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THE EFFECT OF THERMOCYCLING ON THE MARGINAL INTEGRITY OF 3D PRINTED AND MACHINED HYBRID RESIN-CERAMIC CROWNS: AN IN-VITRO STUDY

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ABSTRACT

Objective: To compare the marginal integrity of 3D printed hybrid resin-ceramic crowns to that of milled lithium disilicate and milled hybrid resin ceramic crowns.

Materials and methods: A typodont prepared lower first permanent molar tooth was optically scanned for manufacturing 12 crowns divided into three groups (n=4). Group 1 were milled from lithium disilicate ceramics (IPS e.max CAD), group 2 were milled from hybrid resin-ceramic (Nanoksa G-plus ®, Ionx) while group 3 were 3D printed from hybrid resin-ceramic (Nanoksa Bioguard ®, Ionx). Using a digital stereomicroscope (Leica L2, Germany), the marginal gap was assessed before and after 5000 cycles of thermocycling. The collected data were analyzed using Wilcoxon signed ranks test and Kruskal-Wallis test followed by Mann-Whitney test ($P \leq 0.05$).

Results: The values of the marginal gaps of the three groups before thermocycling reported no statistically significant difference (p-value = 0.090). In addition, the values of the marginal gaps of the three groups after thermocycling reported no statistically significant difference (p-value = 0.387). Regarding the effect of thermocycling, group 1 showed a non-statistically significant difference in the marginal gap values (p-value = 0.343). However, group 2 and 3 exhibited a statistically significant increase in the marginal gap values after thermocycling (p-value = 0.011 and 0.025 respectively)

Conclusion: The marginal gap values of 3D printed hybrid resin-ceramic crowns was similar to milled lithium disilicate and hybrid resin-ceramic crowns. Although, the thermocycling negatively affected the marginal gap, this effect remains within the accepted clinical range.

KEYWORDS: marginal integrity, 3D printed resins, Lithium disilicate, hybrid resin-ceramic.

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INTRODUCTION

Digital manufacturing of the dental restorations has been increased in the last two decades. Regarding fixed prosthodontics, the computer-aided designing/computer aided manufacturing (CAD/CAM) technique decreased the required steps of making the final restoration in comparison to manual techniques. Consequently, an increase in restorations accuracy and reduction of the treatment time was achieved with that innovative technique. [1,2]

The digital construction of the dental prostheses could be performed by one of two ways; subtractive or additive. The former way utilizes milling of the restoration from a prefabricated block or disk. While the later way requires building the restoration layer by layer using the raw material. After printing of the layers, they are fused together until forming the whole final restoration. [3,4]

The additive manufacturing technique provides many advantages over the subtractive technique such as minimizing the wastage of the material, reduced CO_2 emission, more energy efficiency, fabrication of the complex shapes with undercuts or inaccessible zones that can't be milled and the less need for tool maintenance. In addition, the produced complexed parts had lower residual stresses. [3,5,6]

The additive manufacturing of the permanent fixed prosthodontics is an evolving trend in the dental field. For that, ceramic fillers has been added to the methacrylate resin to produce a hybrid resin-ceramic material. This combination has been suggested to improve the criteria of the printed prosthesis to serve as a permanent restoration. [4]

Lithium disilicate is an excellent treatment modality for full coverage restoration. Despite of its drawbacks such as cracking and chipping, it is extensively used as indirect aesthetic restorative material. This is because of its high biocompatibility, aesthetics and comparable mechanical properties with zirconia and porcelain-fused to metal restorations. It reported 100% survival rate after two years and 97.8% after five years. [7]

Marginal adaptation between the fixed prosthodontics and tooth structure is a very important parameter in the success rate of the restorations. Poor marginal adaption leads to microleakage, plaque accumulation and gingivitis. As the 3D printed are structures subjected to shrinkage during the manufacturing process, therefore the study of their marginal adaptation should be of a great concern. [8]

Thermocycling of the restorative material can be considered a consistent method of invitro simulated aging of the restorative materials. The thermal changes during the thermocycling testing represent the intra-oral thermal changes occurred as a result of eating or drinking hot and cold substances. These thermal changes result in mechanical stresses and cracks occur which can be an indicator for the longevity of the restorations. [9]

Therefore, this current work aimed to assess the marginal adaptation of milled and 3D printed hybrid resin-ceramic crowns and milled lithium disilicate crowns and evaluate the thermocycling effect on their marginal adaptation. The null hypothesis was that there would be no difference in the marginal gap values in the three tested groups either before or after thermocycling.

MATERIAL AND METHODS

Sample size calculation:

According to a previous study [6], the sample size was calculated with a power of 95% and alpha error probability = 0.05. A total sample size of 12 sample (4 for each group) was required. Sample size was determined using G power version 3.1.9.7. (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany).

Samples grouping:

The samples were divided according to the material of the crowns into three groups; group 1 samples were machined from lithium disilicate (IPS e.max CAD, Ivoclar Vivadent, Liechtenstein, Germany), group 2 samples were machined from hybrid resin-ceramics (Nanoksa G-plus ®, Ionx, USA) while the group 3 samples were 3D printed with hybrid resin-ceramics permanent resin (Nanoksa Bioguard ®, Ionx, USA).

Samples preparation:

A lower first molar typodont tooth (Nissin Dental, Kyoto, Japan) was prepared using a low-speed tapered with round end stone (Ceramic One®, China). The prepared typodont was 5.5mm in height with 12°±2 total convergence angle. The finish line was 1mm deep chamfer finish line. The prepared tooth was digitally scanned by an intra-oral scanner (Medit i600, Medit Corp, Seoul, Republic of Korea) and checked using scanner software to confirm the reduction parameters then the obtained STL file was used for crowns' fabrication using CAD software (Galway 3.0; Exocad, Darmstadt, Germany).

Regarding the samples of both group 1 and group 2, they were milled using a 5-axis milling machine (Coritec 250i, imes-icore GmbH, Eiterfeld, Germany). Samples of group 1 were subjected to post-milling crystallization with a furnace (Vita Vacumat 6000 M; VITA Zahnfabrik GmbH, Bad Säckingen, Germany) to reach the final crystallization and shade of the lithium disilicate crowns.

3D printed crowns were manufactured by additive technique according to manufacturer's instruction. The crowns were 3D printed using a chairside 3D printer (Inox S2, USA) followed by cleaning with 96% 2-propanol and post cured using nitrogen curing machine (Inox, USA).

Measuring of the vertical marginal gap:

Each crown was seated over the prepared tooth then fixed by a spring clamp under 12 kg load (Total Co. LTD. China). The marginal gap was measured using a digital stereomicroscope at 40X magnification (Leica L2, Leica microsystems Ltd. Germany). The image was processed using the software of the stereomicroscope to measure the vertical gap (Leica Application Suite, V4.0.0, Leica microsystems. Switzerland).

For each crown, two points were measured on each surface. The mean of the eight readings was calculated and considered the marginal gap value of the sample. (Figure 1).

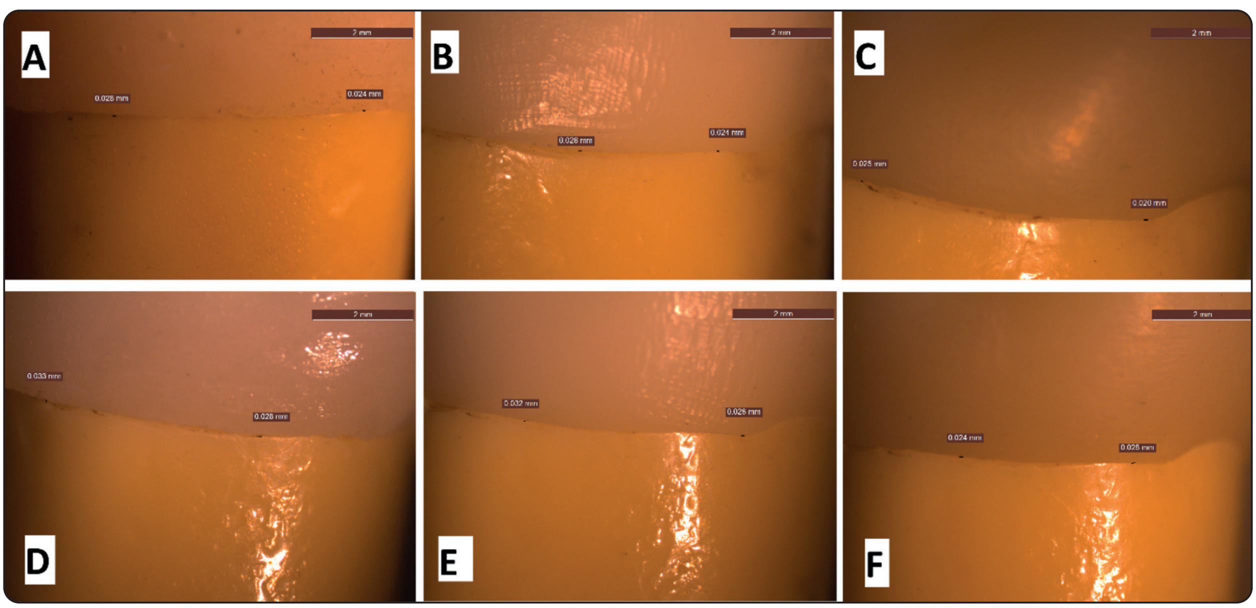

Fig. (1) Representative samples of measuring the marginal gap on the buccal surface of the crowns using digital stereomicroscope images; A; group 1 before thermocycling, B; group 2 before thermocycling, C; group 3 before thermocycling, D; group 1 after thermocycling, E; group 2 after thermocycling and F; group 3 after thermocycling.

Thermocycling

The crowns were subjected to thermocycling for 5000 cycles. Each cycle consisted of immersion of the samples into a cold-water bath at 5 ±2 °C for 30 seconds followed by immersion into a hot-water bath at 55 ± 2°C for the same time. The transfer time of the samples between the cold and hot baths was 5 seconds. The marginal gap was remeasured at the same measurement points for each sample after thermocycling.

Statistical analysis

The collected data were represented as means and standard deviations. The data reported a non-homogenous distribution. Therefore, Wilcoxon signed ranks test was performed to assess the statistically significant difference before and after thermocycling for each group. Moreover, the statistically significant difference between the three groups was assessed by Kruskal-Wallis test followed by Mann-Whitney test to reveal the statistically significant difference between each two groups. The Significance level was set at 0.05.

RESULTS

The values of the marginal gaps of the three groups before thermocycling reported no statistically significant difference (p-value = 0.090). In addition, the values of the marginal gaps of the three groups after thermocycling reported no statistically significant difference (p-value = 0.387). Regarding the effect of thermocycling, group 1 showed a non-statistically significant difference in the marginal gap values (p-value = 0.343). However, group 2 and 3 exhibited a statistically significant increase in the marginal gap values after thermocycling (p-value = 0.011 and 0.025 respectively) (Table 1)

TABLE (1) The mean and standard deviation values (μm) of the marginal gap of the three tested groups before and after thermocycling.

	Group 1		Group 2		Group 3		P-value
	Mean (μm)	S.D	Mean (μm)	S.D	Mean (μm)	S.D	
Before thermocycling	28.75	5.44	22.75	4.13	24.13	4.79	0.090 NS
After thermocycling	26.75	3.81	29.63	4.34	30.63	5.88	0.387 NS
P-value	0.343 NS		0.011*		0.025*		

NS: indicates non- statistically significant difference between the variables ($p \le 0.05$).

****: indicates statistically significant difference between the variables ($p \le 0.05$).***

DISCUSSION

As a rapidly evolving manufacturing technique, the present work aimed to evaluate the marginal gap of the 3D printed crowns in comparison to the milled crowns. The tested resin is claimed by the manufacture to be reinforced with 70% nano zirconia that qualifies it for manufacturing permanent restorations. Therefore, the current study aimed to assess the marginal accuracy of the 3D printed crowns before and after thermocycling in comparison to milled hybrid resin-ceramic and lithium disilicate crowns.

Digital stereomicroscope was chosen to measure the marginal integrity of the restorations in the present study. The digital stereomicroscope offers a non-expensive, a non-destructive way to assess the marginal integrity. In addition, the measurement can be done without using an intermediate material such as impression material or luting cement. However, this measuring method had some limitations such as difficulty in determining measuring points at the margin, difficult of reproducibility of the measuring points and difficulty in distinguishing the tooth from shaded restoration. [10,11]

The dimensional accuracy of the margins of the restorations depends to great extent on the manufacturing procedures such as the accuracy of the scanner, the advancement of the design software, the properties the restoration material and the accuracy of the manufacturing machine. For subtractive technique, the milled material hardness, the milling burs sharpness and their dimensions may limit the production of sharp designs. These factors may chip the restorations margins. [2,12] On the other hand, the margins of the produced restorations by the additive technique are affected by building angle. [6,10]

In an attempt to decrease the variables that affects the marginal accuracy of the crowns, the crowns of the three tested groups were manufactured over one prepared tooth with one scanned STL file. In addition, the marginal gap was assessed without cementing the crowns where cementing crowns may change the marginal integrity of the final restorations. This is because in clinical situations the luting cement is prone to dissolution. [11,13].

The current results reported a statistically non-significant difference between the marginal gap values of the three groups before thermocycling. **Arafa** and **Ziada** (2023) [11] reported that the marginal gap of 3D printed polymeric endo-crowns showed a non-significant difference compared to polymeric endo-crowns manufactured by milling. Moreover, **Al-Ramadan** et al., (2024) [5] reported that the marginal adaptation of 3D printed resinous crowns and milled polymer infiltrated glass ceramic crowns (Vita Enamic®) recorded a non-statistically significant difference.

On the contrary, **Suksuphan** et al., (2024) [6] reported lower marginal gap values in 3D printed polymeric crowns when compared with milled polymeric and polymer infiltrated glass ceramic crowns. Moreover, **Donmez** et al., (2022) [13] examined the marginal gap in implant-supported crowns and reported that lowest marginal gap was in 3D printed resin composite crowns in comparison to three milled crowns manufactured from reinforced composite, polymer-infiltrated ceramics and hybrid ceramics. This confliction may be referred to the difference in the chemical compositions of the tested resin composite materials either their matrix or fillers. [14]

Thermocycling is used for simulating the changes of the temperatures inside the oral environment. Although the ISO recommends 500 cycles, many authors considered this number is the minimum limit. [15] In the present work, the crowns were subjected to 5000 cycles that is equivalent to 6 months of clinical use. [14]

The current results reported that the thermocycling of the lithium disilicate crowns recorded a statistically non-significant difference in their marginal gap values. This result is in agreement with **Salem** (2024) who measured the marginal gap of advanced lithium disilicate crowns before and after thermocycling with three different finish lines and found no changes in the marginal gaps in the three groups. [16]

However, **Hasaneen** and **Mogahed** (2021) reported that thermocycling increased the marginal gap values of ceramic crowns. [17] In addition, **Tantawy** et al., (2022) tested the marginal gaps of ceramic crowns and reported increasing in the marginal gap values after thermocycling. This controversy may be related to the cementing of the restorations as in the both studies they cemented the crowns. Therefore, the deterioration of the resin cement may be the cause of increasing the marginal gap values. [18]

Regarding the current research, the marginal gap of the hybrid resin-ceramic crowns either milled of 3D printed recorded a statistically significant increase after thermocycling. Thermocycling reported a degradation effect on the resin composites. This effect may be referred to the difference in the coefficient of thermal expansion and contraction between fillers and matrix of the resin composite. The temperature fluctuation during thermocycling resulted in development of internal stresses within the resin composite restorations that creates minute microcracks within the material. The hydrophilic nature of the material and the development of minute microcracks resulted in water sorption of the material. All these factors resulted in degradation of the resinous material. [11,19,20]

Regarding the thermocycling effect on the marginal gap of the milled and 3D printed hybrid resin-ceramic crowns, the current results were in accordance with **Arafa** and **Ziada** (2023). They subjected 3D printed and milled resin composite endo-crowns to thermo-mechanical aging and reported a statistically significant increase in their marginal gap. [11]

Therefore, the null hypothesis was partially accepted regarding the difference in the marginal gap between the three groups before and after thermocycling. However, it was partially rejected regarding the effect of thermocycling on marginal gaps of group 2 and 3.

The marginal gap values of all the three tested materials either before thermocycling or after thermocycling were within the acceptable clinical values. **McLean** [21] reported that the acceptable marginal gap is 120 μm. Therefore, the three tested materials can afford a durable restorative choice for the patients.

CONCLUSION

Within the study limitations, the obtained conclusions are:

1. 3D printing of hybrid resin-ceramic crowns provides similar marginal integrity values as the milled type.
2. Thermocycling negatively affected the marginal gap values of the hybrid resin-ceramic crowns.

REFERENCES

1. Suganna M, Kausher H, Ahmed ST, Alharbi HS, Alsubaie BF, Aruna DS, et al. Contemporary Evidence of CAD-CAM in Dentistry: A Systematic Review. Cureus. 2022; 14(11): e31687.
2. Shah N, Lundholmb N. Achieving Accuracy and Precision in Dental Restoration Using CAD/CAM Technology. IJRPR. 2024; 5(8): 1275-1281.
3. Pot GJ, Van Overschelde PA, Keulemans F, Kleverlaan CJ, Tribst JPM. Mechanical properties of additive-manufactured composite based resins for permanent indirect restorations: a scoping review. Materials (Basel). 2024; 17(16):3951.
4. Metin DS, Schmidt F, Beuer F, Prause E, Ashurko I, Sarmadi BS, Unkovskiy A. Accuracy of the intaglio surface of 3D-printed hybrid resin-ceramic crowns, veneers and table-tops: An in vitro study. J Dent. 2024; 144:104960.
5. Al-Ramadan A, Abualsaud R, Al-Dulaijan YA, Al-Thobity AM, Alalawi H. Accuracy and Fit of Ceramic Filled 3D-Printed Resin for Permanent Crown Fabrication: An In Vitro Comparative Study. Prosthesis. 2024; 6(5):1029-1041.
6. Suksuphan P, Krajangta N, Didron PP, Wasanapiarnpong T, Rakmanee T. Marginal adaptation and fracture resistance of milled and 3D-printed CAD/CAM hybrid dental crown materials with various occlusal thicknesses. J Prosthodont Res. 2024; 68(2):326-335.
7. Al-Dulaijan YA, Aljubran HM, Alrayes NM, Aldulaijan HA, AlSharief M, Aljofi FE, et al. Clinical outcomes of single full-coverage lithium disilicate restorations: A systematic review. Saudi Dent J. 2023; 35(5):403-422.
8. Hasanzade M, Yaghoobi N, Nematollahi P, Ghazanfari R. Comparison of the marginal and internal fit of PMMA interim crowns printed with different layer thicknesses in 3D-printing technique. Clin Exp Dent Res. 2023; 9(5):832-839.
9. Kim SY, Bae HJ, Lee HH, Lee JH, Kim YJ, Choi YS, et al., The Effects of Thermocycling on the Physical Properties and Biocompatibilities of Various CAD/CAM Restorative Materials. Pharmaceutics. 2023; 15(8):2122.
10. Farag E, Sabet A, Ebeid K and El Sergany O. Build angle effect on 3D-printed dental crowns marginal fit using digital light-processing and stereo-lithography technology: an in vitro study. BMC Oral Health. 2024; 24(1):73.
11. Arafa AM, Ziada A. Marginal adaptability and fracture resistance of endodontically treated premolars restored with 3d printed and milled endo-crowns. Egy Dent J. 2023; 69(3):2137-2152.

12. Balestra D, Lowther M, Goracci C, Mandurino M, Cortili S, Paolone G, et al. 3D Printed Materials for Permanent Restorations in Indirect Restorative and Prosthetic Dentistry: A Critical Review of the Literature. Materials (Basel). 2024; 17(6):1380.

13. Donmez MB, Okutan Y. Marginal gap and fracture resistance of implant-supported 3D-printed definitive composite crowns: An in vitro study. J Dent. 2022; 124:104216.

14. Taha AI, and Hafez ME. An in vitro study measuring marginal gaps of inlay restorations fabricated from different CAD-CAM materials after thermocycling. BMC Oral Health. 2023; 23:974

15. Qian K, Yang X, Feng H, Liu Y. Marginal adaptation of different hybrid ceramic inlays after thermal cycling. Adv Appl Ceram. 2020; 119:1-7.

16. Salem RM. The Effect of Preparation Design on The Marginal Adaptation of Monolithic Crowns Made of New CAD/CAM Ceramic Material. An In-Vitro Study. ACDJ. 2024; 3(1):27-41.

17. Hasaneen FA, Mogahed MM. Comparative in-vitro study of marginal gap of four CAD/CAM all ceramic systems with thermal aging. Tanta Dent J. 2021; 18:12-19.

18. Tantawy AA, Saad AA, Fahmy NZ. The Influence of Thermocycling on The Marginal adaptation of Different Glass Ceramic Sectional Veneers. MSA Dent J. 2022; 1(1):1-10.

19. Refai OM, El-Refai DA. Flexural behavior of thermocycle polyether ketone ketone (PEKK) and micro-strains induced on its application as double crown-retained removable partial denture in Kennedy class I: In Vitro Study. Ain Shams Dent J. 2024; 35(3):264-275.

20. Ghorab S, Mehesen R, El Nawawy M, Mohammed H. Effect of Restoration Depth and Thermocycling on Color Matching of a Smart Single Shade Universal Resin Composite with the Surrounding Hard Dental Tissues. *Egy Dent J*. 2024; 70(1):427-435.

21. McLean JW, von Fraunhofer JA. The estimation of cement film thickness by an in vivo technique. Br Dent J. 1971;131(3):107-111.