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Evaluation of Marginal Accuracy of PEEK Vs. Lithium Disilicate Single Crowns Constructed By Two Fabrication Techniques: CAD/CAM And Heat Press (In-Vitro Study)

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ABSTRACT

Background: Metal-ceramic restorations were considered the gold standard; however, all-ceramic restorations gained popularity owing to their remarkable properties. ***Purpose:*** To evaluate the marginal accuracy of IPS e.max and PEEK Bio.HPP monolithic crowns constructed by two fabrication techniques (Heat Press and CAD/CAM). ***Materials and methods:*** Twenty monolithic crowns were divided into two equal groups according to the materials used. **Group E:** Lithium disilicate crowns and **Group P:** PEEK BioHPP crowns. Each group was further subdivided into two equal subgroups according to the fabrication technique with five crowns per subgroup (n=5). **Subgroup H:** Heat Press technique and **Subgroup C:** CAD/CAM technique. A biogeneric copy STL file was generated biogeneric and sent to a 5-axis CAM machine to mill identical IPS e.max, PEEK BioHPP, and wax patterns. IPS e.max and PEEK Bio.HPP crowns were then heat-pressed using the milled wax patterns. The vertical marginal gap (VMG) distance was evaluated for each crown surface at five predetermined equally distributed points using the direct view technique. ***Results:*** There was no statistically significant difference in the VMG distance between IPS e.max (23.1±2.8µm) and PEEK Bio.HPP (24.4±1.6µm) crowns. Crowns heat-pressed from IPS e.max ingots (23.1±2.8µm) and PEEK Bio.HPP pellets (24.4±1.6µm) showed a lower statistically significant mean VMG distance than the crowns CAD/CAM milled from IPS e.max blocks (29.5±3.2µm) and PEEK Bio.HPP blanks (30.2±1.4µm). ***Conclusion:*** IPS e.max and PEEK crowns fabricated using either technique showed clinically acceptable results, meanwhile the heat-pressing technique showed better marginal adaptation when compared to milled crowns.

Keywords: Marginal gap, lithium disilicate, PEEK Bio.HPP, fabrication techniques, fit.

INTRODUCTION

Metal-ceramic restorations were considered the gold standard used in clinical practice. However, all-ceramic dental restorations surpassed porcelain fused to

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metal system in terms of their properties, especially the esthetic appearance. Several modifications in dental ceramics have been made to achieve clinically acceptable restorations without compromising aesthetics.[1-3]

Lithium disilicate is a ceramic material that gained popularity in the last decade. Lithium disilicate is supplied in two forms, ingot for the heat-pressing technique or as a block for CAD/CAM machining. Its remarkable ability in mimicking natural dentition makes a seamless transition with adjacent oral structures. Its modulus of elasticity (60-70GPa) is close to that of enamel (40-80GPa); however, it is still far beyond that of bone and dentin (7- 30GPa).[1–8]

PEEK Bio.HPP is a ceramic-filled polyetheretherketone (PEEK) thermoplastic polymer. It was preliminarily manufactured for dental prosthetic use. Their modulus of elasticity of 4GPa is comparable to that of the dentin and spongy bone. This makes it a material option for endocrowns, crowns, and bridges. It is supplied in the form of blanks and prefabricated granules and pellets for the CAD/CAM and the heat pressing techniques of fabrications, respectively.[9–16]

The fit of dental restorations is a vital marker in predicting the longevity of dental restorations, hence, the clinical success. Thus, it acts as a fundamental component for evaluating indirect dental restorations. The gap between the tooth and restoration, if enlarged, renders an ill-fitting restoration which reflects in its imprecise seating and the uneven thickness of the luting cement layer beneath it. A large discrepancy accelerates cement dissolution, hindering the interface susceptible to discoloration, microleakage, and plaque accumulation, and resulting in gingival irritation, recurrent caries, and consequently pulpal disease. The amount of misfit is directly proportional to recurrent caries and periodontal disease, and therefore jeopardizes the restoration's lifespan.[17–21]

There are several factors during restoration manufacturing that may negatively influence its fit. These includes the preparation design, impression technique, cement gap space, material processing and manufacturing, type of material used, core thickness, wax pattern manufacturing, cementation procedure, and veneering and glaze layer application.[20,22–48]

To quantify the fit, the restoration's VMG is measured. **McLean J and von Fraunhofer J**[49] concluded that most restorations with marginal discrepancy ≤120μm are highly probable to be successful, rendering it the clinically acceptable value.

However, there is no consensus on the clinically acceptable marginal gap. The clinically acceptable values have a wide range as they are highly dependent on the fabrication technique used to make the restorations.[19,21,50,51]

One of the major factors affecting the fit of the restorations is the fabrication techniques. The conventional heat-pressing technique provides homogenous and non-porous restorations. Technology developments added new options to the dental prosthetic field. CAD/CAM is an automated subtractive three-dimensional (3D) fabrication of an object with the aid of computer numerical control (CNC) machines. It reduces chair time and enhances the accuracy of workflow.[52–56]

There are limited studies evaluating the fit of PEEK Bio.HPP crowns, and the influence of different fabrication techniques on its overall fit. This study aims to assess the effect of different manufacturing techniques on the marginal adaptation of IPS e.max and PEEK Bio.HPP single crowns, and to compare the marginal adaptation of IPS e.max crowns with that of PEEK Bio.HPP single crowns.

In this study, the proposed null hypothesis was that there will be no difference in the marginal accuracy between lithium disilicate (IPS e.max) and PEEK (Bio.HPP) crowns using the two different techniques (Heat-Press and CAD/CAM).

MATERIALS AND METHODS

A stainless-steel metal die was fabricated to simulate the preparation design of a mandibular first molar to receive a ceramic crown. The die was milled using Computer Numerical Control (CNC) machine (CNC lathe machine, Compact 5, EMCO Maier, Austria) with 6º taper, a 1mm deep shoulder finish line, a flat occlusal surface, and a 4.5mm height extending from the finish line to the occlusal surface.[26,57–69]

The die was stabilized on a resin cube milled using a CNC milling machine with a centralized hole of 4mm depth. The walls of the hole were designed to be parallel to the long axis of the base to allow the insertion of the die with a frictional fit. To standardize the placement of the crowns on the die, contralateral rectangular and semi-circular grooves were made on the top surface of the base as illustrated in **Figure (1)**.[70,71]

A power analysis of 2 x 2 fixed effect analysis of variance was used. The first factor is the material type and the second factor is the fabrication technique. Each factor includes two levels. The outcome is vertical marginal gap distance. Based on the results of **Azar et al.**[20] and **Riccitiello et al.**[22] studies in

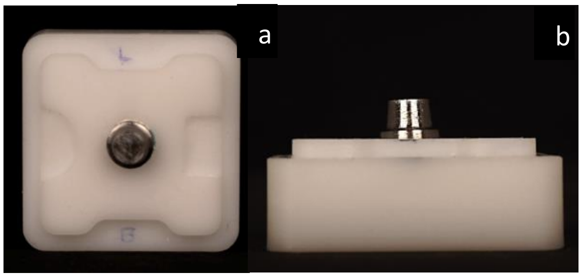

Figure 1:
a. Top view showing contralateral rectangular and semi-circular grooves.
b. Side view of the resin base and the fixated metal die.

2018 the effect sizes of the two factors were 2.25 and 17.8, respectively. These effect sizes were obtained assuming that the alpha (α) level is 5% and the Beta (β) level is 20% which corresponds to 80% power and 5% significance. Thus, the minimum estimated sample size was 5 crowns per cell giving a total of 20 crowns.

Samples were divided equally according to the material used into two groups, lithium disilicate **(E)** (IPS e.max¸ Ivoclar Vivadent AG, Germany) and PEEK BioHPP **(P)** (BioHPP, Bredent GmbH & Co. KG, Germany) crowns. Each group was subdivided equally according to the method of fabrication heat press technique **(H)** and CAD/CAM **(C)**. A total of four groups **(EH, EC**, **PH**, and **PC** (n=5).[72] **(Table 1)**

To digitize the die, it was sprayed with an anti-reflection fine-grained scanning powder (SHERA-Scan spray, Germany). For standardization, the spray's nozzle was fixed at a distance of 50 cm and each surface was sprayed for 3s. The die was then scanned and the acquired STL data set was transferred to CAD designing software (Exocad Dental CAD 2.2 software, Germany).[73–75]

For standardization, a biogeneric copy was designed with a thickness of 2mm occlusally, 1.5 mm axially, 1mm at the margin, and a minimum thickness and cement space of 1mm and 50 µm, respectively. The margin thickness was enhanced by 0.1mm. The restoration fit was analyzed and conformed on the virtually scanned die.[51,64,76,77]

The generated biogeneric copy STL file was sent to a 5-axis CAM machine (CORiTEC 250i Loader PRO, imes-icore GmbH, Germany) to mill identical lithium disilicate (IPS e.max CAD¸ Ivoclar Vivadent AG, Germany), PEEK BioHPP (breCAM.BioHPP, Bredent GmbH & Co. KG, Germany), and wax patterns as shown in **Figure (2)**.[34]

Figure 2: Milled crown showing the design.

Table 1: Sample grouping.

Type of material (Group)	*Fabrication technique (Subgroup)*		
	Heat Press (H)	CAD/CAM (C)	Total
Lithium disilicate (E)	**EH** n=5	**EC** n=5	n=10
PEEK BioHPP (P)	**PH** n=5	**PC** n=5	n=10
	n=10	n=10	n=10

Following the manufacturer's instructions, wax blocks (VITA CAD-Waxx, VITA Zahnfabrik H. Rauter GmbH & Co.KG, Germany) were used to mill wax patterns. After milling and finishing, wax pattern remargination was done with red margin wax (Margin wax, Avtek, USA). The margins were visually checked on the prepared die. Consecutively, the wax patterns were attached to a sprue former of a 4mm length and diameter. For investing, the crowns were then fixed by wax in the funnel former.[78,79]

Randomization of the CAD/CAM milled wax patterns were done using Statistics Data Editor software (IBM SPSS Statistics Data Editor software (Version 20.0), IBM Corp., USA). The wax patterns were coded and the data were input into the software datasheet. The "50% Random sample of cases" feature was selected to divide the wax patterns equally and randomly. The divided patterns were used for the heat-pressing of lithium disilicate and PEEK BioHPP monolithic crowns.

Wax patterns were then invested and burnout. The muffle was then placed in a pressing furnace (Programat P310 G2, Ivoclar Vivadent AG, Germany). The material used was selected and pressed using a preset pressing program. IPS e.max ingots and PEEK Bio.HPP pellets were filled in the investment mold with a plunger to press IPS e.max and PEEK Bio.HPP crowns, respectively. Crowns were then divested with aluminum oxide particles of size 110µm.[80]

Crown margins were visually checked on the prepared die and then finished and polished following the manufacturer's instructions. After polishing, CAD/CAM milled IPS e.max crowns were crystallized in the ceramic furnace.[5,81–84] All the crowns were then cleaned for 5min in an ultrasonic cleaner (Ultrasonic T14, L&R manufacturing, USA). Crowns were coded and numbered to eliminate bias during the testing procedure.[21,25,85–87]

To measure the VMG distance, the direct view technique was used. The metal die has a cylindrical geometry without anti-rotational features; thus, a placement key was fabricated using putty (Aquasil Ultra+ Smart Wetting Putty Impression material, Dentsply Sirona. Inc., Canada.) and light-viscosity PVS impression (Aquasil Ultra+ Smart Wetting LV Impression material, Dentsply Sirona. Inc., Canada.) materials to record the placement of the crowns on the die. The contralateral geometrical grooves that were previously made on the resin base were also recorded. This procedure was repeated twice. One impression was sectioned buccolingually, whilst the other was sectioned mesiodistally. Each putty section acted as a placement key during the examination of its contralateral side as seen in **Figure (3)**. A stainless-steel stabilizing jig was specially designed with a holding screw and a stabilizing resin block to hold the crown in its correct position as illustrated in **Figure (4)**.[88]

To assess the marginal fit of the dental restoration, a USB Digital microscope with a built-in camera (U500x Digital Microscope,

Figure 3: Mesial placement key placed during the examination of the crown's distal surface.

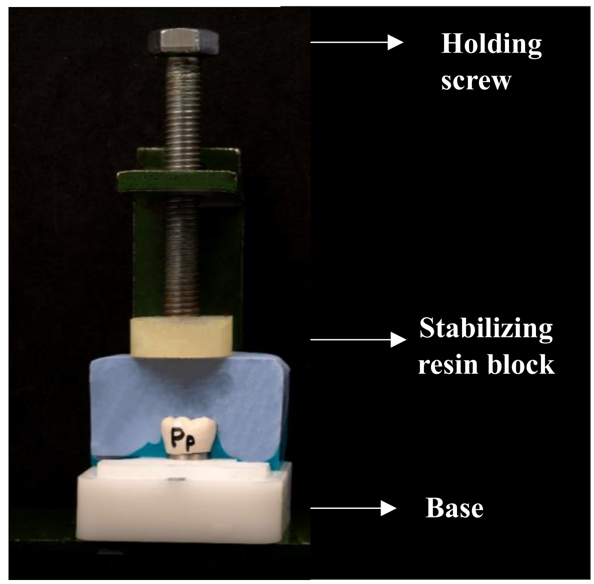

Figure 4: Stainless-steel stabilizing jig with a holding screw holding the crown in its correct position with the aid of a placement key on the base plate.

China) of 3 Mega Pixels resolution attached to a compatible IBM computer was used. The crown was seated on the model using the impression keys and screwed by the stabilizing jig. The assembly was then placed on a point marked on the microscope base plate. The generated images were recorded with a resolution of 1280 x 1024 pixels and imported to a digital image analysis special software (Image J 1.43U, National Institute of Health, USA) to measure the VMG (Vertical Marginal Gap) of crowns.[88]

The software measured and evaluated the VMG between the outer extremities of the preparation finish line and the restoration's margin. For each crown surface, morphometric measurements were taken at five predetermined equally distributed points (the midline, line angles, and a midpoint in between the midline and each line angle) as shown in **Figure (5)**. A total of 20 points were recorded per crown.[21,85]

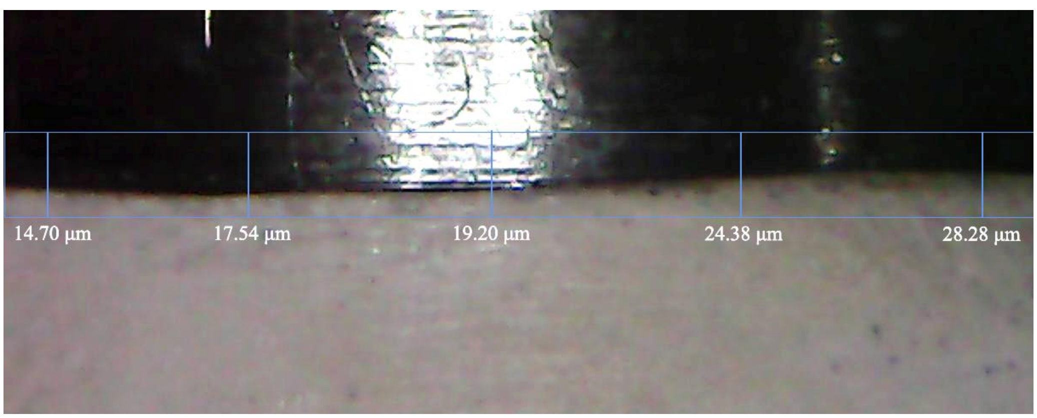

Figure 5: Marginal gap readings of heat-pressed PEEK Bio.HPP crown (PH).

To standardize the procedure, all the crowns were measured under invariable parameters. For verification, each measurement was repeated three times and the mean value was recorded. The data collected was analyzed, tabulated and subsequently sent for statistical analysis.

Statistical analysis

Numerical data were checked for normality by the distribution of data and using Kolmogorov-Smirnov and Shapiro-Wilk normality tests. All data showed normal parametric distribution. Data were presented as mean and standard deviation (±SD) values. A two-way ANOVA test was used to study the effect of material type, fabrication technique, and their interactions on mean VMG distance. Bonferroni's post-hoc test was used for pair-wise comparisons when the ANOVA test is significant. The significance level was set at $P \leq 0.05$. Statistical analysis was performed with statistics software (IBM SPSS Statistics for Windows, Version 23.0., USA).

RESULTS (Table 2) (Figure 6)

There was no statistically significant difference between the mean VMG distances of IPS e.max (23.1±2.8µm) and PEEK Bio.HPP (24.4±1.6µm) monolithic crowns fabricated using the heat-press technique and the IPS e.max (29.5±3.2μm) and PEEK Bio.HPP (30.2±1.4μm) crowns fabricated using the CAD/CAM fabrication technique.

distance than the crowns CAD/CAM milled from IPS e.max blocks (29.5±3.2μm) and PEEK Bio.HPP blanks (30.2±1.4μm). (*P*-value = 0.795, Effect size = 0.004)

Table 2: Comparison between the monolithic crowns VMG distance in μm using the heat-press and CAD/CAM fabrication techniques with different interactions of variables using two-way ANOVA test.

Material used	Heat-Press		CAD/CAM		*P*-value	Effect size *(Partial eta squared)*
	Mean	±SD	Mean	±SD		
IPS e.max	23.1	2.8	29.5	3.2	0.028*	0.248
PEEK Bio.HPP	24.4	1.6	30.2	1.4	0.020*	0.3

**: Significant at P ≤ 0.05.*

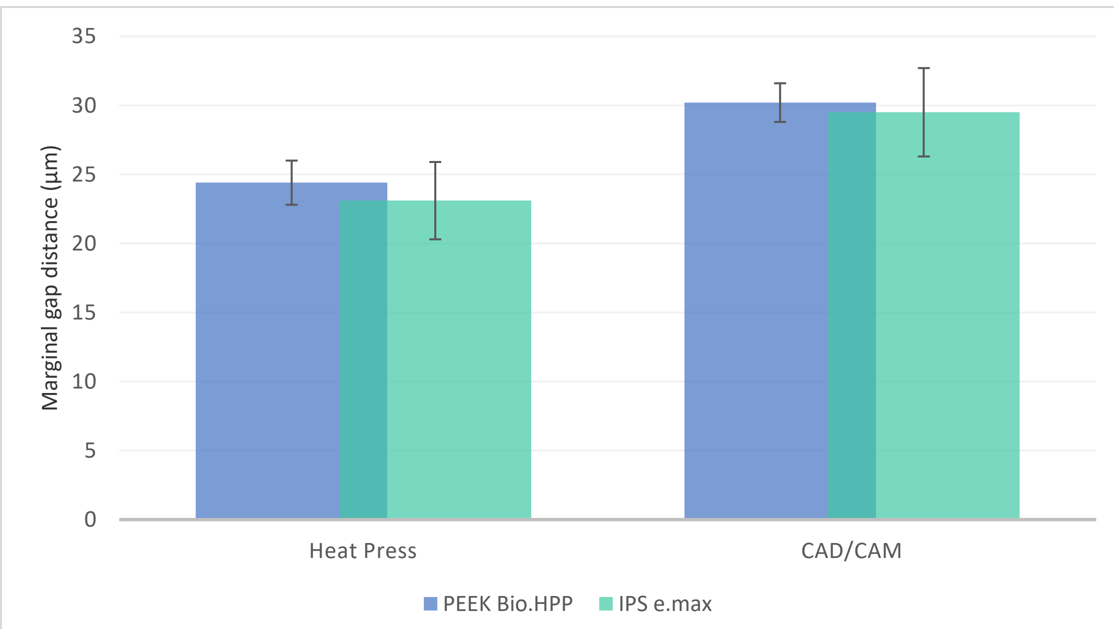

Figure 6: Bar chart representing the monolithic crowns VMG distances in μm with different interactions of variables using mean and standard deviation values (±SD).

The crowns heat-pressed from the IPS e.max ingots (23.1±2.8μm) and PEEK Bio.HPP pellets (24.4±1.6μm) showed a lower statistically significant mean VMG

DISCUSSION

This study aims to assess the influence of two fabrication techniques (heat-press and CAD/CAM) on the VMG distance of monolithic lithium disilicate and PEEK Bio.HPP single crowns.

Metal dies were used as they have a higher wear resistance and can withstand the repeated seating of the crowns during measurements. Additionally, the color contrast between the metal die and the crowns helped in the VMG distance measurement when viewed under the microscope. The metal die was milled using a CNC milling machine to ensure a standardized uniform finish line all around.[68]

To standardize the preparation design, the preparation guidelines of lithium disilicate restorations were used to mill the cylindrical die. The die taper was set to 6˚ as it is the clinical gold standard for ideal preparation. The height of the metal die was set to 4.5mm with a flat occlusal surface simulating an average size of a mandibular first molar with a 2mm occlusal reduction. Studies showed that the flat occlusal design has a better mean marginal fit and allows for an even distribution of the seating force compared to the anatomic planar occlusal design.[24,26,57,61,69]

A deep shoulder finish line was used in this study as it showed superior marginal adaptation compared to other finish line designs. This is attributed to the rounded gingivo-axial surface which allows for accurate crown seating. A 1mm margin thickness was used to avoid marginal chipping and horizontal fractures in the materials. A flat non-anatomic finish line was used to counteract the effect of the variation in the sintering shrinkage between different steepness along the margin curvature.[23,27–29,31,44,67,89–92]

For standardization, a fully digital approach was implemented as it yields restorations with remarkable marginal accuracy compared to conventional workflow. It also offers repeatable highly accurate restorations. To obtain an accurate scan, a scan spray was used to mattify the shiny metal surface.[20,34,74,93–95]

Exocad designing software was used to design a biogeneric copy of a monolithic mandibular molar. This designing software was used as it has an embedded library that offers a variety of choices as it has myriad teeth forms and outlines. This design was used to negate the negative influence of veneering on the crown's VMG distance as the firing heat shrinkage impedes the restoration's marginal adaptation.[32,47,96]

The cement space was set to 50µm, as it offered the least VMG discrepancy and the most repeatable and reliable marginal fit values. The crowns' margin thickness was horizontally enhanced by 0.1mm to reduce their marginal chipping during CAD/CAM milling. For standardization and to obtain identical crowns, CAD/CAM milled crowns for (**EC)** and **(PC)** groups and the wax patterns for the heat-press groups **(EH)** and **(PH)** were milled using a 5-axis milling machine as it has superior accuracy.[25,34,47,51,97–100]

To eliminate bias, randomization software was used to equally and randomly divide the milled wax patterns into two equal groups **(EH)** and **(PH)**. They were then invested and heat pressed in a lithium disilicate and PEEK Bio. HPP -specific heat cycle. This was done to ensure that the whole process was computerized and meticulously controlled with the highest precision.[2,3,38,45,46,77]

PEEK Bio.HPP was heat-pressed in the form of pellets as they showed restorations with higher mechanical properties and fewer fragmentary fractures compared to others heat-pressed from granules. IPS e.max CAD blocks were milled in their "blue state" as partially crystallized lithium disilicate blocks aid for easier and stabilized milling which offers better marginal adaptation for the milled restorations.[8,38,39]

Crowns were not cemented on the master die as the type and amount of cement used may constrain their full seating owing to the hydrostatic pressure. The direct view technique was used to evaluate the VMG distance. It was favored over other methods of measurement as it is a non-destructive technique that has minimal technique sensitivity and produces repeatable results. Corresponding to this, a digital microscope was used to evaluate the VMG distance of the monolithic crowns.[27,48,85,89]

As the die's design is cylindrical, impression placement keys and a stabilizing jig were used to contravene the crown's rotational movement and to standardize the placement of all the crowns on the die. The stabilizing jig also locked the placement key on the crown and model during the VMG assessment.

Five equidistant points were recorded for each crown surface making a total of 20 points per crown and 100 points per sample group. Following **Groten et al.**[21] recommendation, 20-25 points per sample are considered sufficient for the restoration's VMG assessment. The results were then collected and statistically analyzed.

The null hypothesis was partially rejected. The study findings showed no statistically significant difference between the VMG distance of crowns fabricated from IPS e.max and PEEK Bio.HPP materials, whereas the fabrication techniques (heat-press and CAD/CAM), showed a statistically significant difference in the VMG distance of the fabricated crowns.

This could be attributed to the difference between the two material's microstructures and the manufacturer's form of supply.[6,43,96,101]

IPS e.max ingots and blocks are supplied by the manufacturer with different crystalline forms and arrangements. The processed ingots are composed of ~70% vol. scattered 3µm–6µm long needle-like crystals in a glassy matrix. Unlike heat-pressable ingots, CAD/CAM blocks constitute ~60% nano-lithium orthophosphate nuclei and uniformly dispersed metasilicate platelet-like crystals with sizes ranging between 0.2µm- 1.0µm.[1–5]

Hence, it is essential to expose CAD/CAM milled restorations to a crystallization cycle to allow for the transformation of nano-lithium orthophosphate nuclei and lithium metasilicate crystals into ~70% vol. 1.5µm interlocked rod-like lithium disilicate crystals. This crystal transformation causes 0.2% linear volumetric shrinkage of the restorations. The heat-pressed lithium disilicate restorations do not require an additional crystallization cycle.[1–3,5]

During, the crystallization cycle, the crystallization process initiates shrinkage at the core of the crown and propagates to the occlusal and marginal regions. This distorts the material and impacts the VMG distance of the crowns negatively. This is translated by an increase in the mean VMG distance of the CAD/CAM milled IPS e.max crowns compared to that of the heat-pressed IPS e.max crowns.[71,102]

These findings go in agreement with **Anadioti E and Holloway J**[103] study in 2014, **Mounajjed R et al.**[104] study in 2016, and **Azar B et al.**[20] study in 2018. This also confirms the findings of **Kim J et al.**[36] study in 2016 that showed a statistically significant difference in the VMG distance of CAD/CAM milled IPS e.max crowns before and after the crystallization cycle exposure.

Contradicting results were also found by **Dolev E et al.**[19] study in 2019. They found that CAD/CAM milled lithium disilicate crowns had a lower absolute marginal discrepancy compared to those heat-pressed using the same material. The difference in the results may be because all the crowns were cemented before being sectioned and the wax patterns were manually fabricated using a 60µm spacer thickness.

Mostafa N et al.[34] study in 2018 also found controversial results. Their study found that the CAD/CAM milled lithium disilicate crowns had less VMG distance than the heat-pressed lithium disilicate crowns. This may be because they used an ivorine die simulating a maxillary premolar with an anatomic finish line and planar occlusal anatomy.

PEEK Bio.HPP is a semicrystalline polymer with a ceramic-filled matrix. Owing to its polymeric nature and the absence of the glass matrix, it does not require a crystallization cycle.[105]

Even though the difference was statistically insignificant, heat-pressed PEEK Bio.HPP crowns showed higher mean VMG value compared to heat-pressed IPS e.max crowns. This goes back to the difference between the two material's resistance to flow which is a crucial parameter for heat-pressing. Heat-pressed IPS e.max has remarkable flowability and compressibility owing to its small crystal size. On the contrary, thermoplastic materials need to be exposed to higher temperatures during heat-pressing which induces deformation. However, PEEK Bio.HPP has a high molecular weight and a complex chemical composition, which causes an increase in its viscosity and hence impedes its flow into small areas.[96,106]

This also justifies the increase in the mean VMG distance value of the heat-pressed PEEK Bio.HPP crowns compared with that of the CAD/CAM milled PEEK Bio.HPP crowns. This difference showed statistical significance.

Controversial results were found by **Osman A et al.**[96] study in 2022. Their study found that PEEK Bio.HPP showed superior marginal adaptation compared to IPS e.max endocrowns. This controversy may be because the study used PEEK granules instead of pellets. The study also used PEEK Bio.HPP cores were layered with composite and glazed monolithic IPS e.max endocrowns. The exposure to an additional heat cycle and the bilayered design may have affected the results of the IPS e.max and PEEK Bio.HPP.

The heat-pressed monolithic crowns showed a lower mean VMG distance compared to that of the CAD/CAM milled monolithic crowns. This owes back to the previously mentioned microstructure difference between IPS e.max ingots, IPS e.max blocks, and PEEK Bio.HPP. It may also be attributed to the influence of the crystallization cycle on the CAD/CAM milled IPS e.max crowns.[38,39,43,51,96,107]

This may also be due to the remargination of the CAD/CAM milled wax patterns was done as per the manufacturer's instructions to enhance the margins of the wax patterns prior to the heat-pressing procedure.[78]

These findings are in agreement with the results of **Saadallah S et al.**[108] study in 2017. They correlated their findings to the effect of the crystallization cycle on the overall fit of the CAD/CAM milled crowns. **Hashem E et al.**[27] study in 2018 also found similar results and attributed their findings to the remargination of the wax patterns.

There was no statistically significant difference in the VMG distance of the CAD/CAM milled crowns fabricated using IPS e.max blocks and PEEK Bio.HPP blanks. This is because they were both milled using a high-precision 5-axis milling machine. In addition, the milling burs used to mill IPS e.max and PEEK.Bio.HPP crowns had large and small diameters. This ensures that the restorations were cut with the highest speed, detailing, and precision. Moreover, special milling burs supplied specifically for milling ceramics and thermoplastic polymers were used to mill IPS e.max and PEEK Bio.HPP crowns, respectively.[109,110]

All the heat-pressed and CAD/CAM milled IPS e.max and PEEK Bio.HPP monolithic crowns showed VMG distances within the clinically acceptable range of ≤120µm as stated by **McLean J and von Fraunhofer J.**[49]

There are limitations to this study. As this is an in-vitro study, it does not simulate the intraoral condition. Moreover, the non-anatomic preparation design does not mimic the oral condition of the preparation.

CONCLUSION

Within the limitations of this study, it could be concluded that:

1. IPS e.max and PEEK Bio.HPP crowns showed comparable clinically acceptable marginal adaptation.
2. The crowns fabricated using the heat-pressing technique showed better marginal adaptation than the CAD/CAM milled crowns.
3. All the heat-pressed and CAD/CAM milled IPS e.max and PEEK Bio.HPP crowns showed VMG and internal gap distances within the clinically acceptable range of ≤120µm.

CLINICAL RELEVANCE

PEEK Bio.HPP monolithic crowns can be used as a treatment option to restore a mandibular first molar.

FUNDING SOURCE

This study was conducted with no funding source.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

REFERENCES

1. Bajraktarova-Valjakova E, Korunoska-Stevkovska V, Kapusevska B, Gigovski N, Bajraktarova-Misevska C, Grozdanov A. Contemporary dental ceramic materials, a review: chemical composition, physical and mechanical properties, indications for use. Maced. J. Med. Sci; 2018;6(9):1742–55.
2. Saint-Jean SJ. Advanced Ceramics for Dentistry: Chapter 12. Dental glasses and glass-ceramics. Elsevier Inc. Chapters; 2013. p. 255–77.
3. Pavlović VB, Vulićević Z, Pavlović VP. Proceedings of the IV advanced ceramics and applications conference: 9. Contemporary dental ceramics. In: Lee B, Gadow R, Mitic V, editors. Springer; 2017. p. 95–171.
4. IPS e.max Press - Pressed lithium disilicate all-ceramic restorations from your laboratory. Ivoclar Vivadent AG.
5. IPS e.max CAD - Labside user manual. Ivoclar Vivadent AG.
6. Phark JH, Duarte Jr S. Microstructural considerations for novel lithium disilicate glass ceramics: A review. J Esthet Restor Dent. 2022 Jan;34(1):92–103.
7. Silva LH, Lima E, Miranda RB, Favero SS, Lohbauer U, Cesar PF. Dental ceramics: a review of new materials and processing methods. Braz Oral Res. 2017 Aug 28;31:133–46.
8. Willard A, Chu TM. The science and application of IPS e.Max dental ceramic. Kaohsiung J Med Sci. 2018 Apr 1;34(4):238–42.
9. Sharma S, Bhasin A, Mantri S, Khatri M. Polyether-Ether-Ketone (PEEK) and its application in prosthodontics: A review. South Asian Res J Oral Dent Sci. 2021 Jun 2;3(3):60–4.
10. Tekin S, Cangül S, Adıgüzel Ö, Değer Y. Areas for use of PEEK material in dentistry. International Dental Research. 2018 Aug 27;8(2):84–92.
11. Qin L, Yao S, Zhao J, Zhou C, Oates TW, Weir MD, et al. Review on development and dental applications of polyetheretherketone-based biomaterials and restorations. Materials. 2021 Jan 15;14(2):1–25.
12. Panayotov IV, Orti V, Cuisinier F, Yachouh J. Polyetheretherketone (PEEK) for medical applications. J Mater Sci: Mater Med. 2016 July;27(7):1-11.
13. Georgiev J, Vlahova A, Kissov H, Aleksandrov S, Kazakova R. Possible

application of BioHPP in prosthetic dentistry: A literature review. J of IMAB. 2018 Feb 7;24(1):1896–8.
14. Najeeb S, Zafar MS, Khurshid Z, Siddiqui F. Applications of polyetheretherketone (PEEK) in oral implantology and prosthodontics. J. Prosthodont. 2016 Jan 1;60(1):12–9.
15. Kern M, Lehmann F. Influence of surface conditioning on bonding to polyetheretherketon (PEEK). Dent Mater. 2012 Dec 1;28(12):1280–3.
16. Iyer RS, Suchitra SR, Hegde D, Coutinho CA, Priya A. BioHPP: Properties and applications in prosthodontics: A review. J. Dent. Res. 2020 Mar 19;7(4):72-6.
17. Revilla-León M, Olea-Vielba M, Esteso-Saiz A, Martínez-Klemm I, Özcan M. Marginal and internal gap of handmade, milled and 3d printed additive manufactured patterns for pressed lithium disilicate onlay restorations. Eur J Prosthodont Restor Dent. 2018 Mar 1;26(1):31–8.
18. Boitelle P, Mawussi B, Tapie L, Fromentin O. A systematic review of CAD/CAM fit restoration evaluations. J Oral Rehabil. 2014 Nov;41(11):853–74.
19. Dolev E, Bitterman Y, Meirowitz A. Comparison of marginal fit between CAD-CAM and hot-press lithium disilicate crowns. J Prosthet Dent. 2019 Jan 1;121(1):124–8.
20. Azar B, Eckert S, Kunkela J, Ingr T, Mounajjed R. The marginal fit of lithium disilicate crowns: Press vs. CAD/CAM. Braz Oral Res. 2018 Jan 22;32.
21. Groten M, Axmann D, Pröbster L, Weber H. Determination of the minimum number of marginal gap measurements required for practical in vitro testing. J Prosthet Dent. 2000 Jan;83(1):40–9.
22. Riccitiello F, Amato M, Leone R, Spagnuolo G, Sorrentino R. In vitro evaluation of the marginal fit and internal adaptation of zirconia and lithium disilicate single crowns: Micro-CT comparison between different manufacturing procedures. Open Dent J. 2018 Feb 23;12(1):160–72.
23. Tiu J, Al-Amleh B, Waddell JN, Duncan WJ. Clinical tooth preparations and associated measuring methods: A systematic review. J Prosthet Dent. 2015 Mar 1;113(3):175–84.
24. Carbajal Mejía JB, Yatani H, Wakabayashi K, Nakamura T. Marginal and internal Fit of CAD/CAM crowns fabricated over reverse tapered preparations. J Prosthodont. 2019 Feb1;

28(2):e477–84.

25. Halawani SM, Al-Harbi SA. Marginal adaptation of fixed prosthodontics. IJMDC. 2017;1(2):78–84.
26. Yuan F, Liang S, Lyu P. A novel method for adjusting the taper and adaption of automatic tooth preparations with a high-power femtosecond laser. J Clin Med. 2021 Jul 30;10(15):1-11.
27. Hashem E, Shehab GI, Sallam HI. Effect of finish line steepness and construction technique on vertical marginal gap of machinable and pressable IPS e.max ceramic copings (an in-vitro study). Egypt Dent J. 2018;64(1):441–9.
28. Yu H, Chen Y hui, Cheng H, Sawase T. Finish-line designs for ceramic crowns: A systematic review and meta-analysis. J Prosthet Dent. 2019 Jul 1;122(1):22-30.
29. Gulati V, Agrawal A, Singh B. Evaluation of influence of finish line design on marginal discrepancy of all-ceramics lithium disilicate crown restorations using μ-CT. In: IOP Conf Series: Mater Sci Eng. 2020 Mar 1;802(1):1–9.
30. Rizonaki M, Jacquet W, Bottenberg P, Depla L, Boone M, de Coster PJ. Evaluation of marginal and internal fit of lithium disilicate CAD-CAM crowns with different finish lines by using a micro-CT technique. J Prosthet Dent. 2022 Jun 1;127(6):890–8.
31. Mai HN, Han JS, Kim HS, Park YS, Park JM, Lee DH. Reliability of automatic finish line detection for tooth preparation in dental computer-aided software. J Prosthodont Res. 2023; 67(1):138-43
32. Abdullah M, Kenawi L. Influence of porcelain firing and core thickness on marginal gap of cad/cam and pressable all-ceramic crowns (in-vitro study). Egypt Dent J. 2021 Jul 1;67(3):2377–85.
33. Vasiliu RD, Porojan SD, Porojan L. In vitro study of comparative evaluation of marginal and internal fit between heat-pressed and CAD-CAM monolithic glass-ceramic restorations after thermal aging. Mater. 2020 Sep 23;13(19):1–14.
34. Mostafa NZ, Ruse ND, Ford NL, Carvalho RM, Wyatt CCL. Marginal fit of lithium disilicate crowns fabricated using conventional and digital methodology: a three-dimensional analysis. J Prosthodont. 2018 Feb 1;27(2):145–52.
35. Makky MR, Shokry TE, Metwally MF. Comparison of marginal and internal fit of copings fabricated from polyetheretherketone and zirconia: an

in-vitro study. Al-Azhar J. Dent. Sci. 2020 Oct 1;23(4):355–62.

36. Kim JH, Oh S, Uhm SH. Effect of the crystallization process on the marginal and internal gaps of lithium disilicate CAD/CAM crowns. Biomed Res Int. 2016 Jan 1;2016:1-6.
37. Al Hamad KQ, Al Rashdan BA, Al Omari WM, Baba NZ. Comparison of the fit of lithium disilicate crowns made from conventional, digital, or conventional/digital techniques. J Prosthodont. 2019 Feb 1;28(2):e580–6.
38. Stawarczyk B, Eichberger M, Uhrenbacher J, Wimmer T, Edelhoff D, Schmidlin PR. Three-unit reinforced polyetheretherketone composite FDPs: Influence of fabrication method on load-bearing capacity and failure types. Dent Mater J. 2015 Jan 30;34(1):7–12.
39. Merk S, Wagner C, Stock V, Eichberger M, Schmidlin PR, Roos M, et al. Suitability of secondary PEEK telescopic crowns on zirconia primary crowns: the influence of fabrication method and taper. Mater. 2016 Nov 8;9(11):1-9.
40. Lalama M, Rocha MG, O'Neill E, Zoidis P. Polyetheretherketone (PEEK) post and core restorations: a 3D accuracy analysis between heat-pressed and CAD-CAM fabrication methods. J Prosthodont. 2022 Jul 1;31(6):537–42.
41. Bae SY, Park JY, Jeong I do, Kim HY, Kim JH, Kim WC. Three-dimensional analysis of marginal and internal fit of copings fabricated with polyetherketoneketone (PEKK) and zirconia. J Prosthodont Res. 2017 Apr 1;61(2):106–12.
42. Li Y, Cheng X, Ling S, Zheng G, Liu H, He L. Study of milling process basics for the biocompatible PEEK material. Mater Res Express. 2020 Jan 20;7(1):1-13.
43. Godil AZ, Kazi AI, Wadwan SA, Gandhi KY, Dugal RJS. Comparative evaluation of marginal and internal fit of endocrowns using lithium disilicate and polyetheretherketone computer-aided design - computer-aided manufacturing (CAD-CAM) materials: An in vitro study. J Conserv Dent. 2021 Mar;24(2):190–4.
44. Fuzzi M, Tricarico MG, Cagidiaco EF, Bonadeo G, Sorrentino R, Ferrari M. Nanoleakage and internal adaptation of zirconia and lithium disilicate single crowns with feather edge preparation. J. Osseointegration. 2017 Jun 29;9(2):250–62.
45. Homsy FR, Özcan M, Khoury M, A. K. Majzoub Z. Marginal and internal fit of

pressed lithium disilicate inlays fabricated with milling, 3D printing, and conventional technologies. J Prosthet Dent. 2018 May 1;119(5):783–90.
46. Alshehri HA, Altaweel SM, Alshaibani R, Alahmari EA, Alotaibi HN, Alfouzan AF, et al. Effect of different wax pattern manufacturing techniques on the marginal fit of lithium disilicate crowns. Mater. 2022 Jul 7;15(14):1-9.
47. Torabi K, Vojdani M, Giti R, Taghva M, Pardis S. The effect of various veneering techniques on the marginal fit of zirconia copings. J Adv Prosthodont. 2015 Jun 1;7(3):233–9.
48. Ganapathy D, Sathyamoorthy A, Ranganathan H, Murthykumar K. Effect of resin bonded luting agents influencing marginal discrepancy in all ceramic complete veneer crowns. J Clin Diagn Res. 2016 Dec 1;10(12):ZC67-70.
49. McLean JW, von Fraunhofer JA. The estimation of cement film thickness by an in vivo technique. Br Dent J. 1971 Aug 3;131(3):107–11.
50. Vecsei B, Czigola A, Róth I, Hermann P, Borbély J. Chapter 3: Digital impression systems, CAD/CAM, and STL file. In: Guided Endodontics.2021. p. 27–63. Springer, Cham.
51. Dauti R, Lilaj B, Heimel P, Moritz A, Schedle A, Cvikl B. Influence of two different cement space settings and three different cement types on the fit of polymer-infiltrated ceramic network material crowns manufactured using a complete digital workflow. Clin Oral Investig. 2020 Jun;24(6):1929–38.
52. Galante R, Figueiredo-Pina CG, Serro AP. Additive manufacturing of ceramics for dental applications: A review. Dent Mater. 2019 Jun 1;35(6):825–46.
53. Zimmermann M, Mörmann W, Mehl A, Hickel R. Teaching dental undergraduate students restorative CAD/CAM technology: evaluation of a new concept. Int J Comput Dent. 2019 Jan 1;22(3):263-71
54. Methani MM, Revilla-León M, Zandinejad A. The potential of additive manufacturing technologies and their processing parameters for the fabrication of all-ceramic crowns: A review. J Esthet Restor Dent. 2020 Mar 1;32(2):182–92.
55. Ahmed KE. We’re going digital: The current state of CAD/CAM dentistry in prosthodontics. Prim. Dent. J. 2018 Jun;7(2):30–5.
56. Hallmann L, Ulmer P, Gerngross MD,

Jetter J, Mintrone M, Lehmann F, et al. Properties of hot-pressed lithium silicate glass-ceramics. Dent Mater. 2019 May 1;35(5):713–29.

57. Deutsch AS, Musikant BL. Morphological measurements of anatomic landmarks in human maxillary and mandibular molar pulp chambers. J Endod. 2004 Jun 1;30(6):388–90.
58. Chandra Shekar S, Giridhar K, Suhas Rao K. An in vitro study to evaluate the retention of complete crowns prepared with five different tapers and luted with two different cements. J. Indian Prosthodont. 2010 Jun;10(2):89–95.
59. Strain KJ, Mackie J, Bonsor SJ, Macfarlane TV. Crown taper angles achieved by dental students: a systematic review. J Dent Educ. 2018 Nov;82(11):1203–12.
60. Colpani JT, Borba M, della Bona Á. Evaluation of marginal and internal fit of ceramic crown copings. In: Dent Mater. 2013 Feb 1;29(2):174–80.
61. Abdullah LS, Ibraheem AF. The effect of finishing line designs and occlusal surface reduction schemes on vertical marginal fit of full contour CAD/CAM zirconia crown restorations (a comparative in vitro study). Int J Dent Oral Health. 2017;4(1):1-6.
62. Wahsh M, Taha D. in vitro evaluation of the marginal integrity of monolithic ceramic crowns utilizing different machinable blocks fabricated for minimally invasive vertical preparation designs. Egypt Dent J. 2020 Oct 1;66(4):2597–606.
63. Attia MA. Marginal fit of Polyetheretherketone single crown copings obtained using different fabrication techniques. Egypt Dent J. 2019 Apr 1;65(2):1653–61.
64. IPS e.max Clinical Guide. Ivoclar Vivadent AG.
65. IPS e.max System - all you need. Ivoclar Vivadent AG
66. Jalali H, Hajmiragha H, Farid F, Tabatabaie S, Jalali S. Effect of scanner type on marginal adaptation of e.max cad crowns. J Islam Dent Assoc Iran. 2018 Oct 10;30(4):139–44.
67. Memari Y, Mohajerfar M, Armin A, Kamalian F, Rezayani V, Beyabanaki E. Marginal adaptation of CAD/CAM all-ceramic crowns made by different impression methods: a literature review. J Prosthodont. 2019 Feb 1;28(2):e536–44.
68. Khaledi AA, Farzin M, Akhlaghian M, Pardis S, Mir N. Evaluation of the marginal fit of metal copings fabricated

by using 3 different CAD-CAM techniques: Milling, stereolithography, and 3D wax printer. J Prosthet Dent. 2020 Jul 1;124(1):81–6.

69. Nabil O, Halim CH, Mokhtar AH. Fracture resistance and 3D finite element analysis of machined ceramic crowns bonded to endodontically treated molars with two planes versus flat occlusal preparation designs: an in vitro study. F1000Res. 2021 Jul 11;8:1-21.
70. Bukhari S, Goodacre BJ, AlHelal A, Kattadiyil MT, Richardson PM. Three-dimensional printing in contemporary fixed prosthodontics: A technique article. J Prosthet Dent. 2018 Apr 1;119(4):530–4.
71. Azarbal A, Azarbal M, Engelmeier RL, Kunkel TC. Marginal fit comparison of CAD/CAM crowns milled from two different materials. J Prosthodont. 2018 Jun 1;27(5):421–8.
72. Kohorst P, Brinkmann H, Dittmer MP, Borchers L, Stiesch M. Influence of the veneering process on the marginal fit of zirconia fixed dental prostheses. J Oral Rehabil. 2010 Apr;37(4):283–91.
73. Identica Hybrid Medit scanner- User Guide. MEDIT. 2015.
74. Burde AV, Dudea D, Cuc S, Moldovan M, Septimiu Campian R. Three-dimensional evaluations of the coating thickness of two optical conditioning scanning sprays. Metr Plast. 2016 Mar 1;53(1):65-7.
75. Lerner H, Nagy K, Pranno N, Zarone F, Admakin O, Mangano F. Trueness and precision of 3D-printed versus milled monolithic zirconia crowns: An in vitro study. J Dent. 2021 Oct 1;113:103792.
76. Piras FF, Ferruzzi F, Ferrairo BM, Ramalho IS, Bonfante EA, Rubo JH. Analysis of correlation between optical and microtomography measurements of cementation space in CAD-CAM ceramic crowns. J Prosthet Dent. 2020 Jul 1;124(1):87-e1
77. Fathi H, Al-Masoody A, Johnson A. The accuracy of fit of crowns made from wax patterns produced conventionally (hand formed) and via CAD/ CAM technology. Eur J Prosthodont Restor Dent. 2016;11–7.
78. VITA CAD-Waxx Instructions for use. VITA.
79. Belur D. Marginal Adaptation & Internal fit of digitally designed lithium disilicate crowns manufactured by CAD/CAM and the Conventional Heat-Press Technique. (Doctoral dissertation), Texas A & M University; 2018.
80. IPS PressVEST - Instructions for use.

Ivoclar Vivadent AG.

81. Dental Laboratory Rotary Grinding and Polishing Instruments. EVE.
82. Guide for grinding and polishing feldspar ceramic, lithium disilicate and zirconia. EVE.
83. Mota EG, Smidt LN, Fracasso LM, Burnett LH, Spohr AM. The effect of milling and postmilling procedures on the surface roughness of CAD/CAM materials. J Esthet Restor Dent. 2017 Nov 12;29(6):450–8.
84. da Silva TM, Salvia AC, de Carvalho RF, Pagani C, da Rocha DM, da Silva EG. Polishing for glass ceramics: which protocol?, J. Prosthodont. 2014;58(3):160–70.
85. Nawafleh NA, Mack F, Evans J, Mackay J, Hatamleh MM. Accuracy and reliability of methods to measure marginal adaptation of crowns and FDPs: A literature review. J. Prosthodont. 2013 Jul;22(5):419–28.
86. Kwong B, Dudley J. A comparison of the marginal gaps of lithium disilicate crowns fabricated by two different intraoral scanners. Aust Dent J. 2020 Jun 1;65(2):150–7.
87. Su S, Dudley J. The marginal gaps of lithium disilicate crowns constructed by different scanner and milling unit combinations. Aust Dent J. 2022 Jun;67(2):125-31
88. Garg S, Kumar S, Jain S, Aggarwal R, Choudhary S, Reddy NK. Comparison of dimensional accuracy of stone models fabricated by three different impression techniques using two brands of polyvinyl siloxane impression materials. J Contemp Dent Pract. 2019 Aug 1;20(8):928–34.
89. Son K, Lee S, Kang SH, Park J, Lee KB, Jeon M, et al. A comparison study of marginal and internal fit assessment methods for fixed dental prostheses. J Clin Med. 2019 Jun 1;8(6):785.
90. Miura S, Kasahara S, Yamauchi S, Egusa H. Effect of finish line design on stress distribution in bilayer and monolithic zirconia crowns: a three-dimensional finite element analysis study. Eur J Oral Sci. 2018 Apr 1;126(2):159–65.
91. Miura S, Inagaki R, Kasahara S, Yoda M. Fit of Zirconia all-ceramic crowns with different cervical margin designs, before and after porcelain firing and glazing. Dent Mater J. 2014 Jul 30;33(4):484–9.
92. Asavapanumas C, Leevailoj C. The influence of finish line curvature on the marginal gap width of ceramic copings.

J Prosthet Dent. 2013 Apr;109(4):227–33.

93. Hasanzade M, Aminikhah M, Afrashtehfar KI, Alikhasi M. Marginal and internal adaptation of single crowns and fixed dental prostheses by using digital and conventional workflows: A systematic review and meta-analysis. J Prosthet Dent. 2021 Sept 1 ;126(3):360–8.
94. Abdulla M, Ali H, Jamel R. CAD-CAM Technology: A literature review. Al-Rafidain Dental Journal. 2020 Apr 1;20(1):95–113.
95. Anadioti E. Internal and marginal fit Of pressed and cad lithium disilicate crowns made from digital and conventional impressions: Master Thesis. The University of Iowa; 2013.
96. Osman AM, el Mahallawi OS, Khair-Allah LS, el Khodary NA. Marginal integrity and clinical evaluation of polyetheretherketone (PEEK) versus lithium disilicate (E-Max) endocrowns: Randomized controlled clinical trial. Int J Health Sci. 2022 Apr 25;1831–45.
97. Shim JS, Lee JS, Lee JY, Choi YJ, Shin SW, Ryu JJ. Effect of software version and parameter settings on the marginal and internal adaptation of crowns fabricated with the CAD/CAM system. J Appl Oral Sci. 2015 Sep 1;23(5):515–22.
98. Grajower R, Lewinstein I. A mathematical treatise on the fit of crown castings. J Prosthet Dent. 1983 May 1;49(5):663–74.
99. Miranda JS, Barcellos AS de P, Campos TMB, Cesar PF, Amaral M, Kimpara ET. Effect of repeated firings and staining on the mechanical behavior and composition of lithium disilicate. Dent Mater. 2020 May 1;36(5):e149–57.
100. Reich S. Tooth-colored CAD/CAM monolithic restorations. Int J Comput Dent. 2015;18(2):131–46.
101. Pani P. Minimally Invasive Dentistry-a boon for patients. Book Rivers; 2022 May 9. p.1-171.
102. Lien W, Roberts HW, Platt JA, Vandewalle KS, Hill TJ, Chu TM. Microstructural evolution and physical behavior of a lithium disilicate glass–ceramic. Dental materials. 2015 Aug 1;31(8):928-40.
103. Anadioti E, Aquilino SA, Gratton DG, Holloway JA, Denry I, Thomas GW, et al. 3D and 2D Marginal Fit of Pressed and CAD/CAM Lithium Disilicate Crowns Made from Digital and Conventional Impressions. J Prosthodont. 2014 Dec 1;23(8):610–7.

104. Mounajjed R, Layton DM, Azar B. The marginal fit of E.max press and E.max CAD lithium disilicate restorations: A critical review. Dent Mater J. 2016 Nov 28;35(6):835–44.

105. Merk S, Wagner C, Stock V, Eichberger M, Schmidlin P, Roos M, et al. Suitability of Secondary PEEK Telescopic Crowns on Zirconia Primary Crowns: The Influence of Fabrication Method and Taper. Mater. 2016 Nov 8;9(11):908.

106. Singh S, Prakash C, Ramakrishna S. 3D printing of polyether-ether-ketone for biomedical applications. Eur. Polym. 2019 May 1;114:234–48.

107. Azarbal A. Marginal fit comparison of CAD/CAM crowns milled from two different materials. J Prosthodont. 2018 Jun;27(5):421-8.

108. Saadallah S, Kareem A, Al-Azzawi J. The Influence of different fabrication and impression techniques on the marginal adaptation of lithium disilicate crowns (A comparative in vitro study). J Bagh Coll Dentistry. 2017 Dec 15;29(4):20–6.

109. Park JY, Bae SY, Lee JJ, Kim JH, Kim HY, Kim WC. Evaluation of the marginal and internal gaps of three different dental prostheses: Comparison of the silicone replica technique and three-dimensional superimposition analysis. J Adv Prosth. 2017 Jun 1;9(3):159–69.

110. Vág J, Nagy Z, Bocklet C, Kiss T, Nagy Á, Simon B, et al. Marginal and internal fit of full ceramic crowns milled using CADCAM systems on cadaver full arch scans. BMC Oral Health. 2020 Dec 6;20(1):1-2.