The Effects of Coping Design and Firing Temperature to the Marginal Adaptation of Metal Porcelain Crowns

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Abstract

The metal-porcelain crown is one of the restorative techniques in dentistry to improve aesthetic value via mechanical properties, well-adapted characteristics, but the esthetic properties in metal-porcelain appear to be unsatisfied features due to the presence of darker shades in cervical area; thus, it is necessary to design collarless coping. In this study, three designs were performed, i.e. metal collar, full metal collarless, and modified metal collarless, in which all of these designs were heated in temperature at 950°C and 975°C. The aims of this study are to investigate the effects of coping design and firing temperatures to the marginal adaptation of metal-porcelain crowns. The preparation and duplication of incisivus centralis typodont were designed via CAD/CAM scan, and the materials for fabricating the samples were zirconia with total of 30 samples of metal-porcelain. The application of opaque layers for the three designs were composed of dentine, enamel and glazing layers. The measurement of marginal adaptation in metal-porcelain samples were performed via stereomicroscope with statistical analysis of SPSS software. Statistical analysis of one-way Anova tests showed significant effects of marginal adaptation among three designs particularly at 950°C of heating temperature with p value for 0.001 ($p < 0.05$), while at 975°C of firing temperature, it contributed to p value for 0.001 ($p < 0.05$). A decrease in temperature demonstrated smaller average value of marginal adaptations in all designs than that made from commercial products, which are 61.69±1.13 µm for metal collar, 87.70±0.72 µm for full metal collarless, and 66.71±1.29 µm for modified metal collarless. The independent t-test showed significant results between 950°C and 975°C for all three designs which p equals to 0.001, indicated the $p < 0.05$. The designs of modified metal collarless had the best marginal adaptation value with the smallest gap in this study. Thus, it is recommended to clinical application in cases that require maximum aesthetical restoration.

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Introduction

Highly-popularity of metal-porcelain fixed denture among dentists are still being used. This is due to the well-adapted marginal value of the metal-porcelain denture, providing natural esthetic translucent characteristics of the porcelain and high mechanical properties of metal. However, the esthetic optimal feature appears to be unsatisfactory as conventional restoration is not achieved particularly in margin labio gingival area. Grey discolouration occurs in a-third cervical parts in the thin porcelain restoration, which causes darker shades in the adjustment of opaque layers and gingiva tissues[1,2]. In 1956, Brecker introduced the use of metal collar as denture material to improve esthetic feature in cervical parts, in which this material becomes the supporter to strengthen and prevent damages during the sintering cycles of temperature of porcelain. Although this emerges dark shades below the gingiva tissues which affects the esthetic displays, it has improved esthetical aspects compared to those made from metal margin[3,4].

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Based on the classification of dental porcelain material, sintering temperature of porcelain follows the low fusing parameter in between 850°C to 1100°C[5], and commercial standards of fabrication for porcelain is at 950°C. To laminate the opaque, dentine and enamel layers, McLean has suggested that the sintering temperature should have been higher at 20°C compared to that performed by manufacturers[6]. Meanwhile, it has been reported that highly-bonding strength were obtained at 975°C within argon or vacuum conditions[7].

Porcelain is an insulator material with medium thermal expansion coefficient which resembles to original tooth. During the sintering, the left water contents are evaporated as well as the removal of bonding agents which generates 10%-30% of shrinkage volume; this shrinkage causes distortion[8]. The build-up correction and distortion in marginal feature of porcelain during the sintering affects marginal adaptation features, and the shrinkage during the sintering process becomes significant causative factor which leads to distortion[9,10]. Therefore, precise control in condensation and sintering techniques are necessary to balance the shrinkage value during the construction of porcelain crowns[11–13].

The marginal adaptation is an essential factor in term of restorative achievements[14]. A study has reported that the marginal adaptation in the conventional restoration by utilizing porcelain-fused-to-metal is affected by high-temperature of firing[15]. Dimensional alteration occurs during the casting stage, and it causes distortion to the alloy which is the residual stress release from the casting and oxidation steps. A well-adapted marginal could preserve sufficient lifetime of restoration, while poor-adapted marginal implies to imperfect margin, so tooth tends to have sensitive characteristics and to increase plague. It has been confirmed in *in vitro* study, relatively certain volume of microleakage was statistically obtained, indicated by dye penetration within dog and bovine primary teeth[16]. As a result, calculus and gingivitis are occurred as the penetration of liquids, debris, as well as microorganisms into a gap area between the restorative denture and wall braces, which initiates early periodontal damages and tooth loss[14,17].

Although marginal adaptation is a fundamental factor in clinical achievements, no consensus in term of maximum width of marginal gap which can be accepted clinically. The number of widths that have been reported to be considered acceptable is in between 50 – 200 µm, so no objective limitation which is based on scientific reasons is demonstrated[17,18]. McLean and Von Fraunhofer have investigated marginal gap concrete up to 120 µm as a clinical acceptable limit, and in five years within 1000 restoration, they have concluded that this number is a considerable limitation[15,19–21].

Full metal collarless coping design could replace the metal collar by utilizing the porcelain layer within marginal area. The opaque colour of the metal is an alternative solution in this area particularly for the insufficient preparation. It has been reported that the conventional collarless crowns have exact marginal values of modified coping design. This internal exact number is commonly lower than that in external marginal on the facial surface, so that the modified design with shortening edge at the end of metal layers (around 1-2 mm from the cervical area) can solve the esthetic issue[7,22].Thus, this study aims to evaluate the effects of three coping designs (metal collar, full metal collarless, and modified metal collarless) and firing temperatures to the marginal adaptation of metal-porcelain crowns.

Materials and methods

Sample Fabrication

The preparation of typodont structure tooth was carried out by using micromotor and handpiece attached to surveyor to determine recommended thickness. This procedure was performed based on previous studies[10,23]. In brief, the samples were designed with the reduction of 2 mm in incisal, while the depth guides as the preparation guidance was carried out for 1.5 mm in labial area.

The reduction was also done in area of proximal and palatal which accounted for 1 mm each, and this reduction generated shoulder shape in cervical area for 1.5 mm in the area of labio-marginal to the mesio-distal to be united in palatal area.

A CAD/CAM procedure was performed to scan the samples which subsequently was converted into die zirconia. The zirconia tooth roots were implanted into square-shaped acrylic resin swapolymerization beams to form zirconia with the dimension of 3 cm x 3 cm x 3 cm.

Fabrication of Metal Ni-Cr Coping

Firstly, spacer application was performed onto the surface of dai with the exception of 1 mm in marginal gaps. Then, coating process was carried out by utilizing liquid inlay wax followed by thickness measurement with caliper. The samples were then fabricated into three groups, and they are group A, B, and C which are composed of 10 unit of inlay wax crowns respectively. For group A, the position of the inlay wax was placed exactly in the area of labio marginal (0.3 mm), and for group B, the inlay wax was positioned only at the edge of surface area of labio marginal (0.3 mm), while the group C had the inlay wax on 1.5 mm of surface area of labio marginal.

The assembly step for all 30 green inlay wax was performed, and the implantation into moffel was carried out by using investment gyps with ratio of powder and liquid in accordance of manufacturer instructions in vacuum mixer. The burn out procedure was done via burn out oven in which the casting procedure took final composition to reach Ni for 61.27%, Cr 26.44%, Mo for 10.46%, Mn 0.001%, and C for 0.02%. Then, the sandblasting procedure was also conducted by involving alumina sand with 50 microns in the sandblasting machine. Afterward, the samples were oxidized inside vacuum furnace at 980°C, and finally the samples were purified in ultrasonic cleaning with distilled water for 10 minutes.

Porcelain Layers Applicating

The applicating of opaque layers in all groups with 0.3 mm on the metal Ni-Cr was performed via vibrating condensation sequences for 10 times, and these samples were placed in firing temperature at 950°C and 975°C which were accounted for 15 samples (5 from each group), and 15 samples (5 from each group too). Then, the dentin layers applicating on the opaque layers were carried out via vibrating condensation too with 10 times of repetition, however, the sintering temperature was performed at 940°C and 965°C for 15 samples respectively. Next, the applicating of enamel layers on the dentin was performed via heating treatment at 930°C and 955°C for 15 samples respectively, and finally the glazing process was done at 920°C and 945°C respectively. The following Figure 1 shows the flowchart of porcelain layers applicating.

Marginal Gap Measurement

All the samples of metal-porcelain crowns were measured to determine the marginal by using stereomicroscope. The basic model of dai zirconia was marked by reference lines on the facial surface, which are proximal mesial (Line A), in between mesial and middle area (Line B), middle (Line C), and in between middle and distal (Line D), and proximal distal (Line E). The measurements were done with the support of computer software Axiovision Rel. 4.8 from the edge of metal porcelain crowns to the edge of the ends of cervical dai zirconia within the five lines of reference.

Results

The Fabrication of Typodont Tooth and Dai Zirconia Case Report

The results of marginal gap measurements were performed via Axiovision Rel. 4. 8 software in micrometer. It can be seen that the smallest marginal gaps among the groups were found in metal collar coping with firing temperature at 975°C, accounted for 60.58 µm. On the other hand, the highest marginal gap was found in full metal collarless design with firing temperature at 950°C with 113.86 µm, and in the group of metal collar design, the firing temperature at 950° and 975°C contributed for the smallest marginal gap with 88.09 µm and the biggest marginal gap with 90.58 µm. For the design of metal collar coping with firing temperature at 975°C, it contributed to 60.59 µm and 63.44 µm for the highest and smallest marginal gaps respectively, and the metal collarless coping design with temperature of firing at 950°C provided 11.46 µm for the smallest marginal gap, while the highest marginal gap accounted for 113.86 µm.

Then, the full metal collarless coping design which was heated at 975°C, 87.15 µm and 88.69 µm were produced respectively for the highest and the lowest marginal gaps. On the other hand, the modified metal collarless coping design for 950°C and 975°C had the highest marginal gaps respectively for 93.84 µm and 68.15 µm, while their smallest marginal gaps were obtained for 91.56 µm and 64.87 µm in respective way. The following table 1 highlights the samples average marginal gaps for every design.

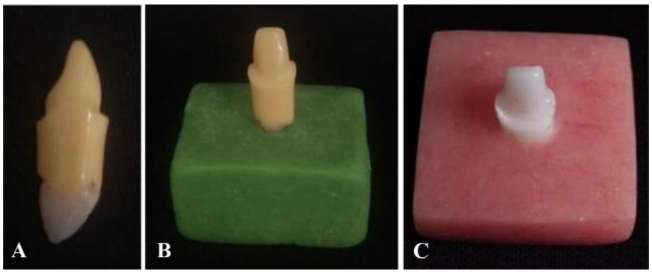

Figure 1. The Photographic Image of Samples (A) Typodont Tooth that have been prepared, (B) Typodont Tooth Attached to a Base, and (C) Dai Zirconia.

The Fabrication of Metal Coping Samples

Figure 2. Wax-Up Coping Photographic Images, (A) inlay wax was placed exactly in the area of labio marginal (0.3 mm), (B) inlay wax was positioned only at the edge of surface area of labio marginal (0.3 mm), (C) inlay wax on 1.5 mm of surface area of labio marginal .

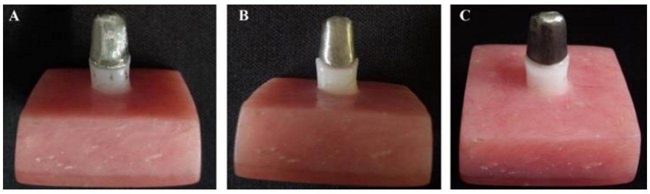

Figure 3. Metal Coping Photographic Images, (A)Metal collar, (B)Full metal collarless, (C)Modified metal collarless.

Samples Measurement

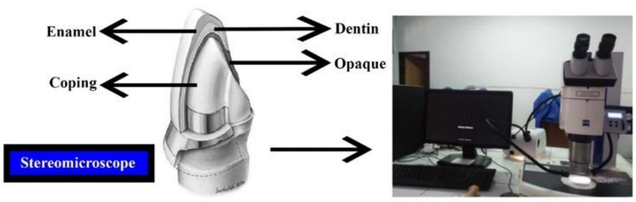

Figure 4. The Schematic Illustration of Marginal Gap Measurements.

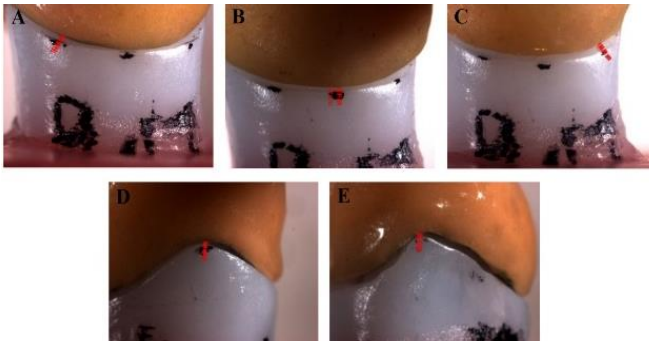

Figure 5. Marginal Gap References Points of Measurements, (A) Middle Distal, (B) Middle, (C) Middle Mesial, (D) Proximal Distal, (E) Proximal Mexial.

Samples	A Metal Collar (µm)		B Full Metal Collarless (µm)		C Modified Metal Collarless (µm)	
	950˚C	975 ˚C	950 ˚C	975 ˚C	950 ˚C	975 ˚C
1	90,58 **	63,44 **	113,86**	87,15 *	91,88	67,12
2	88,09 *	62,17	113,44	87,19	93,77	67,42
3	88,89	61,01	113,14	88,69 **	93,84**	68,15**
4	88,81	61,25	111,46 *	87,21	92,27	65,99
5	88,50	60,59 *	113,35	88,26	91,56 *	64,87 *
X± SD	88,97±0,95	61,69±1,13	113,05±0,93	87,70±0,72	92,66±1,07	66,71±1,29

Table 1. Samples Statistical Average Measurement.
*the smallest measurements, and **the highest measurement.

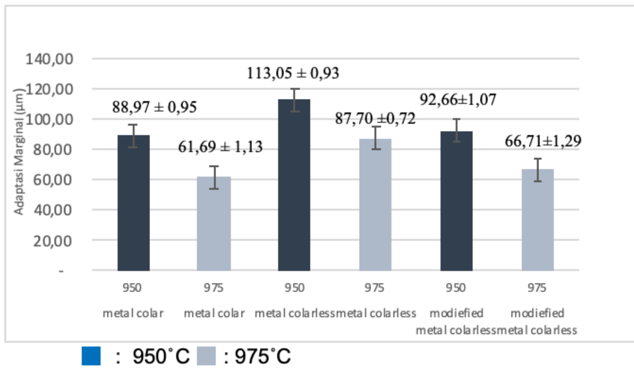

Figure 5. Marginal Adaptation Results of Samples.

Based on the One Way Anova test, significant differences with p value = 0.001 ($p < 0.05$) were obtained, and this implies to the presence of significant effects on the different designs to the marginal adaptation of metal-porcelain crowns at 950^{o}C of firing temperature. The following Table 2 displays the Anova test results.

As the average measurement of marginal gaps were found, univariant tests were performed to analyse for the average gap values. For the metal collar coping design with the temperature of firing at 950^{o}C and 975^{o}C had the average gaps for 88.97 μm (±0.95 μm), and 61.69 μm (±1.13 μm) respectively, while the full metal collarless in respective order had 113.05 μm (±0.95 μm) and 87.70 μm (±0.72 μm). In the meantime, the modified metal collarless coping design at 950°C contributed for 92.66 μm with ±1.07 μm averagely, whereas the firing temperature at 975°C was accounted for 66.71 μm with ± 1.29 μm. In order to observe the gap error of the samples, the following Figure xx displays the error bar of every sample design.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1681.431	2	840.716	866.074	.000
Within Groups	11.649	12	.971		
Total	1693.080	14			

Table 2. Anova Test Results at 950°C T_950.

Coping Designs	Marginal Adaptation		
	N	$\bar{X} \pm SD$	P
Metal Collar	5	88.97±0.95	0.001
Full Metal Collarless	5	113.05±0.93	
Modified Metal Collarless	5	92.66±1.07	

Table 3. Statistical Results of Samples Designs with Firing Temperature at 950°C.
*Significant (p<0.05)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1903.627	2	951.814	821.410	.000
Within Groups	13.905	12	1.159		
Total	1917.533	14			

Coping Designs	Marginal Adaptation		
	N	$\bar{X} \pm SD$	P
Metal Collar	5	61.69±1.13	0.001
Full Metal Collarless	5	87.70±0.72	
Modified Metal Collarless	5	66.71±1.29	

Table 4. Anova Test Results of Samples Designs at 975°C T_905.
*Significant (p<0.05).

Firing temperatures at 950°C and 975°C in all designs, which all of them had p = 0.001 (p < 0.05). All of the t-test results are displayed by the following Table 5, 6, and 7 below.

Sintering Temperatures	n	Marginal Adaptation of Metal Collar ($\bar{X} \pm SD$)	p
950°C	5	88.97±0.95	0.001
975°C	5	61.69±1.13	

Table 5. t-Test Results of Metal Collar Marginal Adaptation.
*Significant (p<0.05).

Sintering Temperatures	n	Marginal Adaptation of Full Metal Collarless ($\bar{X} \pm SD$)	p
950°C	5	113.05±0.93	0.001
975°C	5	87.70±0.72	

Table 6. t-Test Results of Marginal Adaption of Full Metal Collarless. *Significant (p<0.05).

Sintering Temperatures	n	Marginal Adaptation of Modified Metal Collarless ($\bar{X} \pm SD$)	p
950°C	5	92.66±1.07	0.001
975°C	5	66.71±1.29	

Table 7. t-Test Results of Modified Metal Collarless Marginal Adaptation.
*Significant (p<0.05).

Moreover, at 975°C of firing temperature, significant p value = 0.001 (p <0.05) was obtained which implies to the significant effects in coping design for every sample to the marginal adaptation of metal-porcelain crowns. The Table 4 below displays the Anova test results.

Discussion

In term of average marginal gaps, the metal collar coping design as the control group in this study had the lowest average values among the designs. This finding is in accordance to previous studies that have stated the well-adapted of marginal characteristics for the metal collar design[7,24]. At 975°C of firing temperature, the metal collar design had smaller gap than that made at 950°C. It indicated the presence of shrinkage during the sintering process of porcelain, however, at 975°C, this temperature causes sufficient event for particles to enter the cavities. Subsequently, the porcelain tends to be compact which reduce shrinkage, so well-adapted marginal features are achieved. On the firing temperature at 950°C, particles also move to enter the cavities, however, compactness occur partially which vacate several pores as well as increase the risk of shrinkage to be higher. It has been reported that the shrinkage in porcelain generated contraction within the metals, in which the alteration of marginal adaptation was affected[12].

Shrinkage phenomenon during the sintering of porcelain is the causative factor which significantly affects the distortion feature. This phenomenon has been proven particularly in the early stage of oxidation within the composites before the applicating of porcelain. Furthermore, the assumption that shrinkage in porcelain temperature in causing the metal distortion has been reported to emerge in the early stages by a previous study[13].

The one-way Anova test has implied that the effects of coping design for metal collar, full metal collarless, and modified metal collarless to the marginal adaptation of metal-porcelain crowns at 950°C of firing temperature with p=0.001 (p<0.05) was occurred. As far as metal collar coping design is concerned, this design has complete support from the metal in particular in the labio-marginal area, so that well-adapted of marginal characteristics is accomplished due to the presence of porcelain layer. This layer also has metal supported which strengthen the porcelain to alter its form during the firing cyclic process. Meanwhile, in the coping design of full metal collarless, the metal coping was found in corona axial walls, so that the edge area from the cavities are merely coated by porcelain. This can be observed from the porcelain thickness in cervical parts which had different thickness from the metal collar coping design. Thus, considerable increase of marginal adaptation is higher compared to that from the metal collar design, which is also compared to previous studies[25,26]. On the other hand, at 975°C of firing temperature, a significant result of marginal adaptation was also obtained for all design of metal-porcelain coping, with value p=0.001 (p<0.05). The metal collar design at this temperature had the lowest marginal gaps among the designs, and this is because of the presence metal in reinforcing the porcelain to prevent form alteration within the porcelain layer during sintering.

Moreover, the use of metal coping must have had optimum thickness to prevent distortion by the time it is firing. The thickness size is in between 0.2 – 0.7 mm to achieve acceptable mechanical properties, but the size depends on the process of sample preparation[5,27–29].

In this study, the opaque firing temperature was risen to 25°C higher than that used by the manufacturers, so that bonding strength tents to be improving, which also increased the density of samples or marginal adaptation features. It also has been reported that an improved sintering temperature, the increase to 975°C, could reduce the numbers of pores, which indicates more bonding to be filled by particles[29]. Meanwhile, in full metal collarless coping design, thin porcelain thickness in cervical area was found which differs to metal collar coping design. Whilst, the modified metal collar in this study had smaller coping designs compared to full metal collar in the cervical areas, so that a thicker porcelain layer was found compared to full metal collar design.

Based on t-independent tests for metal collar coping design, a significant effect was found in both firing temperatures in the difference of marginal adaptation gaps. During the firing process of porcelain, metals substructure experiences heating treatment firstly, so that its structure is altered following the changes of temperatures and pressures due to the thermal convection from the porcelain which coats the metal. The thermal resistance contributes to the ability of metals in preventing the form changes due to the pressure caused by the increasing heat[5]. An increasing in firing temperature affects the unification of particles which leads to reduction of pores as well as increasing densities. Subsequently, the shrinkage is experienced slightly which also reduces the metal contraction. On the other hand, the firing temperature which has been performed by manufacturers' standardization generates distortion features due to the high amounts of shrinkage as the results of metals contractions[5,12].

In the design of full metal collarless coping, the marginal adaptation was smaller at 975°C of firing temperature than that at 950°C. It is assumed that the higher amounts of oxide layers during the heating treatments are considered to provide high impacts to the bonding features of metal and porcelain. Hence, the increasing temperature to be at 975°C affects an improved bonding characteristic between metal and porcelain as well as the reduction of pores in term of amounts and sizes. This is in accordance to a study that has reported by Gupta in 2011 in which the smaller pores were obtained by the increasing temperature at 975°C[7]. Another study also has reported that the increasing temperature, the solubility and distribution of porcelain and metals were also increasing. During the process of smelting, alloy compositions and ceramics were able to be melted, whereas their atoms were diffused randomly to form oxide layers as transitional layers. The interaction among porcelain and oxide compositions could have formed a very strong oxide bonds between metal and porcelain. These porcelain particles smelt and form bonds during the sintering process, so that these particles move to fill the pores. Metal and porcelain could bond firmly at low fusing porcelain firing temperature, so that thermal coefficient contraction of porcelain must have been in accordance to the thermal coefficient contraction of metal[5,6,23,30,31]. In the meantime, it was obtained that different firing temperatures affected the marginal adaptation of metal porcelain crowns in the design of modified metal collarless significantly. The average marginal gaps were found to be smaller at 975°C which was 92.66 µm compared to that at 950°C with 66.71 µm. In this design, it is necessary for technician to measure precisely as the unsupported metal coping which is 1.5 mm shorter from the cervical edge was fabricated. A controllable porcelain applicating layer with certain thickness of 1.5 mm to 2.0 mm would provide a dense mass which reduce the shrinkage during firing as well as distortion and fractures that are preventable due to the slight shrinkage. Thus, the smaller marginal adaptation gap is achieved[9,32–35].

Visual observation of all designs has shown texture differences in particular on the porcelain surface which have been treated with both temperatures. A more visual shine and smooth textures were obtained for the samples treated at 975°C compared to that in 950°C of firing temperatures, and different colours of metal-porcelain crowns were highlighted. The increasing firing temperatures displayed brighter colours compared to that from manufacturers standard sintering, so that for clinical application, more aesthetical features are found in the design of modified metal collarless which can be recommended for patients. Therefore, this design is more approachable to those who require prosthodontics treatments in anterior tooth which have acceptable satisfaction for both dentists and patients.

In controlling the thickness of coping and porcelain with manual applications that are not the same, with future technological advances, the use of CAD/CAM models and porcelain margins in the cervical area can be performed to accomplish maximum results particularly in the reduction of shrinkage.

Conclusions

Based on the results of the study, the metal collar design has the best marginal adaptation with the smallest average marginal gap value. That is due to the presence of metal as a support that is used to strengthen porcelain during combustion. Collarless modified metal coping designs have better marginal adaptations and still meet clinically acceptable requirements, and can be recommended for clinical applications in cases that require maximum aesthetics.

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Authors' Contributions

A. A. : Conceptualization, Methodology, Investigation, Formal Analysis, Drafting, Editing
H. Z. T. : Conceptualization, Formal Analysis, Review and Editing
R. C. : Conceptualization, Writing – Draft Preparation and Editing

Declaration of Interest

The authors report no conflict of interest.

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