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Evaluation of Color Difference and Translucency of Modified PEEK Restorations Veneered with Different Veneering Materials Before and After Thermal Cycling

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ABSTRACT

The aim of this study was to investigate the effect of different PEEK veneering materials, as well as thermocycling on the color difference (ΔE) and the translucency parameter (TP) of modified PEEK veneered restorations. **Materials and Methods**: Thirty-disc shaped specimens of veneered BioHPP (1.5 mm X 12 mm) were randomly divided into three groups (n=10) based on the type of the veneering material. Group (A): Discs veneered with CAD milled Lithium Disilicate, group (B): Discs veneered with pre-cured milled composite, and group (C): Discs veneered with conventional light cured composite. CIELab values were calculated for all specimens over white and black backgrounds using a laboratory spectrophotometer and then (ΔE) and (TP) were calculated. Specimens were subjected to thermal cycling, after which the same procedure for calculating (ΔE) and (TP) was repeated. **Results**: Repeated measures ANOVA showed that both the veneering material, and thermocycling had a statistically significant effect on mean ΔE, and on (TP) (P-value). **Conclusions**: All veneering techniques rendered an amount of color difference that was clinically unacceptable, as well as displaying much lower translucency levels than that of natural enamel and dentine.

1. INTRODUCTION

The continuously increasing patients' awareness about cosmetics generally, and the demand for naturally looking dental restorations specifically encouraged researchers to work on the development of new materials and techniques. Such alternative materials aim at providing higher strength together with maximum esthetics (1).

Among those newly developed materials is Poly-Ether-Ether-Ketone (PEEK) that is regarded as a promising alternative in the area of fixed prosthodontics (2, 3).

PEEK is a semi-crystalline linear polycyclic aromatic polymer that was developed in the late 1970s by English scientists. Its main advantage lies in its low modulus of elasticity similar to that of bone allowing better transmission of forces to the tooth structure while tolerating high stresses without fracture. Also, displaying a good marginal fit makes it a promising substitute to metal frameworks to be veneered. Further perks of PEEK are their high wear resistance along with decreased enamel abrasion, as it showed marked wear resistance (4,5).

Ongoing efforts dedicated to improving both physical and mechanical properties of PEEK resulted in introduction of a modified PEEK material known as BioHPP. It contains ceramic micro-particles such as aluminum oxide and zirconium oxide, which contributed to attaining higher polishing abilities while maintaining its elastic properties (6).

Regardless of all its superior mechanical properties, BioHPP is considered opaque and displays less than favorable optical properties thus its clinical use as a fully contoured monolithic restoration is severely limited by its low translucency and greyish or even snow-white color. Hereby, additional veneering is considered crucial (7,8).

The esthetic performance of a core veneered restoration is not just limited to its good color stability, but rather to the translucency of the bi-layered block, which is considered by many authors as a cornerstone for the esthetic success of ceramic restorations. The interplay between the masking capacity of the core material to block the background color with a sufficient material thickness on one hand, and the amount of translucency of the veneering material allowing the background color of the core material to shine through and to mimic the natural vivid appearance on the other hand, makes the nature and composition of the PEEK veneering material major player in its esthetic success (9-10).

Several veneering materials and techniques of PEEK have been introduced for optimizing its esthetic outcome. Among those materials is; the newly introduced direct light cured composite resin consisting of 50 percent opalescent nano-ceramic particles and high-strength oligomers without any ground glass-fillers (11-13).

On the other hand, CAD-milled composite blanks such as High Impact Polymer Composite (HIPC) could also be used for PEEK veneering.

The presence of micro-ceramic fillers, the complete polymerization of composite blank during the manufacturing process avoiding light cured plasticization, as well as its manufacturing under pressure and heated conditions are all claimed to help in achieving a higher degree of color stability (14,15).

Considering the superior translucency and optimum strength properties of lithium disilicate, it could also be considered as a veneering option for PEEK. It is well documented in literature that the pairing of a crystalline phase with similar refractive index as the glass matrix, along with the linear organized crystalline structure attributed mainly to the high translucency of lithium disilicate allowing it to have a refractive index of 1.55 (16,17).

However, the color stability of a restoration is not just the product of the intrinsic properties of the material itself, but is highly affected by the oral environment and its repercussions on the behavior of the restoration. Continuous exposure of the restoration in the oral environment to various deleterious stimuli such as humidity, and temperature fluctuations is likely to cause material degradation and consequently affect its physical and mechanical properties. Laboratory simulations of long-term exposure to such oral conditions can be useful to assess the stability of the material where changes including optical and mechanical properties can be evaluated over time under these conditions. Thermal cycling is one of the means employed to reproduce stresses allowing the prediction of the longevity of dental material. It is based on exposing the tested material to repeated cycles of hot and cold temperatures in a water bath reproducing thermal changes mimicking those occurring in the oral cavity (18,19).

Yet, currently, limited data is available concerning the effect of thermal cycling on the optical properties and color stability of PEEK - based restorations (20-23).

Bearing in mind the close relationship between a dental material and its chemical composition, the micro-structure of the veneering material as well as the amount of reflectance at the interface between the core and the veneering material in a bi-layered restoration, this study was designed to test the effect of various PEEK veneering materials, as well as the effect of thermal cycling on the color difference and translucency parameter of PEEK veneered restorations (24).

The null hypothesis was that neither of the veneering material type nor thermal cycling would have an effect on color difference or translucency parameter.

2. MATERIALS AND METHODS

Thirty disc-shaped specimens of modified PEEK (Bre.CAM BioHPP, Bredent GmbH & Co KG) were constructed and randomly divided into three groups (n=10) based on the veneering material used that is either; lithium disilicate glass-ceramic (IPS e.max CAD, Ivoclar Vivadent AG) of A3 shade, A3, pre-cured CAD-milled composite (HIPC, Bredent GmbH & Co KG) or A3 direct light-cured composite resin (Crea.lign, Bredent GmbH & Co KG) (Table 1). The specimens were fabricated as bi-layered disks having a diameter of 12 mm and a total thickness of 1.5 mm with the core thickness being 0.7 mm while that of the veneering material is 0.8 mm.

The total sample size of thirty specimens employed in this study was employed based on a power analysis that was designed to have adequate power to apply a statistical test of the null hypothesis that there is no difference between tested groups by adopting an alpha (α) level of 0.05 (5%), a beta (β) level of 0.2 (20%) (i.e. power=80%) and an effect size (f) of (0.626).

Discs of Bre.CAMBioHPP, HIPC and IPS e.max CAD were obtained by first creating a disc-shaped design of dimensions (12 mm diameter x 0.7 mm thickness) for the Bre.CAMBioHPP and (12 mm diameter x 0.8 mm thickness) for both the HIPC and the IPS e.max CAD by the help of a design software program (Exocad GmbH, Germany). The STL files were exported to the milling machine for milling of the discs of different materials and then each disc thickness was verified using an electronic digital caliper.

Afterwards, Bre.CAM BioHPP and HIPC discs were air-abraded on one surface by 110 microns aluminum oxide powder at a distance 1 cm for 10 seconds at 0.25 MPa pressure following the manufacturer's instructions. Subsequently, discs were cleaned ultrasonically in a bath of deionized water (L&R, Kearny, NY, USA). The air-abraded surface of all discs was then conditioned with a thin layer of Visio.link (Bond.lign; bredent GmbH & Co KG) and light polymerized (bre.Lux Power Unit, bredent GmbH & Co KG) for 90 seconds.

Table (1):

Samples Grouping

Veneering Material	Unaged	Aged
IPS e.max CAD (Gr. A) (n=10)	n=10	n=10
HIPC CAD (Gr. B) (n=10)	n=10	n=10
Crea.lign (Gr. C) (n=10)	n=10	n=10
Grand Total	n=30	

On the other hand, IPS e.max CAD discs were crystallized in Programat P300/G2 ceramic furnace (Ivoclar Vivadent, Schaan, Liechtenstein) according to the manufacturer's recommendations and then etched for 20 seconds (9.5 % hydrofluoric acid etchant, BISCO, USA). Specimens were then washed, dried with air, and finally salinized with a silane coupling agent (BISCO, USA) for 1 minute.

For both IPS e.max CAD and HIPC veneered specimens, each Bre.CAM BioHPP disc together with its veneering HIPC or IPS e.max CAD disc were assembled in a special metal mold, luted together using Dua-Link (BISCO, USA) dual cured resin cement of universal shade, and pressed between two glass plates under a loading device to standardize the pressure applied over the specimens. After the loading device was removed, polymerization was continued for 180 seconds (bre.Lux Power Unit, bredent GmbH & Co KG) to ensure full polymerization.

For the Crea.lign veneered group, each Bre.CAM BioHPP disc, placed in the metal mold, was additionally coated with a thin layer of Crea.lign opaquer (Bredent GmbH, Germany) and light-cured for 360 seconds (brelux Power Unit). Crea.lign paste (Bredent GmbH, Germany) of A3 shade was then injected to fill the mold where the final thickness of each bi-layered specimen was determined by the mold thickness. To obtain a smooth veneering layer of uniform thickness, each Crea.lign veneered disc was finally pressed between two glass plates before light polymerization was continued.

Subsequently, each specimen in each group was polished according to the manufacturer's guidelines; (OptraFine, Ivoclar Vivadent, Schaan, Liechtenstein) for IPS e.max CAD veneered specimens, and (Visio.lign Toolkit, Bredent GmbH, Germany) for HIPC and Crea.lign veneered specimens.

Color difference (ΔE) measurement for all specimens was carried out against a white background in Agilent Cary 5000 UV-Vis-NIR spectrophotometer (Agilent Technologies, USA). It is a double beam direct ratio recording system based on the emission of a light beam from a tungsten halogen lamp. The light beam passes through the double monochromator, and then it is chopped by a chopper mirror into the sample beam and reference beam. The light beam is then detected by a photo-multiplier which is sensitive to the visible/ultraviolet region where the wavelength scan in our measurements was carried out from 380 nm to 780 nm.

CIELab color parameters for each specimen were then calculated from the diffuse reflectance data by using the color software application and (**ΔE**) was calculated through the equation;

$$\Delta E=[(L^*_1-L^*_2)^2+(a^*_1-a^*_2)^2+(b^*_1-b^*_2)^2]½$$

Where: L* value, which is the degree of lightness of an object, a* is the degree of redness/greenness, and b* is the degree of yellowness/blueness. L^*_1, a^*_1 and b^*_1 represent the color parameters of the A3 shade tab of the Vita Classical shade guide (Vita, Zahnfabrik H. Rauter GmbH&Co. KG). On the other hand, L^*_2, a^*_2 and b_2* represent the measured color parameters for each specimen.

For translucency measurements, Agilent Cary 5000 UV-Vis-NIR spectrophotometer was also used where each specimen was measured against both white and black backgrounds. The translucency parameter (TP) was calculated through the following equation;

$$TP = ((L^*_B-L^*_W)^2 +(a^*_B-a^*_W)^2+ (b^*_B-b^*_W)^2)^{1/2}$$

Where: L* is the degree of lightness of an object, a* is the degree of redness/greenness, and b* is the degree of yellowness/blueness. 'B' refers to the color coordinates over the black background, and 'W' refers to those over the white background.

After color and translucency measurements, specimens were subjected to 5000 cycles of thermal cycling. They were placed in thermocycler (Feldkirchen-Westerham, Germany) consisting of two water baths of 5-55˚C temperature range with a dwell time of 30 seconds in each water bath and a transfer time of 10 seconds.

After thermocycling, (**ΔE**) and (TP) for all specimens in all groups were measured again in the same way as before thermocycling

3. RESULTS

Numerical data were explored for normality and showed parametric distribution. Data were presented as mean and standard deviation (SD) values. Repeated measures ANOVA test was used to study the effect of material, and aging on (ΔE) and (TP). Bonferroni's post-hoc test was used for pair-wise comparisons when ANOVA test was significant. The significance level was set at $P \leq 0.05$.

Mean CIELab values for the three groups were displayed before and after thermal cycling. There was a clear shift in the a* and b* values into a positive direction to a more reddish and yellowish color after thermal cycling (Table 2).

Table (2)

The mean, and standard deviation (SD) values for CIELab values with different veneering materials before and after aging

Aging	CIELab Values	IPS e.max CAD		HIPC CAD		Crea.Lign	
		Mean	SD	Mean	SD	Mean	SD
Before aging	L	82.35	0.59	77.27	0.48	72.97	0.51
	a*	-0.30	0.08	-1.04	0.11	2.18	0.16
	b*	11.18	0.32	14.20	0.28	21.54	0.23
After aging	L	81.4	0.55	75.54	0.27	71.03	0.48
	a*	0.27	0.09	0.20	0.39	3.42	0.18
	b*	13.06	0.30	17.24	0.24	24.86	0.18

Repeated measures ANOVA showed that both the veneering material, and thermocycling had a statistically significant effect on mean ΔE (P-value <0.001).

Pair-wise comparisons between materials before thermal cycling revealed that IPS e.max CAD veneered group showed the statistically significantly highest mean ΔE (10.91). HIPC veneered group showed statistically significantly lower mean ΔE (7.12) while Crea.lign veneered group showed the statistically significantly lowest mean ΔE (4.82). On the other hand**,** after thermal cycling IPS e.max CAD veneered group showed the statistically significantly highest mean ΔE (8.86), Crea.lign veneered group showed statistically significantly lower mean ΔE (8) while HIPC veneered group showed the statistically significantly lowest mean ΔE (4.41) (Table 3).

Thermal cycling caused statistically significant decrease in mean ΔE (P-value <0.001) for both IPS e.max CAD and HIPC veneered groups while with the Crea.lign veneered group, there was statistically significant increase in mean ΔE (P-value <0.001).

For translucency parameter (TP), repeated measures ANOVA showed that the veneering material as well as thermocycling had a statistically significant effect on mean TP (P-value <0.001).

Pair-wise comparisons between materials before thermal cycling revealed that IPS e.max CAD veneered group showed the statistically significantly highest mean TP (1.09). There was no statistically significant difference between HIPC and Crea.lign veneered groups where both showed statistically significantly lower mean TP values of (0.83) and (0.75) respectively. However, following thermal cycling, there was no statistically significant difference between materials (P-value = 0.164) (Table 4).

Table (3)

The mean, standard deviation (SD) values and results of repeated measures ANOVA test for comparison between ΔE of the three materials before and after aging

Aging	IPS e.max CAD		HIPC CAD		Crea.lign		P-value	Effect size (Partial eta squared)
	Mean	SD	Mean	SD	Mean	SD		
Before aging	10.91^A	0.39	7.12^B	0.27	4.82^C	0.48	<0.001*	0.929
After aging	8.86^A	0.37	4.41^C	0.21	8^B	0.4	<0.001*	0.916
P-value	<0.001*		<0.001*		<0.001*			

**: Significant at $P \leq 0.05$* *Different superscripts in the same row indicate statistically significant difference between materials*

Table (4):

The mean, standard deviation (SD) values and results of repeated measures ANOVA test for comparison between TP of the three materials before and after aging

Aging	IPS e.max CAD		HIPC CAD		Crea.lign		P-value	Effect size (Partial eta squared)
	Mean	SD	Mean	SD	Mean	SD		
Before aging	1.09 ^{A}	0.11	0.83 ^{B}	0.1	0.75 ^{B}	0.1	<0.001*	0.372
After aging	1.09	0.2	1.02	0.11	0.94	0.14	0.164	0.077
P-value	0.990		<0.001*		<0.001*			

*: Significant at $P \leq 0.05$ Different superscripts in the same row indicate statistically significant difference between materials

As for the effect of thermal cycling, there was no statistically significant change in mean TP after aging for the IPS e.max CAD veneered group. On the other hand, thermal cycling caused a statistically significant increase for both the HIPC and Crea.lign veneered groups.

4. DISCUSSION

Through the results of this study, the null hypotheses was rejected as both; the type of veneering material, and aging, through thermocycling, had a significant impact on color difference and translucency parameter.

Having a look on (ΔE) values in our study, it was clear that the CIELab parameters of the IPS e.max CAD veneered group resulted in an overall color lighter than the intended A3 shade consequently leading to the highest mean value for (ΔE) (11.62). Such result is supported through findings obtained by **Fahmy et al.** (11) in a previous study.

That higher (ΔE) values for the lithium disilicate veneered group compared to the two composite veneered groups could be reverted to two factors; the high translucency of lithium disilicate ceramics, as well as the masking ability of the composite resin. Lithium disilicate is known for its high crystalline content, being composed of 70% disilicate crystals embedded in glassy matrix, together with a refractive index close to that of the matrix thus decreasing the amount of scattered light and increasing the material's translucency (16,17). Such high translucency of lithium disilicate could have led to an increase in the amount of light reaching the PEEK core surface and being reflected from it thus causing the opaque greyish PEEK shade to interfere with the final desired color resulting in higher ΔE values. On the other hand, it was stated in literature that having higher amount of fillers and crystals within the matrix provided the nano-filled composites with a more profound masking ability relative to glass ceramics (25).

Though both the pre-cured and direct composite veneered groups demonstrated low (ΔE) values, yet the amount of color difference for the Crea.lign veneered group was lower than that for the HIPC veneered group. This finding is well-explained through the reduced translucency parameter of the direct veneering composite resins relative to the pre-cured CAD/CAM composite resins. Such reduced translucency is manifested as an increase in the material's opacity which in turn enhances the masking ability of the direct composite veneering material. Consequently, a reduced effect of the underlying PEEK core is observed with a significant decrease in the amount of color difference (26).

Analysis of the effect of the veneering material on the amount of color difference alone without simulated aging won't be sufficient since dental materials placed intra-orally are under continuous exposure to variable mechanical, thermal and chemical influences. Thus, in our study this effect of aging was simulated through thermal cycling by subjecting all specimens to thermal variations with baths between 5 to 55°C for 5000 cycles simulating 6 months of intra-oral service (22).

Thermocycling resulted in a significant decrease in the mean (ΔE) in both the IPS e.max CAD and HIPC veneered groups where a* and b* color parameters showed a marked shift into a positive direction (27).

Such results are supported by a previous study carried out by **Ashy et al.** (28) who showed that thermocycling caused an increase in both a* and b* values expressing more reddish and more yellowish shades when dual cured resin cement was used under high translucency monolithic lithium disilicate. This change could be attributed to the degradation of the unreacted polymers of the resin cement in the polymerization process, oxidation of the unreacted carbon double bonds, dehydration, and water sorption (29).

On the other hand, the increase in mean ΔE value for Crea.lign group, is thought to be due to the shift of the a* and b* values away from the compared A3 color parameters.

These findings were in accordance with **Lee et al**. (30) and **Yu et al.** (31) who demonstrated similar pattern to the current study. Nevertheless, the difference in the amount of color change between Crea.lign and HIPC in the current study after exposure to water during thermocycling can be due to the different nature of the matrix and could also be correlated with filler particles size (32).

Though there was a varying effect for both the veneering material and thermocycling on the amount of color difference, yet all (ΔE) values were clinically unacceptable except for the pre-thermocycled Crea.lign and the post thermocycled HIPC veneered groups since it was suggested that the perceivable color difference for 50% of the dentists was ΔE 2.6 while that at which 50% of the dentists would go for remake of the restoration due to color mismatch was 5.5 units (10).

Along with the final color of a restoration, translucency is deemed as a critical factor in the esthetic demand while aiming to mimic the natural appearance of the restorations. In the present study, rather than constant ratio, translucency parameter was chosen for translucency measurement as it corresponds directly to the common visual assessment (33).

Shedding the light on the (TP) values in our current study, it could be seen that the veneering material used had an impact on TP with IPS e.max CAD veneered group showing the highest values when specimens were tested before thermal cycling. This could be due to the inherent high translucency of the lithium dislicate glass ceramic itself (17).

Considering the effect of thermal cycling, literature has been contradicting regarding its effect on the optical properties and the color stability of PEEK (21, 22).

As per our results, thermal cycling caused a significant increase in (TP) values in both HIPC and Crea.lign veneered groups with no noticeable effect on IPS e.max CAD veneered group. Such findings support the claim that thermal cycling has no significant effect on the optical properties of PEEK itself (21). Rather, this increase in (TP) can be attributed to the change of the refractive index of the composite resins where the thermal fatigue induced by thermocycling is known to cause a change in the properties of the resinous polymer matrix (34). It has been stated in literature that thermal cycling is associated with water sorption causing hydrolytic breakdown and degradation of the matrix-filler interface and the surface of the filler particles. Additional, several studies have reported that soaking resin composite in aquas solution has resulted in a water diffusion-controlled process associated with leaching of the unreacted monomers and swelling of the matrix. These changes can contribute to changes of the refractive index between the resin matrix and the inorganic filler (35, 36).

However, the mean TP values of the specimens in our study were all in the interval of 0.5–1.9, which can be considered relatively opaque compared to the natural tooth where the mean TP values of enamel and dentin range between 16.4 and 18.7 respectively. Therefore, these differences in (TP) values with different veneering materials either before or after thermal cycling may not be significant in clinical practice and it can be concluded that PEEK cores are highly opaque to be used for an esthetic restoration regardless of the veneering material (37).

5. CONCLUSIONS

Considering the limitations of this current study, we can conclude that Crea.lign veneered PEEK restorations gave far much better results in terms of color reproduction when compared to other veneering techniques, yet translucency of lithium disilicate veneered PEEK cores was the best among all groups. However, it was clear that all the veneering techniques rendered an amount of color difference that was clinically unacceptable, as well as displaying much lower translucency levels than that of natural enamel and dentine.

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