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Impact of Different Wax Pattern Construction Techniques on the Marginal and Internal Fit of Celtra Press Ceramic Restoration.

Rana Refaat[1], Lamia E. Dawood[2], Rania Mostafa Mahmoud.[3]
[1]*Dentist at the Ministry of Health,Egypt.*
[2] *Associate Professor, Fixed Prosthodontics Dept, Faculty of Dentistry, Mansoura University and Delta University for Science and Technology.*
[3] *Associate Professor, Production Engineering and Mechanical Design Dept Faculty of Engineering, Mansoura University.*
**Corresponding Author: Rana Refaat, Dentist at the Ministry of Health,Egypt.*

Objectives:
The purpose of this In-vitro study was to evaluate the effect of different wax pattern construction techniques on marginal accuracy and internal fit of Celtra press crown restorations.
Materials and methods:
A maxillary 1st premolar was selected and prepared to receive all ceramic crown restoration, 30 identical dies of the prepared tooth were printed using 3D printing resin and divided into 3 groups according to wax pattern fabrication technique. Group C: conventional, Group S: Subtractive, Group A: additive wax pattern. Vertical marginal gap of each wax pattern on its corresponding die was measured using USB digital microscope with built-in camera. All wax patterns were sprued, invested, pressed with Celtra press restoration and cemented on their corresponding dies according to manufacturer recommendation. Vertical marginal gap of all specimens was measured before and after cementation. Internal adaptation was evaluated using replica technique. Data were collected, tabulated and statistically analyzed using Tukey post-hoc test (P= 0.05).
Results:
The results showed that there was a statistical significant difference between the three groups regarding the vertical marginal gap distance and internal adaptation. The highest mean marginal and internal gap values were found in group C followed by group S while the lowest value was found in group A.
Conclusion:
3D printed wax pattern construction technique resulted in the highest marginal and internal adaptation of crown restorations compared with conventional and subtractive techniques.
Keywords: *3D printing, wax pattern, Celtra press, resin die, CAD/CAM.*

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I. Introduction:

Patients' increasing demand for highly natural-looking restorations has prompted the development of new all-ceramic materials with improved mechanical properties, ensuring appropriate longevity while reducing technical drawbacks, which are now replacing traditional metal-ceramic restorations.[1] Lithium disilicate ceramics and its new modified class known as zirconia reinforced lithium silicate (ZLS) CeltraTM Duo have gained a great popularity owing to their high fracture resistance and superior esthetic properties making them very strong alternative for a wide range of clinical situations.[2] The addition of 10% weight zirconia particles to the lithium silicate ceramic acts as nucleating agent, reinforcing the ceramic structure by crack interruption.[3] ZLS ceramics consist of a dual microstructure; a very fine lithium meta-silicate and lithium disilicate crystals (average size: 0.5–0.7μm) and a glassy matrix containing zirconium oxide which has a beneficial impact on the material's light-optical and mechanical properties.[4] Besides esthetic and mechanical properties, marginal adaptation and internal fit are crucial for the clinical success of restorations.[5] An accurate pattern fabrication is a key step that affects marginal and internal adaptation of all pressed restorations. Manual manufacturing of excellent quality dental wax patterns depends on the ability of skilled technicians; it is a time-consuming process,[6]so finding new wax pattern manufacturing techniques was necessary to improve the quality of the pressed restorations.

With the advancement of Computer Aided Design and Computer Aided Manufacturing (CAD\CAM), it was logic to start using subtractive CAD / CAM machines to produce wax patterns and achieve excellent results, producing precise and large numbers of wax patterns in considerably less time than traditional methods.[7] A more recent technology where a three dimensional component which can built up pattern layer-by layer using a computerized numerical control (CNC) machine; this additive CAD/CAM approaches (also known as 3D printing technology) are beginning to be used in dental CAD/CAM systems.[8]

Little data is available about the marginal adaptation and internal fit afforded by the newer methods of wax pattern construction compared with the conventional method. The aim of this study was to evaluate the effect of different wax pattern construction techniques on marginal accuracy and internal fit of Celtra press crown restorations.

II. Materials And Methods:

A sound, caries-free upper first maxillary premolar was ultrasonically cleaned and thoroughly examined by the aid of magnifying lens and trans-illumination to ensure the absence of hypo-plastic defects, cracks and micro-fractures. The tooth was stored in distilled water with 0.1% thymol disinfectant solution at room temperature.[9] Approval for this project was obtained from Faculty of Dentistry, Mansoura University Research Ethics Committee (REC) number: M18090419.

Tooth was mounted in self-curing epoxy resin block (Acrostone cold cure cross-linked, Egypt) by a specially designed centralizing device[10] with the cemento-enamel junction (CEJ) located 2 mm coronal to the resin top surface.

Two silicone putty indices of the tooth were done using silicone polyvinylsiloxane putty impression material (Ghenesyl Kit, LASCOD, Italy).One index was cut carefully in a bucco-palatal direction and the other in a mesio-distal direction with razor blade (PARAGON, no.12, Sheffeild England).

An optical impression of the unprepared tooth was taken using a non-contact digital scanner (Ceramill map 400, AmannGirrbach, Germany) with its special scanning software (Ceramill mind, AmanGirrbach, Germany), the file was saved as STL file to be used as a reference to reproduce the subtractive and additive wax patterns.

The tooth was prepared for an all-ceramic crown restoration with 1.0 mm rounded corner shoulder finish line, 1.5mm uniform occlusal reduction, 1.0 mm axial reduction and total convergence angle of 12°. All preparation dimensions were verified by the putty indices, which were made before preparation. Tooth preparation was conducted using a straight hand piece attached to dental surveyor (Marathon 103, New York USA,Sirona).

Fabrication of the resin dies:

The prepared tooth was scanned from all surfaces reproducing the finest details. After optical impression, the CAD/CAM software (flash print and Chitu box, CBD-Tech, Guangdong, China) was used to make the design of the resin die, then merging and saving the information as STL file was done. The STL file was transferred to a 3D printer (phrozen shuffle 3D printer, Xiangshan Dist., Hsinchu City 300, Taiwan), and 30 identical replicas of the tooth were printed using printing resin (Dentifix 3D, light cured methacrylate, Lumi Industries, Piazza Poloni, Don Vittorio 2, 31044, Italy).Once printing was completed, dies were agitated in ultrasonic cleaner with detergent solution for 1-2 minutes. Then cured using light curing chamber (Light Zone II, Denstar, Korea) for 20 min.

Specimen grouping and wax pattern construction:

Thirty standardized dies were randomly divided into 3 groups (n=10) according to the wax-pattern fabrication method used. Group C: Wax patterns constructed by conventional method; group S: Wax patterns constructed by subtractive method and group A: Wax pattern constructed by additive method.

III. Fabrication of Group C wax patterns:

The margins of each 3D printed resin die used for group C were marked using a graphite-free pencil (pilot twin marker, permanent type, Japan). Die Spacer (KerrR, USA) was painted on the die surfaces; a band of 1 mm was left unpainted at the margin to ensure strong marginal adaptation. Two coats of die spacer were painted to gain 30 μm thickness[11] for cement space. A thin layer of separating medium (Ainsworth separating medium, Australia) was painted on all the die walls using a painting brush. Dipping wax technique (GEO-Dip, Renfert ,German) was used to form wax copings using dipping unit (hotty LED, Renfert ,German) at the recommended temperature setting. Each resin die from group C was dipped just below the preparation margin and withdrawn slowly and uniformly from the wax dipping unit, so an accurately fitting coping with uniform thickness was formed .The inlay wax (Reinfert Crowax Renfert; Renfert GmbH, Hilzingen, Germany) was added and molded by electric wax knife to match the die's emergence profile. The wax pattern was built to the full contour of upper first premolar guided by the previously made putty indices. This procedure was repeated for the conventional wax pattern specimens.

1. Fabrication of Group S wax patterns :

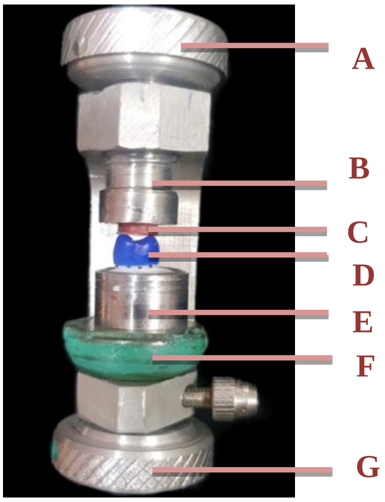
The STL file of each scanned die was subtracted from the STL file of the un-prepared tooth by CAD/CAM software (Exo Cad 2019, Gmbh, Germany), so the resultant STL file of the wax pattern design was used for both subtractive and additive wax patterns. Simulated cement gap was set to be 30µm started 1mm coronal to the finish line. The STL file of the wax pattern was transferred to the 5th axis milling machine (Ceramill Motion 2; Amann Girrbach, Koblach, Austria); to mill 10 identical wax patterns using milling wax blank (Ciramill wax Amann Girrbach AG,Germany).

2. Fabrication of Group A wax patterns:

The CAD STL file of the wax pattern of each die was sent to the 3D printer, the 3D printer uses an offshoot of 3D printing by Stereolithography (SLA), known as Masked Stereolithography (MSLA).The 3D printer printed 10 identical wax patterns using 3D printing wax (Dentifix Castable –blend, Lumi Industries,Italy)**.** The wax patterns were additionally cured using light curing chamber (Light Zone II, Denstar, Korea) for 20 min.

Marginal gap measurements of wax patterns:

The die spacer on the conventional group was removed with steam cleaner (I&B. Lab, China) after wax pattern fabrication to provide a cement space of 30 µm equal to subtractive and additive groups. A specially designed metallic C-shaped holding device was constructed to aid in handling of specimens during gap assessments (Figure 1).



A. Graduated screw.
B. Vertical rod.
C. Rubber pin.
D. Wax pattern specimen.
E. Cylindrical metal part.
F. Magnetic part.
G. Fixed base.

Figure 1. The specially designed holding device.

The lower arm of the device contains cylindrical metal part with internal diameter equal to the diameter of the resin die base to ensure precise fitting with the die without movement during measuring the marginal gap. The cylindrical part is mounted on a magnetic part which is attached to the lower fixed base with screw. While the upper arm of the C-shaped device consists of graduated screw with vertical rod, the tip of the rod was made from rubber material to avoid distortion of the wax patterns; the configuration of the rubber tip is as the antagonist of the occlusal surface of the wax pattern to allow seating of the specimen in only one position. The resin die with its wax pattern and the rubber tip can move as one unit 90° on a 360° axis during measurement under the microscope to capture the marginal fit from each surface without dis-assembling the device every time, and thus ensuring that the same pressure was exerted on all specimens guided with the graduated screw on it.

To assure measurement accuracy of the marginal gap for all specimens, four points were marked with an indelible marking pen in the middle of the buccal, lingual, mesial and distal surfaces of the copings. Two added marks for each surface were marked 2 mm right and left to the middle points to obtain a total of twelve measuring points for each wax pattern (3 points per surface). A photo for each surface of the specimen was captured using a USB Digital microscope (U500X Digital Microscope, Guangdong, China) with a built-in camera connected with an IBM compatible personal computer using a 45X magnification. The gap width was measured and evaluated using digital image analysis system (Image J 1.43U, National Institute of Health, USA). All limits, sizes, frames, and calculated parameters are represented in pixels within the software. System calibration was then performed to transform the pixels into absolute real world units (µm), this was done by comparing an object of known size (a ruler) to a scale provided by the software.

Fabrication of Celtra press crown restorations:

Each wax pattern from each group was marked on its mesial surface away from the finish line with dental carver according to the method used in the construction of the wax pattern with the letters C, S or A representing conventional, subtractive or additive groups respectively. Specimens in each group were also numbered from 1 to 10 to distinguish them from each other after pressing and to seat each crown on its corresponding die without affecting its marginal fit. 6 wax patterns 2 from each group were placed in one investment ring. All wax patterns were sprued at a point in the lateral aspect of buccal cusps using wax sprues. The wax patterns were sprayed with a very little wetting agent (Silikon-& Waches Entspanne, DFS, Germany) and the excess was removed. Phosphate-bonded investment material **(**Dentsply Caulk**,** Avenue Milford, DE 19963 USA.) was used according to the manufacturer's recommendations.

After setting of the investment material, the investment ring was placed in the preheating furnace. Pressing, divesting and finishing of crown restorations were done according to the manufacturer's recommendations. The pressed crowns were placed on their corresponding dies to check their fitting.

Pre-cementation marginal gap measurements:

Marginal gap of all crowns with their corresponding dies were measured before cementation using the same holding device, with the same magnification and at the previously made landmarks along the circumference for each surface.

Internal fit measurement:

Each crown was loaded with light-body silicone impression material (Express XT Light body; 3 M ESPE) and placed on its corresponding resin die with firm hand pressure followed by the application of constant load 5Kg [12] to the center of the crown and parallel to the long axis till polymerization of the material. The film of the impression material adhering to the crown's inner surface reflects the internal gap. Before setting of the impression material, the excess was removed with a cotton roll to prevent its tearing. Heavy body Vinyl polysiloxane impression material (3M ESPE, Express STD,Germany) was used for reinforcing and stabilizing the replica layer. After complete polymerization of the supporting material, it was removed and carefully sectioned bucco-palataly and mesio-distally using the sharp razor blade producing four equal segments. The thickness of the light-body silicone was measured using the same USB digital microscopy at 25X with three regions measured on each segment: axial wall, axio-occlusal, and mid-occlusal (figure2). To calculate and assess the gap width qualitatively, the digital image analysis program was employed, using the Image software, all limits, sizes, frames, and measured parameters are expressed into pixels. Calibration of the system was then carried out to turn the pixels into (µm).

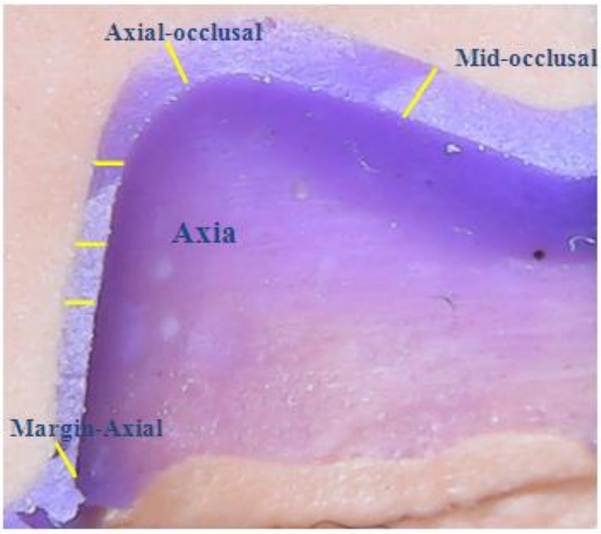


Figure (2): Replica of celtra press crown showing measuring points.

Cementation of the restorations:

According to the manufacturer's instructions for Celtra Press, the crowns were ultrasonically cleaned and the inner surface was etched for 60 seconds with 9% hydrofluoric acid gel (Porcelain etch, Ultradent Products, UT, United Stated) then silane treated (Porcelain silane, Ultradent Products, UT, United Stated) according to the manufacturer's recommendation. The ceramic crowns were cemented onto their corresponding dies using self-adhesive resin cement (Calibra universal resin cement, Dentsply) under a 5kg constant load, the cementation process followed the manufacturer's instructions.

Post cementation marginal gap measurements
The marginal gaps of all specimens were measured after cementation on the same previously made device with the same magnification and at the same landmarks along the circumference for each surface.

Statistical analysis:
All resulted data were collected, tabulated and then subjected to statistical analysis using IBM SPSS Corp (released 2013. IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp). Qualitative data were described using number and percent. Quantitative data were described using mean, standard deviation for parametric data after testing normality using Shapiro-Wilk test. Significance of the obtained results was judged at the 0.05 level.

1. One Way ANOVA test was used to compare more than 2 independent groups with Post Hoc Tukey test to detect pair-wise comparison
2. Repeated Measures ANOVA test was used to compare more than 2 studied periods with post Hoc test Tukey test
3. Two Way ANOVA test for detection of combined effects on dependent outcomes.

IV. Results:

Marginal gap measurements:
Overall marginal gap (µm) among the wax pattern groups, pre-cemented and post-cemented Celtra press groups were shown in (**Figure.3)**

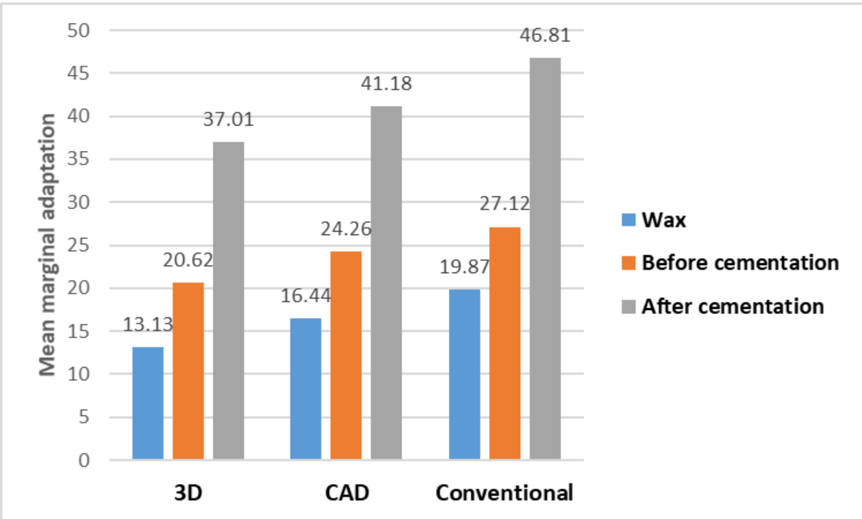


Fig (3): Comparison of marginal gap measurements between the 3 studied groups of wax and Celtra press crowns before and after cementation.

In the wax pattern measurements: The highest mean marginal gap value was found in group **C** (19.87±1.30µm), followed by group **S** (16.44±0.25µm) while the lowest value was found in group **A** (13.13±0.204 µm), Post-hoc test (LSD) revealed a statistical significant difference (P<0.001) (F= 454.23) between the 3 studied groups.

In the pre-cementation measurements: The highest mean marginal gap value was found in group **C** (27.12±0.45µm), followed by group **S** (24.26±0.43µm) while the lowest value was found in group **A** (20.62±0.47 µm), Post-hoc test (LSD) revealed a statistical significant difference (P<0.001) (F=1248.41) between the 3 studied groups.

In the post-cementation measurements: The highest mean marginal gap value was found in group **C** (46.81±0.36µm), followed by group **S** (41.18±0.86 µm) while the lowest value was found in group **A** (37.01±0.26 µm), Post-hoc test (LSD) revealed a highly statistical significant difference (P<0.001) (F=1883.0) between the 3 studied groups.

The degree of marginal gap enlargements of the pre-cemented Celtra crowns compared to the marginal gap of wax pattern showed a relatively uniform increase percentage. Also this percentage increased by a fixed rated between the three studied groups before cementation compared to their corresponding group after cementation.

Two-way ANOVA test was used to assess the effect of different wax pattern fabrication techniques and cementation on marginal adaptation of Celtra press crowns, it indicated that wax pattern fabrication technique has a statistical significant different on the marginal adaptation of Celtra press crowns (P<.001) (F=2865.019). Cementation also affected the marginal gap results significantly as indicated where marginal gap increased after cementation than before cementation (P<.001) (F=32503.508). The interaction between methods of wax pattern fabrication and cementation process showed a statistical significant difference (P<.001) (F=62.000).

Internal fit measurement results:

Statistical analysis including the mean, standard deviation of the overall internal adaptation (µm) among Celtra press crowns constructed by different wax pattern techniques are shown in **Table-1.**

	C	S	A	test of significance	Within group significance
Internal fit	**$31.27^a \pm 11.49$**	**$27.29^b \pm 10.41$**	**$23.59^c \pm 10.05$**	**F=9.32 P<0.001***	**P1= 0.038* P2<0.001* P3=0.027***

Similar superscripted letters denotes non-significant difference between groups with Post Hoc Tukey test.

p1: difference between A & S, p2: difference between A and C, p3: difference between S & C.

The results of the internal fit measurements followed the same pattern of the marginal gap distance, the highest mean internal gap value was found in group **C**, followed by group **S** while the lowest value was found in group **A**. Post-hoc test (LSD) revealed a statistical significant diff erence between the 3 studied groups.

Two-way ANOVA test was used to assess the effect of different wax pattern fabrication techniques and measuring sites on internal adaptation of Celtra press crowns. It indicated that wax pattern fabrication techniques has a statistical significant different on the internal fit of Celtra press crowns (P=.001) (F=110.369). The measuring sites in the replica has a statistical significant different on the internal adaptation of Celtra press crowns (P=.001) (F=83.196).The interaction between methods of wax pattern fabrication and measuring sites showed a statically significant difference (P=.001) (F=3.524).

V. Discussion:

There is a shortage in the literature regarding the fit of wax pattern and Celtra press restoration made by different wax pattern techniques, the purpose of this study was to evaluate the marginal and internal adaptation of Celtra press restoration according to wax pattern fabrication techniques (conventional, subtractive and additive). The hypothesis of this study was that the wax pattern fabrication technique would affect marginal and internal gap of Celtra press crowns restoration. The null hypothesis was accepted, as there were statistical significant differences in the marginal fit and internal gap between the three methods of wax pattern fabrication.

Discussion of the methodology:

Natural teeth exhibit large variations, due to their dimensions, age, individual structures, and storage time after extraction, creating difficulties in obtaining standardized abutments.[13] To overcome these variations and to achieve a standardized preparation for all specimens, 30 identical replicas of the prepared maxillary premolar were printed with 3D printer using printing resin.[14]

For group **C**, 2 layers of die spacer were applied to achieve a thickness of 30 µm. After wax pattern fabrication, the die spacer on group **C** specimens was removed with steam cleaner to provide a cement space of 30 µm similar to **S** and **A** groups. The wax pattern was built to the full contour of upper first premolar guided by the previously made putty index which was made on the tooth before preparation.

In the **S** and **A** wax pattern groups, the tooth was scanned before preparation and the scanned file was used as a reference to reproduce the subtractive and additive wax patterns with an identical anatomy to the original tooth as group **C**. each printed resin die was scanned to ensure that there is no dimensional changes occurred during curing and finishing of the 3D printed resin which may affect the marginal fit of the wax pattern. The STL file of the scanned die was subtracted from the STL file of the un-prepared tooth and the resultant STL file was used for the subtractive and additive wax patterns designing.

Celtra press is the material of choice in this study as it is a new addition to the lithium silicate glass ceramic material which has a great acceptance and use. It has high percentage of glass matrix which offers translucency, natural appearance and shades combined with high mechanical properties due to the addition of 10% zirconia (ZrO_2),[15] it is an etchable ceramics material with excellent flow properties during pressing. The manufacturer has introduced a new investment material used for Celtra press with minimal reaction layer formation, leading to an excellent fit and shortening the time required for finishing, as the surface etching step is eliminated.[16]

To ensure standardization of the circumstances surrounding the specimen during investing and pressing, 2 wax patterns from each group were inserted in the same investing ring.

The tested parameters were the marginal and internal fit, since a good marginal fit is one of the most important factors for the durability of any restoration.[17] The internal fit is a clinically important factor and can influence the strength of the cement system of the crown**.**[18] A large and inhomogeneous internal gaps may negatively aff ect the retention and resistance of the restoration.[19]

The direct measurement technique under digital microscope with image analysis software allowed for non-destructive quantification and multiple measurements of the gaps.[20]

A specially designed holding device was constructed to aid in handling of specimens during gap assessments. Thereby standardizing the all the parameters of measuring the marginal gap.

The replica technique was used for quantitative analysis of the internal adaptation as it is a non-destructive approach, relatively economice and less time consuming.[21]

Marginal gap measurements in this study were conducted in wax pattern stage and Celtra press stage (before and after cementation) as there were no previous studies evaluated the marginal fit of the wax pattern itself with different fabrication techniques. Vertical marginal gap was measured for Celtra press crowns fabricated by different wax pattern techniques before cementation to eliminate the possibility of marginal errors from underlying thickness of the cement and to allow for determination of a system's intrinsic precision. Each crown was cemented on it is corresponding die to simulate the clinical condition and to study the relative impact of cementation on the marginal fit, all specimen were loaded with the same weight.

Calibra Universal self-adhesive resin cement was used for bonding of the Celtra crowns to the resin dies as recommended by the manufacturer of Celtra press.

Discussion of the results:

Marginal gap results of the wax patterns showed that, the highest mean marginal gap value was found in group **C** (19.87±1.30µm), followed by group **S** (16.44±0.25µm) while the lowest value was found in group **A** (13.13±0.204µm) with a statistical significant diff erence between the three groups.

The high marginal gap value of the wax pattern in group **C** may be due to the manual production procedure which depends on the ability of skilled technicians. Also removing the wax pattern from the resin die several times to check the margins before and after margination can cause widening of the pattern and because the wax is glossy, small defects can be difficult to identify. The material itself has some inherited drawbacks, such as delicacy, thermal sensitivity, elastic memory and a high coefficient of thermal expansion,[22] which contribute to the adverse effects on the final restoration. When a wax pattern was removed from a die with a shoulder margin, the margin opened before investing with an average of 35µm as reported by **Zelster et al**.[23]

The enhanced adaptation of the group **S** in relation to group **C** may be due to the elimination of thermal changes, technical errors and human variability. The precision fit of the restoration's inner surface in the subtractive group also depends on the size of the smallest cutting tool available in the system for each material. If the diameter of the cutting tool is greater than that of some parts of the tooth preparation, the CAM system faces the problem of cutting the parts or not cutting them. This leads to a decrease in internal fit accuracy and inferior marginal properties, respectively.[24]

The enhanced adaptation for the group **A** wax pattern may be due to the newer light cured wax-filled methacrylic material which is recommended as pattern forming materials to overcome the shortcomings of wax. it offers strength, rigidity, and dimensional stability if immediate investment is not possible with increased precision and stability after light polymerization.[25]This could be due to the 3D printed software that compensates for polymerization shrinkage and improves accuracy without any risk of manual errors during the manufacturing process.[26,27] The results of the wax pattern could not be evaluated with other studies as there is no previous studies evaluated the marginal gap of the wax pattern itself.

Marginal gaps results of pre-cemented Celtra press crowns showed that the highest mean marginal gap value was found in group **C** (27.12±0.45µm), followed by group **S** (24.26±0.43µ)**,** while the lowest value was found in group **A** (20.62±0.47µm) with a statistical significant diff erence between the three groups. The degree of marginal gap enlargements of the pre-cemented Celtra crowns compared to the marginal gap of wax pattern showed a relatively uniform increase percentage. This may be attributed to the standardization of the circumstances around wax pattern during investing and pressing by inserting 2 wax patterns from each group in the same investing ring.

The highest mean marginal gap value of post-cemented Celtra press crowns was found in group **C** (46.81±0.36µm)**,** followed by group **S** (41.18±0.86µm), while the lowest value was found in group **A** (37.01±0.26µm**)** with a statistical significant diff erence between the three groups.The marginal discrepancies were significantly increased after cementation in each group under this study, which may be due to the increase in hydraulic pressure of the resin cement. **Wolfart et al (2003)**,[28]supported the outcomes of this study, as they found a significant increase in the marginal discrepancies after cementation and attributed this to the viscosity of the luting cement used that could affect the restoration seating.

There is a fixed increase in the percentage of difference in the marginal gaps between the three studied groups before cementation with their corresponding groups after cementation .This may be due to bonding of all specimens with the same resin cement and under the same weight, and thus confirmed that the technique of wax pattern construction is the main and only reason for the differences founds between the three studied groups in the vertical marginal gap.

In this study, all three classes of crown restorations fabricated by different wax pattern techniques could be classified as good fitting restorations as the marginal gaps were less than 120 µm which is reported as a clinically acceptable range.[29]

Regarding the internal adaptation results, group **A** recorded better adaptation (23.59±10.05µ) than both **S** (27.29±10.41µm) and **C** group (31.27±11.49µm) with a statistical significant difference between the three groups. This might be related to the recent development in designing software in the subtractive and additive groups which has superior features related to automatic identification of the margins of the restorations in comparison to earlier systems. All mean values of the internal gaps reported in the current study were clinically acceptable.[30]

Results of this study were in agreements with those of **Eswaran et al (2013),[31]** who reported that the vertical marginal gaps of the Co-Cr copings obtained by three wax pattern manufacturing techniques (conventional, subtractive and additive) have statistical significance difference to each other as in the current study in spite of using Co-Cr copings, St-Steel model die and video measuring system. Also **Fathi et al (2016),[32]** reported that the marginal and internal fit of metal crowns fabricated with 3D printed wax pattern is more accurate than the other two production methods (conventional and subtractive), which are quite similar to the findings of the current study in spite of using stone dies, metal crowns, different cement gap thickness and measuring with sectioning technique . The results of this study were not coincident with those of **Shamseddine et al (2016),[33]** who reported no significant difference between marginal and internal fit of lithium disilicate crowns made with conventional waxing versus subtractive waxing fabrication techniques. This may be due to using stone dies, different ceramic material, and measuring with SEM. Also, the results were not coincident with those of **Homsy et al (2018)[34]** who reported that the marginal and internal fit of lithium disilicate glass-ceramic inlays fabricated by 3D printed wax patterns yielded fit values similar to those made by the conventional technique, while the subtractive wax patterns resulted in better marginal and internal fit accuracy than either conventional or 3D manufacturing, this may be due to the use of stone dies, different ceramic materials and inlay restorations.

Research limitations:

The limitations in this study were:

1. Cemented crowns were not subjected to thermal cycling, which is one of the significant variables influencing the restorations' long-term marginal fit.
2. For the calculation of marginal and internal fit, standardized dies were used; however the use of human teeth would be suitable for simulating the clinical procedures.
3. The study was carried on one type of ceramic material.

VI. Conclusions:

Under the limitations of this *In-Vitro* study, it could be concluded that:

1. Wax pattern fabrication technique is crucial for the accuracy of the final restoration.

2. 3D printed wax pattern construction technique resulted in the highest marginal and internal adaptation of crown restorations compared with conventional and subtractive techniques.

3. All techniques developed for wax pattern fabrications (Conventional, subtractive and additive) produced crown restorations with clinically acceptable marginal and internal fit (< 120µm).

VII. Recommendations:

Under the limitations of this study;

1. Whenever excellent marginal and internal fit is needed, using of additive wax pattern manufacturing technique is recommended.
2. Further *In-vivo* studies are recommended to investigate marginal and internal adaptation of different ceramic restorations fabricated by different wax pattern techniques. Other methods for measurement of the internal gap beside the replica technique like micro-computed tomography could be advice in order to increase the reliability of the measurements.

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