Crowns after Thermo-Mechanical Fatigue

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Codex : 1-06/23.01

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http://adjg.journals.ekb.eg

DOI: 10.21608/adjg.2022.103874.1451

Restorative Dentistry
(Removable Prosthodontics, Fixed Prosthodontics, Endodontics, Dental Biomaterials, Operative Dentistry)

ABSTRACT

Purpose: To evaluate the effect of repeated heat-pressing on marginal and internal fit of lithium disilicate glass ceramic crowns. **Materials and Methods:** A freshly extracted caries free human maxillary 1st premolar was prepared according to standardized preparation for all-ceramic crown restoration. The preparation was duplicated to produce thirty epoxy resin dies. The resin dies were divided into three groups (n=10) according to the number of heat-pressings of IPS e.max Press (Shade A2, LT) used for crowns construction. Group 1: Crowns constructed from freshly pressed ingots, Group 2: Crowns constructed from leftover repressed buttons for 1st time, and Group 3: Crowns constructed from leftover repressed buttons for 2nd time. The constructed crowns were cemented to their corresponding resin dies using adhesive resin cement, then samples were subjected to the thermo-mechanical fatigue with a ROBOTA chewing simulator. Each cemented ceramic crown was vertically sectioned bucco-lingually into 2 sections. Marginal, axial, and occlusal gaps were measured at seven defined points on each section using digital microscope. Data were tabulated and statistically analyzed using One-way ANOVA and Pearson's correlation tests. The significance level was set at $P<0.05$. **Results:** The largest marginal and internal gap values were recorded in Group 1, while the lowest marginal and internal gap values were recorded in Group 3. Statistical analysis revealed that there were no significant differences in marginal and internal gaps between the tested groups ($P<0.05$). **Conclusions:** Repressing and thermomechanical fatigue have no significant effect on marginal and internal fit of IPS e.max Press crowns.

KEYWORDS

Lithium disilicate, IPS e.max Press, Repressing, Thermomechanical fatigue.

- Paper extracted from Master thesis titled "Effect of Repeated Heat-Pressing on Marginal and Internal Fit of Lithium Disilicate Glass Ceramic Crowns after Thermo-Mechanical Fatigue."

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INTRODUCTION

Pressable glass-ceramic materials have undergone significant development, starting with leucite, lithium disilicate, and IPS empress I& II, and ending with IPS e-max Press, which has improved mechanical and optical properties. Glass-ceramics have some differences in composition and microstructure, combining properties characteristic of both ceramics and glasses. To achieve long durability with superior esthetics, a new pressable lithium disilicate glass-ceramic called IPS e.max Press with improved mechanical properties and superior translucency was launched in 2005 [(1)].

This product is not only a core material but can also be used directly for various restorations in the anterior and posterior region. These restorations are translucent due to the absence of a metal framework and therefore provide an excellent opportunity to achieve lifelike esthetic restorations [(2).]

Heat pressing has become one of the most common techniques for fabricating glass-ceramic dental restorations. In addition to its simplicity, the heat-pressing technique promotes better crystalline distribution within the glass matrix, less porosity and better marginal accuracy compared to other techniques [(3)].

IPS e.max Press ceramics are available in ingots with different shades and translucencies to meet various clinical conditions [(3)]. These ingots are pressed into a mold with an aluminum oxide plunger under pressure using a pneumatic press furnace. Sometimes one ingot is used to fabricate only a single restoration. Therefore, large amounts of leftover material (buttons and sprues) are usually discarded. However, in some dental laboratories, these material remnants are considered valuable for repressing for economic reasons. Moreover, this is an eco-friendly solution for materials that would otherwise simply be discarded [(4)]. Therefore, it is very important to evaluate the properties and microstructure of re-pressed glass-ceramic material to determine the feasibility of repeated heat pressing treatment.

A previous study [(5)] evaluated the effect of repeated heat pressing on the strength, hardness, and microstructure of a leucite-based pressable ceramic after multiple pressings. It was concluded that multiple pressing did not affect the evaluated mechanical properties in the long term or change the microstructure.

Also, a study in 2020 [(6)] investigated the effect of re-pressing on the surface topography and micro-shear strength of two press ceramics: IPS e.max press and Celtra press. The results showed that re-pressing glass-ceramics improved the surface topography but compromised the bond strength. It was concluded that both tested glass-ceramic materials can be recycled without significantly changing the surface roughness.

In 2021, another study [(7)] investigated the effect of thermomechanical aging and re-pressing on the fracture strength of lithium disilicate crowns fabricated from leftover buttons. The re-pressed group had a statistically significantly higher mean value of fracture strength than the pressed group; this could be due to the interlocked microstructure of the densely packed lithium disilicate crystals. It was concluded that re-pressing the remaining buttons may increase the fracture strength of IPS e.max press crowns.

Regarding physical properties, a study in 2017[(4)] investigated the effects of re-pressing on the color, translucency, surface roughness, and microstructure of IPS e.max Press. It was found that re-pressing had no significant effect on the color, translucency, and surface roughness of IPS e.max Press. The microstructure of IPS e.max Press did not change before and after re-pressing, indicating that the lithium disilicate glass-ceramic reached its maximum crystallinity before re-pressing. It was concluded that the IPS e.max Press remnants of pressed buttons can be safely reused without any negative effects on color, translucency, surface roughness and microstructure.

Also, another investigation [12] tested the effects of repressing on the color and translucency of lithium disilicate pressable ceramic material. The results showed a statistically significant difference in color after re-pressing. In addition, the e.max press group showed a statistically significant decrease in translucency after re-pressing. It was concluded that re-pressing has a negative effect on both color and translucency of lithium-disilicate pressable ceramics.

There is no scientific evidence on the effect of repeated heat pressing on the marginal and internal fit after thermomechanical fatigue. Therefore, this study was conducted to investigate the effect of repeated heat pressing on the marginal and internal fit of lithium disilicate glass-ceramic crowns (IPS e.max Press) after thermomechanical fatigue. The null hypothesis was that repeated repressing of leftover buttons several times has no significant effect on the marginal and internal fit of IPS e.max press crowns after thermomechanical fatigue.

MATERIAL AND METHODS

Sample size calculation:

To study the effect of repressing on marginal and internal fit, a total sample size of 30 (10 in each group) with the satisfactory level of power set at 80% and a 95% confidence level [9]. Sample size was calculated according to computer sample block randomization type.

Tooth selection and preparation:

A freshly extracted human maxillary right1st premolar with completed roots, free of caries, fractures and cracks was selected for this study. Ethical approval for the use of extracted human teeth was obtained in accordance with guideline from Research Ethic Committee Approval of Faculty of Dental Medicine for Girls Al-Azhar University (ethics code number: REC-CR-21-02). A plastic cylinder (2cm height and 1.5cm diameter) was used as a mold for constructing epoxy resin block (East coast, USA). The inner wall of the cylinder was painted with a separating medium. The premolar was aligned to be parallel to the walls of the plastic cylinder by using milling surveyor (BEGO PARASKOP M, Germany). Epoxy resin was mixed according to the manufacturer instructions and poured in plastic container.

The selected premolar was prepared using a milling surveyor (BEGO PARASKOP M, Germany) by using tapered diamond stone with round end 1.8 mm (no.856L-018, Brasseler, USA) to receive a lithium disilicate posterior crown (1.5 mm occlusal and axial reduction with heavy chamfer finish line with 6º convergence angle) [3].

Production of epoxy resin dies:

Thirty impressions of the prepared tooth were taken using condensation silicon-based rubber impression material (Zetaplus, Zhermack, Italy) in plastic cylinders (2cm heightand 1.5cm diameter) to produce thirty molds. Epoxy resin (Crystal Clear Epoxy Resin, East Coast Resin, USA) was mixed following manufacturer's instructions with a ratio of (2 polymer: 1 monomer) and poured into the molds on a vibrator. The molds were left undisturbed for 24 hours till complete setting of epoxy resin.

Experimental design:

The constructed epoxy resin dies (N=30) were randomly divided into three groups (N=10) according to the number of heat-pressings of IPS e.max Press material used for crowns construction. Group 1: crowns constructed from freshly pressed ingots, Group 2: crowns constructed from leftover repressed buttons for first time, and Group 3: crowns constructed from leftover repressed buttons for second time.

Fabrication of CAD/CAM crown wax patterns of a standard design:

To standardize the constructed crowns among all groups, the design used for the construction of CAD/CAM wax patterns for the control group

(Group 1) was followed during the construction of wax patterns for the tested groups (Group 2 and Group 3). A desktop computer connected to DOF swing Dental Scanner (Structured light tech., South Korea), Exocad (Exocad GmbH, Darmstadt, Germany) computer software that is responsible for designing the restoration then imports an STL file to the milling machine, a 5-axis CAD/CAM Roland machine (Roland DWX-52D) was used for indirect fabrication of crowns wax pattern (DWAX-W14 CO Korea). All milled wax patterns were tried over their corresponding duplicated dies and checked for marginal adaption, and any defective wax pattern was discarded.

Fabrication of IPS e.max Press crowns:

All wax patterns were sprued and invested following manufacturer's instructions (BEGO Bellavest, Begosol, BEGO Co, Germany), the investment was left to set for an hour before starting wax elimination. Wax elimination was performed with wax-burn out furnace (Ney,US Dental Depot, USA) according to the manufacturer's recommendation. The Crowns were pressed following manufacturer's instructions in a EP3000 press furnace (Ivoclar, Schaan, Liechtenstein, Germany) by using new IPS emax ingots following manufacturer's instruction. Immediately after the program was completed, the investment ring was removed from the furnace and left to cool at room temperature for about 60 minutes on a wide-meshed grid (IPS e.max cooling rack, Ivoclar, Schaan, Liechtenstein, Germany) which insured fast and even cooling of the investment ring [3].

Crowns were removed from the investment ring using a disc (Ivoclar, Schaan, Liechtenstein, Germany), rough divestment was done with polishing beads (Ivoclar, Schaan, Liechtenstein, Germany) at 4 bar (58 psi), maintaining a safe distance to avoid damage of the freshly pressed restoration. Once the crowns were exposed, fine divestment was done with polishing beads at 2 bar (29 psi) pressure. The ceramic residue on the Alox Plunger was removed using type 100 Al_2O_3. Then the pressed crowns were immersed in Invex liquid (Ivoclar, Schaan, Liechtenstein, Germany) for 30 minutes to remove the reaction layer of the investment, then rinsed under running water and dried. After that, they were blasted with glass beads at 2 bar pressures to remove any remaining reaction layer.

Buttons preparation for Group 2 and Group 3:

The crowns were cut from the sprues and buttons using a disc mounted on straight angle hand piece. The sprues were discarded, and the buttons were kept for further use. The buttons were finished and adjusted to resemble the shape of a new IPS e.max Press ingot using diamond discs and stones. All the previously mentioned steps were carried out again using the trimmed left-over buttons to produce 1st time-repressed crowns (Group 2). Then the left-over buttons produced from the repressed crowns were trimmed and reused to produce the repressed crowns for the second time (Group 3).

IPS e.max Press crowns of all groups were finished and glazed according to the manufacturer's recommendations. All crowns were inspected and checked over their corresponding dies for marginal accuracy and proper seating by using digital video microscope (EASY view 3D) (Renfert, Germany), and any defective restoration was discarded.

Crowns' cementation:

The fitting surface of the IPS e.max Press crown was etched with hydrofluoric acid gel (5% IPS Ceramic Etching Gel, Ivoclar Vivadent, Liechtenstein, Germany) for 20 seconds, then the surface was rinsed thoroughly and air dried. The internal surface of the crown was treated with Porcelain Primer (Bisco, USA) by using a microbrush (JAAN MED co, China), and allowed to react for 60 seconds then air dried. Each crown was cemented on its corresponding die with gentle finger pressure using self-adhesive, dual-curing resin cement (Aureocem NE, Promedica, Germany).

After seating, excess cement was removed with a scaler after brief polymerization for 2 seconds according to manufacturer's instruction. Glycerin gel was utilized along the margins to eliminate oxygen-inhibition layer. A specially designed loading alignment apparatus was machined from wood to aid in load (3 kg) application during cementation procedure. The crown was light cured from each side on high power for 20 seconds by the aid of high intensity SDI radii plus light curing unit (SDI, Australia) [(7)].

Thermo-mechanical fatigue:

Samples of the tested groups were subjected to thermo-mechanical fatigue using a programmable logic-controlled equipment chewing simulator (ROBOTA, AD-TECH Technology CO., Germany) integrated with thermocycling protocol operated on servomotor. The procedure included the application of a weight of 5Kg, equivalent to 49 N of chewing force, in the center of the occlusal surface for 75000 cycles to clinically simulate 6 months chewing conditions. Simultaneously, samples were subjected to thermocycling between 5-55 ^{0}C with a dwell time of 60 seconds. Chewing parameters used are presented in Table (1).

Table (1) *Chewing Simulator (ROBOTA) parameters:*

Cold/hot bath temperature 5 - 55 ^{0}C	Dwell time 60s
Vertical movement: 2 mm	Horizontal movement: 3 mm
Rising speed: 90 mm/s	Forward speed: 90 mm/s
Descending speed: 40 mm/s	Backward speed: 40 mm/s
Cycle frequency:1.6 Hz	Weight per sample: 5 kg
Torque: 2.4 N.m	

Sample sectioning:

Each sample was mounted inside a silicon ring to receive a clear acrylic resin for the purpose of extra-strength before sectioning. Each sample was vertically sectioned in a bucco-lingual direction from buccal to palatal cusp tips on the occlusal surface of the crowns at a pre-drawn line using IsoMet 4000 linear precision saw. Cutting was carried out at 800 rpm speed using stainless steel saw under copious coolant, then sectioned samples were separated from their resin bases.

Seven measuring points (10) were defined on each section (fig. 1); P1: The buccal marginal discrepancy, P2: The buccal mid-axial discrepancy, P3: The junction of the buccal and occlusal walls, P4: The mid occlusal discrepancy on the occlusal plateau, P5: The junction of the palatal and occlusal walls, P6: The palatal mid-axial discrepancy and P7: The palatal marginal discrepancy.

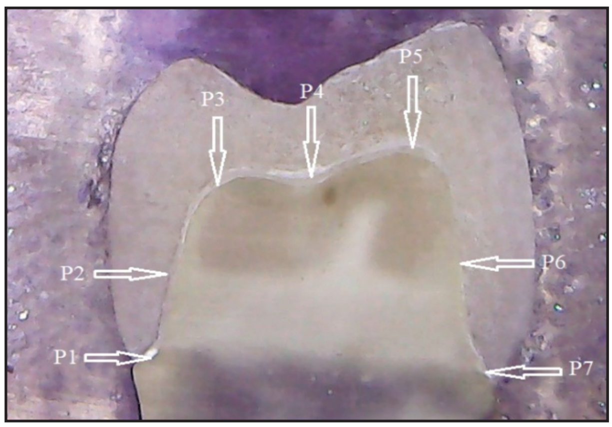

Figure (1) Digital microscopic image illustrating measuring sites

Measurements of the marginal and internal gaps:

The measurements were assessed by using a USB digital microscope connected to a compatible personal computer with a fixed magnification of 30X. The image of the tooth-restoration was captured and transferred to a computer equipped with the image analysis software program (Image J 1.43U, National Institute of Health, USA). Within the Image J software, all limits, sizes, frames, and measured parameters are expressed in pixels.

Therefore, system calibration was done to convert the pixels into absolute real-world units. Calibration was made by comparing an object of known size (a ruler in this study) with a scale generated by the Image J software. at 30 X magnification via a personal computer, connected to the Dino-Lite digital microscope (Dino-Lite).

Statistical Analysis

The obtained data from all groups were collected and statistically evaluated; values were presented as means and standard deviations (SD). Kolmogorov-Smirnov test of normality was performed and indicated that most of the data were normally distributed (parametric data). One-way ANOVA was used to verify whether there was statistical difference between the three groups and student t-test between pairs. Statistical analysis was performed using Graph-Pad InStat statistics software (version 3.16) for Windows. Pearson's correlation test was used to study correlation between marginal and internal fit. P values < 0.05 were statistically significant in all tests. Sample size (n=10/group) was large enough to detect large effect sizes for main effects and pair-wise comparisons, with the satisfactory level of power set at 80% and a 95% confidence level.

RESULTS

Regarding the marginal, axial, and internal gap distances, it was shown that the largest mean ±SD values were recorded for Gr_1; (61.82±10.67 μm, 87.32±5.46 μm, and 96.77±9.95 μm) followed by Gr_2; (61.23±6.91 μm, 82.09±6.49 μm, and 90.84±6.38 μm), whereas the lowest mean ±SD values were registered for Gr_3; (60.97±6.28 μm, 80.60±2.89 μm, and 90.23±5.4 μm), respectively. The difference among groups was statistically non-significant (table 2 and fig. 2).

Regarding the occlusal gap distance, it was shown that the largest mean ±SD values were registered for Gr_1; (106.23 ± 11.07 μm) followed by Gr_3; (99.85 ±7.92 μm), whereas the lowest mean ±SD values were recorded for Gr_2; (99.59 ± 6.26 μm). The difference among groups was statistically non-significant as revealed by ANOVA test (p=0.2920 > 0.05) (table 2 fig. 2).

A direct positive correlation was found between internal and marginal gaps as indicated by Pearson's correlation test; correlation coefficient (r=0.5598, r2=0.3134 and p > 0.05) (table 3 and fig. 3). A positive correlation means a direct relation between marginal and internal fit; an increased marginal gap is accompanied by increased internal fit and vice versa.

Table (2) Comparison of gap test results (mean± SD) between *all groups as function of measurement sites*

Groups		Mean	SD	95%Confidence Interval for Mean		P value
				Low	High	
Marginal	**Gr_1**	61.82	10.67	55.21	68.43	0.9835 ns
	Gr_2	61.23	6.91	56.94	65.52	
	Gr_3	60.97	6.28	57.08	64.86	
Axial	**Gr_1**	87.32	8.83	81.85	92.8	0.1566 ns
	Gr_2	82.09	6.49	78.06	86.11	
	Gr_3	80.60	2.89	78.8	82.39	
Occlusal	**Gr_1**	106.23	11.07	99.36	113.09	0.2920 ns
	Gr_2	99.59	6.26	95.7	103.48	
	Gr_3	99.85	7.92	94.94	104.77	
Internal	**Gr_1**	96.77	9.95	90.6	102.94	0.05622 ns
	Gr_2	90.84	6.38	86.88	94.79	
	Gr_3	90.23	5.41	86.87	93.58	

SD = Standard deviation, P = probability, ns = non-significant (p>0.05)

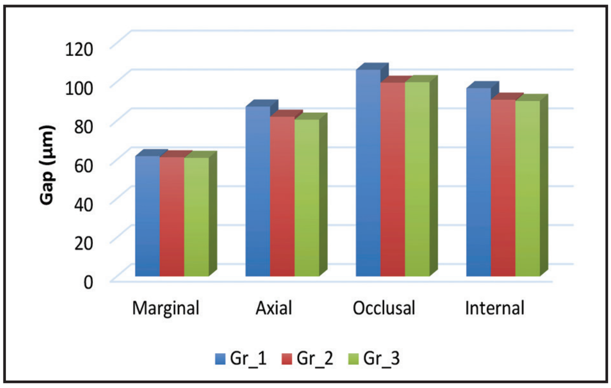

Figure (2) Column chart showing gap mean values for all groups as function of measurement sites.

Table (3): *Linear correlation between marginal and internal fit using Pearson's correlation test*

r	r^2	Interpretation	P value
0.5598	0.3134	direct positive	0.0924

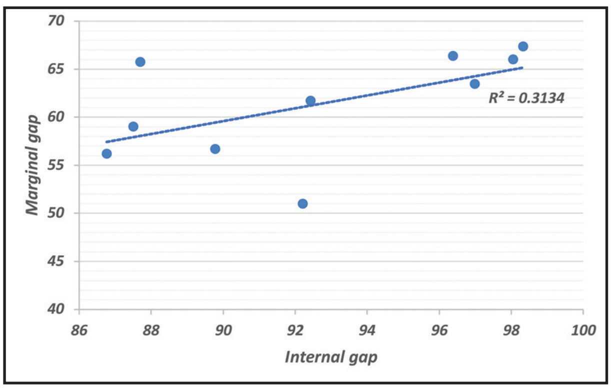

Figure (3) Linear chart showing correlation between internal and marginal gaps

DISCUSSION

There is no doubt that modern dentistry should provide the patients with oral health improvement indicating for clinical success. After esthetic and mechanical properties, crown marginal and internal fit are critical to clinical success. High marginal fit minimizes plaque accumulation, microleakage, and cement degradation, therefore reducing the risk of carious lesions, periodontal disease, and endodontic problems. So, it is important to minimize marginal gaps and hence reduce their associated complications[11].

The internal fit of the crown is critical to its retention and resistance, a better fit increases success and longevity. Increasing the internal gap within limits could decrease the fracture strength of ceramic crowns, as areas with a higher internal gap could induce stress concentrations [12-14].

The effect of repeated hot pressing of IPS e.max Press on marginal and internal fit after thermomechanical fatigue has not yet been studied, but its effect on other mechanical and/or physical properties have been investigated with promising results pushing other researchers to conduct further studies.

To conduct the present study, a single prepared natural premolar was utilized to standardize the preparation and avoid errors that are expected in many preparations. In the present study, a CAD / CAM pattern of wax blocks was used. This technique has the advantage of eliminating human variability and saving time. Moreover, the automatic margin detection, the possibility of selecting the cement restoration space and the computerized planning of the restoration give the CAD / CAM technique more reliability and simplicity as recommended by previous study [15].

In this study, the heat-pressing technique was used because it has become a common technique for fabricating glass-ceramic restorations due to its simplicity, better crystalline dispersion in the vitreous matrix, better marginal adaptation, and lower porosity compared to the sintering technique[16].

It is known that the marginal gap distance increases after final cementation due to the cement film thickness [17]. To support the load (3 kg) during cementation, a specially designed load alignment device was fabricated from wood to ensure an even cement layer and remove excess cement. All measurements of marginal gap distance in this study were taken after cementation to mimic real intraoral conditions.

Preclinical in vitro testing of dental materials is critical to demonstrate their mechanical performance and compatibility for use in the oral cavity. Conventional laboratory tests involve static loading of test specimens in a universal testing machine until failure. While such tests can provide information on material strength, estimate the risk of failure, or compare material variants, they are still insufficient to predict the long-term performance of dentures during use. The oral environment includes many challenging conditions such as humidity, acidic or alkaline pH, and cyclic loading. For the previously mentioned reasons, laboratory tests should simulate various aspects of the oral environment to produce fatigue like those happen clinically [(7)].

To mimic the intraoral environment, it was simulated in this study by subjecting specimens from all groups to artificial thermodynamic fatigue to simulate oral conditions. The procedure involved the application of a weight of 5 kg, comparable to a chewing force of 49 N, to the center of the occlusal surface for 75000 cycles to simulate clinical conditions for 6 months of chewing. Simultaneously, the specimens were subjected to thermocycling between 5-55 0C with a dwell time of 60 seconds [(18)].

The samples of the current study were bucco-lingually cut into two halves. The cross-sectional method allows direct measurement of the cement layer, minimizing errors that can result from software or repositioning errors [(10)]

Because the longevity of a fixed restoration is directly related to its marginal and internal fit accuracy, this study was designed to compare the differences in marginal and internal fit after thermomechanical fatigue and different press cycles.

According to the results of the present study, the IPS e.max Press crowns did not show statistically significant differences in the mean values of the marginal and internal gap between the three tested groups. Regarding the marginal, axial, and internal gap measurements, the best adaptation was registered for group 3, followed by group 2, while the lowest adaptation was recorded for group 1 as shown in Table (2) and Figure (2).

The lowest gap measurement values in group 3 might be due to the stronger interlocking of the platelet-shaped crystals of IPS e-max press after the second repressing [(17)], which increases their strength to withstand thermomechanical fatigue without cement degradation, resulting in higher adaptation.

In the present study, the null hypothesis was accepted indicating that the e.max press could be pressed for several times without adversely affecting the marginal or internal fit.

These findings could be explained and supported with SEM presented by previous study [(4)] which reported that groups (pressed and repressed) were found to be almost free of pores in the surface; this pore-free microstructure was mainly attributed to the use of left-over buttons. This technique prevented trapping of air in-between the repressed material thus producing a repressed ceramic with nearly pore-free structure that is similar to that provided by the manufacturer. It was concluded that the buttons can be repressed and recycled as lithium disilicate glass-ceramic materials have reached their maximum crystallinity before repressing. However, all the gap values shown in this study were within clinically acceptable range (≤ 120 μm) reported previously in many studies [(12,19,20)].

The results of the current study were in disagreement with a previous study [(9)] which evaluated the effect of repeated heat repressing on marginal accuracy of IPS Empress II. The groups tested were divided according to the percentage of repressed material used as follow, Gr1; IPS Empress II 100% freshly pressed, Gr2; IPS Empress II 50% repressed, and Gr3; IPS Empress 100% repressed. It was found that the vertical marginal gap increased in the second group (113.8 ± 1.83μm) but still within the clinically acceptable range (120 μm), while the vertical marginal gap was clinically inacceptable in the third group (150 μm ± 3.05). It was concluded that repressing up to 50% with fresh ingots would not affect the clinical performance and reliability of all ceramic restorations in terms of marginal accuracy.

In addition, another study [21]investigated the effect of repressing of IPS e.max Press with different concentrations on the marginal gap.Twenty-five IPS e.max Press crowns were fabricated. They were divided into 5 groups (5 samples in each group) according to the Wt.% of the new ceramic ingots to the repressed ceramic. Group I is 100 % new ceramics. Group II is 75 % new and 25% repressed ceramics. Group III is 50 % new and 50 % repressed ceramics. Group IV is 25% new and 75% repressed ceramics. Group V is 100 % repressed ceramics. they found that Group 1 (100 % new) recorded the least marginal gap (32.7 ± 2.85μm), while group 5 (100% repressed) recorded the highest marginal gap (120.91 ± 8.21 μm). No statistically significant difference between marginal gap of the first three groups (100 % new, 75% new + 25% repressed, 50% new + 50% repressed). A statistically significant difference was recorded between these 3 tested groups and group 4 (25% new + 75% repressed). There was also a significant difference between group 4 and group 5 (100% repressed). It was concluded that various weight percentages of repressed ceramics affected the marginal gap and had a significant effect when it exceeded 50 %, although all tested groups were clinically accepted.

However, comparing the results of the current study with other studies has the limitation that one studied the repressing of IPS Empress 2 not IPS e.max Press which differs in crystals size and percentage [9]. In addition, most of studies used both leftover sprues and buttons [9,21] to prepare the repressed samples which was not the case in our present study.

CONCLUSIONS

Within the limitations of the present study, the following could be concluded:

1. Repressing of left-over buttons has no statistically significant effect on marginal and internal gap of IPS emax Press crowns.
2. Marginal and internal fit of IPS emax Press restorations are positively correlated to each other.

RECOMMENDATIONS

This study has a broad range of applications and could also push other investigators to evaluate other properties of IPS e.max press manufactured by heat repressing methods. Also, we recommend further investigation evaluating the marginal and internal fit but with increased sample sizing and/or measuring points.

ACKNOWLEDGEMENTS

I would like to acknowledge Dr. Mona Hossam, without your pushing and support, this project would not have been possible. Thank you for your care, kindness, and guide at every turn, and for your capacity for compassion and understanding.

FUNDING

There was no funding received for this study

CONFLICT OF INTEREST

There are no conflicts of interest.

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