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EFFECT OF THERMO-MECHANICAL CYCLING ON THE VERTICAL MARGINAL GAP OF DIFFERENT CAD/ CAM CROWNS (IN-VITRO STUDY)

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ABSTRACT

Objective: To evaluate the effect of Thermo-mechanical cycling on the vertical marginal gap of different CAD/CAM crowns. **Materials and Methods:** A maxillary first premolar tooth was selected, and the tooth was prepared using a Computerized Numerical Control (CNC); the machine was adjusted to reduce the tooth to fulfill the criteria of all ceramic crown designs. Special mold fabrication consists of a flat wide base, stopper part, and mounting part responsible for tooth mounting and replication. The tooth was duplicated twenty-one times with epoxy resin materials with a specially designed tray, paired with the special mold to give twenty-one identical epoxy dies. Then, twenty-one CAD/CAM crowns were fabricated and divided into three groups (n = 7) according to the material used: IPS emax CAD (LD), Vita ENAMIC (VE), and Tetric CAD. All samples were cemented with a universal bond (Tetric N bond) and adhesive resin cement (Variolink Esthetic DC). The vertical marginal gap was recorded with a digital microscope. Subsequently, all samples were Thermo-mechanical cycled TMC (5 °C to 55 °C, 30s, 75,000 cycles). Then, the vertical marginal gap was re-evaluated. **Results:** The vertical marginal gap showed no significant difference between the tested groups before Thermo-mechanical cycling; LD (28.04±8.21μm) had the highest value, followed by VE (26.66±8.1μm) and Tetric CAD (21.18±2.97μm); however, the vertical marginal gap showed a significant difference between the tested groups after Thermo-mechanical cycling the highest mean value was recorded in VE (38.76±8.39 μm), followed by Tetric CAD (34.91±8.73μm), with the lowest value recorded in LD (15.39±1.99). **Conclusions:** Thermo-mechanical cycling affected the vertical marginal gap of all tested materials.

KEYWORDS: Vertical marginal gap, CAD/CAM, Composite resin, Ceramic-polymer, Thermo-mechanical cycling.

INTRODUCTION

Computer-Aided Design/ Computer-Aided Manufacturing (CAD/CAM) restorative materials have been widely used owing to several advantages, including stable quality of materials, lower costs, and time-saving factors [(1)]. Resin-based CAD/CAM materials for definitive restorations are classified into two groups [(2,3)]. The first dispersed nanoparticle-filled composite resin contains a polymeric matrix and a filler of nanosized ceramic particles [(4,5)], and the second Polymer-infiltrated-ceramic-network (PICN) material consists of a ceramic network infiltrated with a polymer [(6)]. The resin-based CAD/CAM materials provide a superior modulus of elasticity, higher loading capacity, and favorable milling properties compared with ceramic materials [(7-10)] and have been applied to single crown restorations as a monolithic structure for the posterior region [(3)]. Due to the development of resin-

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based CAD/CAM materials, Tetric CAD material is currently applied for single crown restorations [11]. However, the clinical performance of single crown restoration materials has not been clarified. In-vivo studies are complex and require a lot of time. Thermo-mechanical cycling is a popular method of artificial accelerated aging of ceramics because it reproduces the oral environment as an extrinsic factor [12,13]. The thermo-mechanical cycling method can affect the longevity of the restoration. The vertical marginal gap (linear distance between the preparation's finish line and the restoration's margin) may be sufficient. Still, a significant reduction of the vertical marginal gap may be found after cycling [14]. In vitro studies offer the advantage of a controlled environment that reduces the sources of variation, potentially allowing for a more accurate characterization of material properties[15]. This study evaluated whether the vertical marginal gap differs between Tetric CAD, Vita ENAMIC, and IPS e.max CAD before and after Thermo-mechanical cycling. The hypothesis was that there would be a difference between the three testing materials before and after Thermo-mechanical cycling.

MATERIAL AND METHODS

A total of twenty-one (N=21) crown restorations were fabricated. They were divided into three equal main groups (n=7), each according to the type of material used: group (LD), lithium disilicate (IPS emax CAD) and group (CC), Composite CAD (Tetric CAD) and group (VE) Polymer infiltrated ceramic network (Vita ENAMIC). Each group specimen was Thermo-mechanical cycled (TMC) (5°C to 55°C, 30s, 5000 Thermal and 75,000 Mechanical cycles). The vertical marginal gap was recorded before and after Thermo-mechanical cycling.

Master die fabrication and crown preparations:

A maxillary first premolar tooth was selected and, with the aid of a parallometer (Paraflex, Bego, Bremer, Germany), embedded using auto-polymerizing polymethylmethacrylate (Acrostone, Acrostone Dental Manufacture, Egypt) inside a customized copper holder. The tooth was prepared using a Computerized Numerical Control (CNC) four-axis milling machine (CNC Premium 4820, imes-icore, Eiterfeld, Germany) to standardize the preparation dimensions. Tooth preparation was done using a diamond endmill under oily water coolant. The CNC machine was adjusted to reduce the tooth to fulfill the criteria of all ceramic crown designs (1-mm rounded shoulder finish line above cementoenamel junction (CEJ) by 1mm, 1.5-2.0mm occlusal surface reduction, and 6 degrees of axial convergence angle.

Duplication of the master die:

Teflon ring was fabricated and seated over the master die (Fig.1e) to allow the pouring of the silicon duplicating material (Replisil; Zubler, U.S.A., Dallas, TX) to form a silicon mold. Then, epoxy resin (Kema poxy 151; CMB Intl. Giza, Egypt) was mixed according to the manufacturer's recommendation, poured into the silicone mold under vibration, and left to polymerize in place for 24 hours; then the epoxy resin die was removed. Twenty-one epoxy dies were made.

Milling of Restorations.

Twenty-one crowns were fabricated by Cerec® inLab® system (Sirona dental system G. Germany). The restoration type was selected (crown), and the design mode (bigeneric individual), and the tooth was selected (maxillary first premolar); the milling device was selected (MC XL), and IPS e.max CAD and VE and Tetric CAD were selected. According to the group, Glazing was done to (LD) group, and finishing, polishing were done to both the (VE, Tetric CAD) groups according to manufacturer instructions.

Cementation of Restorations:

Surface treatment of each restoration was done to IPS emax CAD, VE, and Tetric CAD groups according to manufacturer instructions. Universal bond (Tetric N bond Universal) and Dual cure adhesive resin cement (Variolink Esthetic DC; Ivoclar Vivadent) were used to cement crowns.

Each restoration was seated on its corresponding epoxy resin die and fixed to a specially designed cementation device for load application (50N) [16] during the cementation procedure.

Testing procedures:

Three groups are subjected to Thermo-mechanical cyclic loading via cyclic load multimodal ROBOTA chewing simulator (ROBOTA chewing simulator, Model ACH-09075DC-T, Germany) integrated with thermo-cyclic protocol operated on a servomotor. Each sample underwent 75,000 preloaded cycles accompanied by 5,000 thermal cycles (5˚-55˚c), a dwell time of 60 seconds, and a load of 98 N [17]; the antagonist metal stylus was designed in a milling machine with a tip diameter of 3mm**.** Each specimen was photographed using a USB digital microscope." (U500x Digital Microscope, Guangdong, China) with a built-in camera before and after TMC**.** The measurements were determined at twelve points (Twelve small marks were prepared on the axial surface of the acrylic tooth (mesial, distal, buccal, and lingual) at equal distances under the finish line by about 1 mm), giving twelve readings for each specimen. The mean of all readings was calculated from the mean values of cervical circumferential measuring sites and represented the mean marginal fit value for each crown.

RESULTS

Data management and statistical analysis were performed using the Statistical Package for Social Sciences (SPSS) version 20. Comparisons between groups concerning normally distributed numeric variables were performed using a one-way analysis of variance (ANOVA) test, followed by Tukey's post hoc test for pairwise comparison. Paired t-test was used to study the effect of Thermo-mechanical cycling. Vertical marginal gap distance (μm): Before Thermo-mechanical loading, the highest mean value was recorded in IPS e.max CAD (28.04±8.21μm), followed by Vita ENAMIC (26.66±8.1μm), with the lowest value recorded in Tetric CAD (21.18±2.97μm). The difference between groups was not statistically significant (p=0.172) (Table, Fig.1). After Thermo-mechanical loading, the highest mean value was recorded in Vita ENAMIC (38.76±8.39 μm), followed by Tetric CAD (34.91±8.73 μm), with the lowest value recorded in IPS e.max CAD (15.39±1.99 μm). The difference between groups was statistically significant (p=0.000). The post hoc test revealed no significant difference between Vita ENAMIC and Tetric CAD groups (Table, Fig.1). Effect of Thermo-mechanical loading Results are summarized in (Table and Fig. 1):

TABLE (1) Descriptive statistics and comparison of Vertical marginal gap distance (μm) between groups (ANOVA test) and before and after Thermo-mechanical loading within the same group (paired t-test)

Thermo-mechanical cycling							
	Before		**After**		**Overall**		**P value**
	Mean	SD	Mean	SD	Mean	SD	
IPS e. max	28.04^{a}	8.21	15.39^{c}	1.99	21.71^{y}	8.72	.004*
Vita Enamic	26.66^{a}	8.1	38.76^{b}	8.39	32.71^{x}	10.11	.001*
Tetric CAD	21.18^{a}	2.97	34.91^{b}	8.73	28.05^{x}	9.49	.001*
All groups	25.29	7.19	29.69	12.45	27.49	10.29	.049*
P value	.172 ns		.000*		.001*		

*Significance level p≤0.05, *significant, ns=non-significant*

Post hoc test: means with different superscript letters are significantly different.

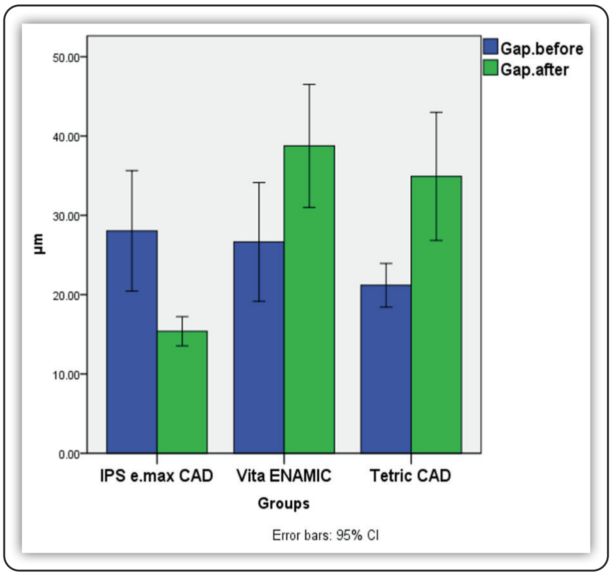

FIG (1) Bar chart illustrating mean Vertical marginal gap distance (μm) before and after TMC in different groups.

DISCUSSION

Due to enhanced mechanical and optical properties, glass-matrix ceramics are frequently used for CAD/CAM restorations [9-11]. Although they are well-established and successful materials, they suffer from several disadvantages; due to hardness, glass-matrix ceramics have mechanical problems such as brittleness and abrasion on the opposing dentition [9-11]. New restorative materials called polymer-infiltrated ceramics and composite CAD for usage with CAD/CAM systems have been developed to improve the unfavourable properties of glass-matrix ceramics (high brittleness index, the need for further heat treatments after milling) [6]. The advantage of polymer-based materials is their good machinability, removing the need to fire restorations after milling. Also, they have a low brittleness index (which substantially reduces marginal chipping during the manufacturing process) and have elastic moduli comparable to those of natural tooth substances [4,18].

Years of repetitive occlusal contact under wet conditions and different temperatures in the patient's mouth can cause failure to dental restorations[17]. Thermo-mechanical cycling (TMC) was simulated in a masticatory simulator. The number of mechanical cycles applied varies significantly between the reviewed studies and ranges from 10,000 to 3.6 million cycles (0.5-month to 14.4 clinical years). This study used 75000 cycles representing six clinical months under function [17]. This study evaluated the marginal gap before and after thermo-mechanical cycling using a USB digital microscope with a built-in camera. This technique has the advantage of non-invasive, accurate, and reproducible measurements and is, therefore, useful to determine the precision of fit of the whole specimen margin.

It was hypothesized that there was a difference between the three testing materials before and after thermo-mechanical cycling and that the vertical marginal gap would be influenced by thermo-mechanical cyclic loading. This hypothesis was partially accepted. Before thermo-mechanical loading, the difference between groups was not statistically significant. However, after thermo-mechanical cycling, the difference between groups was statistically significant. The post hoc test revealed no significant difference between Vita ENAMIC and Tetric CAD groups after thermo-mechanical cycling. Thermo-mechanical cycling significantly affects all groups' vertical marginal gap. The differences in mechanical properties between epoxy resin die and dental ceramics play an essential role. Ceramics are stiff, brittle and transmit much more force during loading, while epoxy resin dies are elastic and will deform during loading. It was assumed that the observed marginal openings of Vita ENAMIC and Tetric CAD were caused by polymerization shrinkage. Polymerization stress retained residual and unreacted monomers, and crack propagation from thermal and occlusal stresses was transmitted to the thin area [19,20]. Fatigue might cause the release of residual stresses, resulting in the loss of resin integrity at the margins [19,21].

Thidarat et al. [22] reported that the marginal gap in four composite materials after aging, although significantly increased, was still within a clinically acceptable range of less than 120 μm. Jiajing Yao et al. [23] reported that the marginal accuracy of the CAD/CAM interim composite crowns did not change. Regarding the ideal marginal gap for ceramic crowns, a few studies have reported that the ideal marginal gap should be 25 to 40 µm for cemented restorations [24]. Many other studies considered the marginal gap values of 100 to 200 µm clinically acceptable for cemented restorations [25,26]. More recent studies have evaluated the clinically good deals of the marginal gap to be less than 100μm [27]. Therefore, the results of marginal gaps for all groups presented in this study can be considered clinically acceptable**.**

The limitations of this study include: 1. Using only 75000 loading cycles, which resembles six months under function, more load cycles may affect the results. 2. The research was done in vitro 3. Using an epoxy resin die to represent a prepared tooth may affect results.

CONCLUSION

Within the limitations of this study, the following conclusions can be drawn:

1. Thermo-mechanical cycling affected the vertical marginal gap of the tested material.
2. All values of the tested materials before and after thermo-mechanical cycling were within the clinically acceptable range.

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