Evaluation of the effects of porcelain firing cycles on the marginal fit changes of porcelain–fused–to–metal crowns constructed utilizing two different marginal designs and alloys

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ABSTRACT

In this study the marginal fit changes that occurred during the porcelain firing cycles of palladium–silver alloy (Pd–Ag) and nickel–chromium alloy (Ni–Cr) coping both with shoulder and heavy chamfer facial finishing lines were investigated with light microscope.

Forty copings were fabricated which were divided into four groups according to alloy type and facial finishing line, each group consisted of ten copings: Group I (Pd–Ag) alloy copings with shoulder finishing line; group II (Pd–Ag) alloy copings with heavy chamfer finishing line; group III (Ni–Cr) alloy copings with shoulder finishing line; and group IV (Ni–Cr) alloy copings with heavy chamfer finishing line.

Five control metal copings (non veneered) from each group were subjected to exactly the same firing cycles without the application of porcelain.

Measurements were made during five stages of crown fabrication: (1) Before degassing, (2) after degassing, (3) after opaque application, (4) after body porcelain application, and (5) after glazing. Changes in the marginal fit of the coping after the various firing stages were calculated for each coping.

The statistical analysis of the results showed that the mean marginal fit changes during porcelain firing cycles of the base metal alloy copings (Ni–Cr) were significantly greater than those of noble metal alloy copings (Pd–Ag).

الخلاصة

الغرض من هذه الدراسة هو تقويم تأثير نوع المعدن المستخدم في صناعة التيجان الخزفية ونوع حافة التحضير على التغير في ضبط حواف التيجان أثناء مراحل طبخ الخزف وذلك باستعمال المجهر الضوئي المتنقل.

تم تصنيع أربعين تاجا وقد قسمت إلى أربع مجاميع حسب نوع المعدن وحافة تحضير السن الوجهية وقد تألفت كل مجموعة من عشرة تيجان و كالآتي: المجموعة الأولى: تيجان مصنعة من معدن باليديوم– فضة مع حافة تحضير كتفية؛ المجموعة الثانية: تيجان مصنعة من معدن باليديوم– فضة مع حافة تحضير مشدوفة بعمق؛ المجموعة الثالثة: تيجان مصنعة من معدن نيكل– كروم مع حافة تحضير مشدوفة كتفية؛ المجموعة الرابعة تيجان مصنعة من معدن نيكل– كروم مع حافة تحضير مشدوفة بعمق.

من كل مجموعة استخدمت خمسة تيجان لتشكل مجموعة سيطرة وذلك بتعريضها لنفس مراحل الطبخ دون استخدام الخزف.

وقد تمت القياسات خلال خمس مراحل لتصنيع التيجان الخزفية وكالآتي: ١. قبل أكسدة المعدن؛ ٢. بعد أكسدة المعدن؛ ٣. بعد وضع الطبقة الخزفية الخاصة بحجب لون المعدن؛ ٤. بعد وضع الجسم الخزفي؛ ٥. بعد التزجيج. إن التغير في ضبط الحافة لكل تاج قد حسب بعد مراحل الطبخ.

أظهرت نتائج التحليل الإحصائي إن معدل التغير في ضبط حواف التيجان المصنعة من سبيكة معدن النيكل– كروم كان اكبر بصورة واضحة من التيجان المصنعة من سبيكة معدن الباليديوم– فضة.

The copings with heavy chamfer finishing line showed significantly greater marginal fit changes during porcelain firing cycles than those with shoulder finishing line.

The greatest amount of marginal fit changes occurred during the degassing stage of porcelain firing cycle followed by body stage of porcelain firing cycles while there were no significant marginal fit changes in the other stages of porcelain firing cycles.

Key Words: Porcelain, marginal changes, alloys.

كما أظهرت النتائج الإحصائية إن حافة التحضير الوجهية المشدوفة بعمق قد سجلت تغيرا واضحا مقارنة بحافة التحضير الكتفية خلال مراحل طبخ الخزف.

حيث إن التغير بدا جليا خلال مراحل الطبخ الأولى (الأكسدة) تليها مرحلة طبخ الجسم الخزفي في الوقت الذي لم يسجل تغيرا واضحا في ضبط حواف التيجان خلال بقية مراحل طبخ الخزف.

INTRODUCTION

The porcelain–fused–to–metal (PFM) restoration have been one of the most common restorations used in fixed prosthodontics because of their casting accuracy, high strength properties of the metal, and the cosmetic appearance of porcelain.[1] In spite of the variables that exist in the fabrication and function of these restorations, the PFM restorations still form the backbone of modern restorative dentistry despite many new systems.[2]

It has been widely observed that the as-cast fit of PFM restoration deteriorated during the high temperature firing cycles used for porcelain veneer application.[3] Studies on marginal fit changes have identified many factors, such as the mismatch of the porcelain–metal thermal contraction, alloy type, and preparation design, as contributing to the distortion. Considerable controversy continues to exist in the literature with regard to the effect of these factors.

The aim of this study was to evaluate the effects of porcelain firing cycles on veneered and non–veneered PFM crowns constructed utilizing two different finishing lines and two different alloys.

MATERIALS AND METHODS

A brass model representing upper central incisor was prepared for PFM crown with heavy chamfer finishing line labially to mid proximal surfaces.

A dental surveyor was modified and used to prepare the axial walls of the brass model to ensure proper degree of axial tapering. A heavy chamfer margin was formed by means of the round–ended tapered bur and was designed for the labial surface to mid proximal surface. The lingual surface was prepared with conventional chamfer margin.

The labial reduction was 1.3 mm and the proximal and lingual reductions were 0.8 mm. The height of the die was 7 mm, with a convergence of 6 degrees.

The prepared sample with heavy chamfer facial finish line, was duplicated in polyvinyl siloxane impression material and poured in inlay wax, invested and casted in nickel–chromium (Ni–Cr) alloy to provide a reference that would be not easily damaged.

Two master metal dies were produced. The heavy chamfer facial finish line of one master die was changed to shoulder finish line, using bur no. 25, producing a finish line characterized by 1.3 mm width with flat 90 degree internal angle.

To create a wax pattern of uniform thickness of 0.5 mm, a split mold was fabricated for each margin design. A split mold framework of steel was turnicated, with two halves to facilitate wax pattern removal. The two metal halves of the split mold could be fixed to each other by two pins in one half and two corresponding pin–holes in the other half. The two halves were then screwed to each other with U–clamp.

A total of 40 wax patterns, 20 with shoulder facial finish lines, and 20 with heavy chamfer facial finish line, were obtained.

The patterns were sprued with a 3mm thick, 6 mm long round wax sprue, each ten wax patterns were sprued together to ensure

that each group would pass through the same investing and casting procedure.

The wax patterns were invested in metal casting rings (size 3X) immediately which were lined with a single layer of ring liner that was wetted by submersion in water, the wax patterns were painted with surface tension reducing agent, then they were gently blown dry and invested in phosphate bonded investment.

All castings were made using the same casting pressure (four turns). The castings were allowed to bench cool to room temperature. Half of the copings of each margin design were casted in a palladium–silver (Pd–Ag) ceramo–metal alloy (Quayle Dental, England) and the other half were cast in a Ni–Cr ceramo–metal alloy (Heraenium NA, Germany). Only new metal was used for each casting.

The castings were then divested and cleaned manually. It is important not to use abrasive materials, which will remove the metal from its surface. The internal surface of each casting was inspected using a magnifying lens for the presence of minute internal nodules that prevented complete seating, which were removed with a round carbide bur at high speed, copings which well fitted their respective dies without any appreciable adjustment were only used.

The external surfaces of the copings were finished sequentially with coarse green and fine white stone burs. The thickness of the finished copings were verified with a caliper (accuracy 0.01 mm) and found to be 0.4 mm. Each coping was kept in a plastic container, which was known and numbered. The copings were then replaced on the mounted dies to measure the marginal fitness.

Copings were degassed (oxidized) according to manufacturer's instructions for Pd–Ag and Ni–Cr alloys.

The final opaque layer of porcelain was approximately 0.3 mm thick.

For the body porcelain stage, a metal jig was constructed to create a uniform contour.

The body porcelain (Vita 95,Germany) was mixed to a creamy consistency with distilled water and applied in two stages. The coping was transferred to the metal jig, and body porcelain was built to the contours dictated by the proximal surfaces of the jig by using a knife attached to the proximal surfaces of the jig. Then the copings were removed from the jig and then dried and baked according to manufacturer's instructions, then a correction bake for incisal and body porcelain was accomplished, using the same procedures, no grinding was done, then the copings were mounted on dies and measured.

The non–veneered copings underwent the same temperature of the glazing cycle similar to the veneered copings.

After the glaze stage (Vitachrom), each coping was mounted on the die and measure.

A measuring microscope (Carlzeiss, Jena, Germany) equipped with mechanical micrometers calibrated to 0.001 μm at 200x magnification was used. The marginal fit change was determined by measuring the space (marginal opening) between the margin of the coping and reference mark on the master die.

The metal die was held in a specially made plastic (resin) block during measurements. Reference marks on the metal die and plastic block were placed to orient the metal die in a fixed repeatable position in the plastic block during each stage of measurement

Easily identifiable reference mark at midpoint of each metal die on the labial surface apical to the cavosurface line angle was used as a point of origin for all future measurements. The measurements were determined by measuring between the reference mark on each die and the most apical point on the margin of the coping in a direction parallel to the long axis of the die and expressed as marginal fit changes.

A screw holding device (specimen holder) was fabricated to seat the coping on the metal die. Measurement between the identified reference mark and the coping was repeated three times. The marginal fit changes value for each coping was the arithmetic mean of these six measurements, so a total of six measurements per coping were made after each firing cycle.

Measurements were made during five stages of crown fabrication: (1) After casting; (2) after degassing; (3) after opaque application; (4) after body and incisal porcelain application; and (5) after glazing. Changes in the marginal fit of the coping after the

various firing stages were calculated for each coping.

The samples were divided into four groups according to the types of finishing line and alloy, each group consisted of ten copings as follow:

Group I: Pd–Ag alloy copings with shoulder facial finish line.
Group II: Pd–Ag alloy copings with heavy chamfer facial finish line.
Group III: Ni–Cr alloy copings with shoulder facial finish line.
Group IV: Ni–Cr alloy copings with heavy chamfer facial finish line.

Five copings from each of the four experimental groups of ten copings were used as non porcelainized control copings. The control copings completed the porcelain firing cycles along with the other five porcelainized copings within each group.

RESULTS

The mean of marginal fit changes and standard deviations for the non–veneered copings and veneered copings of group I (Pd–Ag alloy with shoulder margin), group II (Pd–Ag alloy with heavy chamfer margin), group III (Ni–Cr alloy with shoulder margin), and group IV (Ni–Cr alloy with heavy chamfer margin) during different firing cycles with the total marginal fit changes of each group with standard deviation are presented in Table (1).

The values listed are the changes between the prefiring measurement and various porcelain firing cycles. For example the mean marginal fit changes calculated for the group I after degassing, opaque porcelain, body porcelain, and glaze firing cycles were 12.44, 1.24, 3.33, and –0.65 μm respectively. The total marginal fit change for the group I from the prefiring and to after glazing was 16.36 μm evaluated by the summation of mean marginal fit changes for all firing cycles.

The highest mean scores for marginal fit change for the tested groups happened in the degassing stage with group IV showing the highest mean (34.05 μm) followed by group II (28.84 μm). Both groups having the heavy chamfer finish line in common.

On the other hand, group III and group I showed less marginal fit change (18.03 and 12.44 μm respectively). Both groups having the shoulder type finish line in common.

In the opaque, body porcelain and glaze firing cycles, groups I and III had also lower scores than groups II and IV. In general, the glaze firing cycle had the lowest effect on marginal fit changes on all groups than the previous firing cycles.

The lowest mean marginal fit change for all firing cycles was scored by group I (16.36 μm) followed by group III (26.19 μm) while group IV scored the highest mean value (44.14 μm) (Ni–Cr alloy with heavy chamfer) as shown in Table (1).

Table (1): The descriptive statistics of the mean marginal fit change values of groups I to IV including standard deviation

Firing Cycle	Group I	Group II	Group III	Group IV
	Mean* ± SD	Mean* ± SD	Mean* ± SD	Mean* ± SD
Degassing	12.44 ± 0.90	28.84 ± 1.62	18.03 ± 1.28	34.05 ± 1.28
Opaque	1.24 ± 0.28	1.49 ± 0.37	1.09 ± 0.19	1.47 ± 0.15
Body	3.33 ± 1.73	8.96 ± 3.18	7.68 ± 3.48	9.69 ± 4.76
Glaze	-0.65 ± 0.20	-1.39 ± 0.46	-0.61 ± 0.12	-1.07 ± 0.25
Total	16.36 ± 1.71	37.91 ± 3.72	26.19 ± 4.31	44.14 ± 4.32

* Mean in μm.
SD: Standard deviation.

In Table (2) statistical analysis of variance (ANOVA) among groups during each firing cycle revealed that there was highly significant difference among the four groups at degassing, opaque, body and glaze stages of firing cycles.

The source of difference was investigated by further analysis of the data to examine the difference between different pairs of the different groups, using the least significant differences test (LSD).

Table (2): Analysis of variance ANOVA test for comparison among groups

Firing Cycle	Source of Variance	Sum of Squares	d.f	Mean Square	F–test	Significance
Degassing	Between Groups	2919.60	3	973.20	586.13	0.000
	Within Groups	59.77	36	1.66		HS
	Total	2979.37	39			
Opaque	Between Groups	1.11	3	0.372	5.52	0.003
	Within Groups	2.42	36	6.73 E–02		HS
	Total	3.54	39			
Body	Between Groups	243.20	3	81.07	6.77	0.001
	Within Groups	431.43	36	11.98		HS
	Total	674.63	39			
Glaze	Between Groups	4.07	3	1.36	16.60	0.000
	Within Groups	2.95	36	8.18E-02		HS
	Total	7.02	39			

HS: Highly significant difference.
d.f: Degree of freedom.

Effect of Preparation Margin Design

As shown in Table (3) there was a highly significant difference between groups (I and II), (III and IV) in the total marginal fit changes .

Effect of Alloy Type

As shown in Table (3) there was a highly significant difference between groups (II and IV), (I and III) in the total marginal fit changes.

Table (3): Least significant difference test for comparison between groups

		Degassing	Opaque	Body	Glaze	Total
		Mean Differences				
Effect of Margin Design	Group I	16.40	0.26	5.6	0.74	21.55
	Group II	HS	S	HS	HS	HS
	Group III	16.02	0.38	2.01	0.46	17.95
	Group IV	HS	S	NS	HS	HS
Effect of Alloy Type	Group II	5.21	2.0E-02	0.73	0.32	6.24
	Group IV	HS	NS	NS	S	HS
	Group I	5.59	0.15	4.35	4.00E-02	9.84
	Group III	HS	S	S	NS	HS

HS: Highly significant difference.
S: Significant difference.
NS: Non–significant difference.

Effect of Firing Cycles

As shown in Table (4), degassing and body stages of porcelain firing cycles showed highly significant difference when they were compared with other stages of porcelain firing cycles, while comparison between opaque and glaze firing cycles revealed no significance difference.

Table (4): Least significant difference test for comparison between firing cycles

Firing Cycle		Mean Difference	Standard Error	Significance
Degassing	Opaque	22.02	1.08	HS
Degassing	Body	15.93	1.08	HS
Degassing	Glaze	24.27	1.08	HS
Opaque	Body	6.09	1.08	HS
Opaque	Glaze	2.25	1.08	NS
Body	Glaze	8.34	1.08	HS

HS: Highly significant difference.
NS: Non–significant difference.

DISCUSSION

The marginal "fit" of any dental restoration is vital to its long–term success. Lack of adequate fit is potentially detrimental to both the tooth and the supporting periodontal tissues.[4]

Dentists are concerned with the quality of the marginal fit of a restoration because of the biological ramifications. By minimizing the degree of marginal opening, the surface of the exposed cement will be decreased, reducing the rate of dissolution of cement that occurs in oral fluids.[5]

The fabrication of PFM restorations necessitate the application of different stages of firing cycles.

The marginal fit changes in the body stage of firing cycle could be attributed to factors such as thermal incompatibility stresses, contamination of the internal surfaces of the coping with porcelain, and reduction in the resilience of the metal because of the rigidity of porcelain.[6]

Anusavice and Carroll[7] attributed the deterioration of the marginal fit to be a result of contamination of the inner surface of the copings with porcelain, taking the form of porcelain nodules or of foreign metals that have alloyed with the casting during firing and caused grain growth. They advised that such incomplete seating due to contamination might be corrected by acid etching of the metal coping or by mechanical relief through sandblasting the inner fitting surface for short interval (3 sec) using 20 μm particle size of Al_2O_3 abrasive with low air pressure.

The results of this study agreed with those of Iwashita *et al.*,[8] Faucher and Nicholls,[6] Gemalmaz and Alkumru[9] and Gemalmaz *et al.*[10] On the other hand, our results disagreed with Buchanan *et al.*[11] and Ritcher–Snapp *et al.*[12] who found that there were no differences in the marginal opening associated with porcelain veneer, but in those studies, specific sophisticated measures were followed to remove any traces of body porcelain that could contaminate the internal surfaces of the coping post firing.

When comparing group I with group II and group III with group IV, statistically high significant differences were shown between them (Table 3). The copings made from noble and base metal alloys tested in this study, exhibited significantly less marginal fit changes using the shoulder type finishing line when compared to those made using the heavy chamfer design. This could be attributed to the extra bulk of metal in the internal angle of the shoulder design which reinforced that design, and thus inhibited marginal fit changes.[13]

In this study, the mean amount of opening exhibited by the heavy chamfer design of Pd–Ag alloy, group II 37.91 μm and that by Ni–Cr alloy, group IV 44.14 μm were large enough to be of clinical significance if added to the openings which are inherent in most castings before the copings are subjected to the firing cycle and the latter opening that could result after cementation of the crown due to cement film thickness. The total of marginal gaps could exceed the range of clinical acceptability.

Recognition of the inherent marginal fit changes associated with heavy chamfer margins following veneering procedures is of even greater importance when multiple abutments are used, as in fixed prosthesis.

Absence of fit will be compounded by the number of units acting as retainers.[6]

The finding presented here tended to agree with Shillingburg *et al*.[13] and Faucher and Nicholls,[6] and disagree with Hamaguchi *et al*.,[14] Dehoff and Anusavice[15] and Gemalmaz and Alkumru.[9]

In comparing group II with group IV and group I with group III, there were statistically highly significant differences between them (Table 3), Pd–Ag alloy copings using both shoulder and chamfer designs produced significantly better marginal fit than Ni–Cr alloy copings in both designs.

Buchanan *et al*.[11] attributed the larger marginal discrepancy of Ni–Cr alloy copings to the formation of a thicker oxide layer on the casting surface inside the coping. They added that in a coping with a 5 degree taper (10–degree convergence angle) a 6 μm layer of metal oxide can cause an opening of 70 μm at the margin.

The findings of this study agreed with Buchanan *et al*.[11] and Dederich *et al*.,[16] while it disagreed with Ritcher–Snapp *et al*.[12] who found that there were no significant differences between noble and base metal copings. Also Gemalmaz and Alkumru[9] found that the base metal copings revealed significantly smaller marginal fit changes than the noble metal copings. The possible explanation of that disparity could be due to different metal–ceramic systems.

It has been reported that residual stresses resulting from cold working, casting and polishing processes could be released during the first firing stage and coping distortion may occur due to that. The relaxation of residual stresses seemed to account for a major part of the observed distortion.

The loss of marginal adaptation that occurred during oxidation of the metal may be minimized when the initial thermal cycling was completed before the specimens were cold worked.

It is recommended that the intraoral fit of PFM restorations can best be accomplished by trying the casting on after the initial thermal cycling has been completed. This would allow for a more appropriate assessment of the final fit of the prosthesis, since it has been reported that most of the marginal fit changes of the metal coping during thermal cycles of porcelain could happen during this initial heating cycle.

In this study, the fit of porcelain–fused–to–metal copings tested deteriorated after body porcelain application. The body stage of porcelain firing cycle showed an increase in marginal opening of all the tested groups which was statistically high in significance, but the magnitude of marginal fit changes was smaller than that which occurred at the degassing stage.

Porcelain application on metal coping could cause an increased rigidity of the PFM prosthesis which may result in a further loss of the fit since the alloy can no longer flex as it is being seated on the die. The distortion at body stage of firing cycle could not be attributed to the thermal mismatch because thermally compatible metal–ceramic system was used in this research. The results here are in consistent with that of Shillingburg *et al*.[13] and Gemalmaz *et al*.[10]

CONCLUSIONS

The conclusions drawn from this study are :

1. Veneered crowns exhibited high significant marginal distortion than non-veneered copings at body porcelain firing cycle.
2. The shoulder marginal design exhibited significantly less distortion than the chamfer design.
3. The precious alloy (Pd–Ag) crowns revealed significantly smaller marginal fit changes with both shoulder and chamfer margins in comparison to the non-precious alloy (Ni–Cr) crowns.
4. The highest values of marginal fit change of the PFM crowns tested were found at the degassing (oxidation) and body porcelain firing cycles.

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Received: 10/12/2002 ***Accepted for Publication: 22/1/2003***