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Comparison of Marginal and Internal Fit of Different CAD/CAM Copings

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Abstract This study compared the internal and marginal gap between CAD/CAM copings to determine the clinical acceptability. Hundred dental stone duplications of a metal major maxillary molar die were fabricated and separated into five. All copings were produced by milling and laser sintering method in the form of twenty groups. At x 180 magnification, marginal and internal gaps of each coping were measured at 75 points, and a total of 7500 measurements were performed for six regions on digital photographs taken with video microscope. Data were analyzed using one-way analysis of variance (ANOVA) and post hoc test (Tukey and Bonferroni). The internal and marginal gaps of the milling group were significantly larger than the laser sintering group ($P < 0.05$). The results of this in vitro study show that CAD/CAM milled Co-Cr copings exhibit larger marginal and internal gap values than copings by laser sintering method. All copings were presented clinically acceptable marginal and internal accuracy. Milling and laser sintering systems are suitable for manufacturing of copings.

Keywords: *computer-aided design, dental marginal adaptation, dental crown*

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1. Introduction

The CAD (computer aided design)/CAM (computer aided manufacturing) system is a useful part of dentistry in which restorations are produced with computer support. The advantage of the CAM/CAD system is that it provides many alternatives to traditional measurement and manufacturing techniques [1]. Many different materials can be used with CAD/CAM manufacturing system. The life of the restoration is affected by the selected material [2]. The long-term success of prosthetic restorations is indicated by biocompatibility, aesthetics and strength as well as high marginal adaptation.

Overextended marginal increases cement dissolution and microcracks, and it may cause inflammation of the pulp [3]. Poor marginal adaptation of crown increases plaque retention, changes the composition of subgingival microflora and may cause periodontal disease [4].

There are many different views about marginal adaptation. Mclean and von Fraunhoder stated 120 μm gap as the optimum marginal gap, while some studies indicated this value to be 100 μm or 100 to 150 μm [5]. The materials and methods used during the processes from tooth preparation to crown cementation affect marginal adaptation directly or indirectly [6].

There is no consensus on the methodology for assessing the accuracy of marginal fitting. Many factors affect the comparative study about accuracy of marginal adaptation [7]. Whether the research is in vivo or in vitro, the number of samples and the measurement technique lead to the difference among studies [8]. Nawafleh et al. reported that the type of tooth preparation and cementation of specimen affect the marginal adaptation. Marginal fitting is significant when testing the quality of the CAD/CAM system. The inner surface of the copings must not be adjusted manually [7]. Porcelain firing process can affect the accuracy of the marginal fitting. In evaluating the production accuracy of a CAD/CAM system, it is preferable to measure copies before veneering [3,5].

Laser sintering produces metal components directly from the 3D CAD model by fusing thin metal layers through a focused laser beam source [9]. CAM/CAD technologies enable the fabrication of standardized and reproducible dental restorations from different dental materials including zirconia (Zr), composite and acrylic resins. The most common CAD/CAM manufacturing technique is the milling of metallic and all-ceramic materials. Non-precious metal alloys such as cobalt-chromium (Co-Cr) alloys or titanium (Ti) have been used with this manufacturing technique for more than twenty years [10]. Of these CAD/CAM blocks, Yttria stabilized (Y-TZP) zirconia ceramics have excellent strength and aesthetic properties, increasing their use in fixed dental restoration (FDPs) [11]. The milling of full density zirconia is difficult due to its strength. It increases the wear of the tool and causes longer milling time. The milling process is made in presinterized zirconia and then the milled restoration is sintered. However, 20-25% linear shrinkage may occur and the fit of compatibility of zirconia restorations after firing may change [12].

Polyetherketoneketone (PEKK) is chemically stable which is resistant to mechanical conditions such as tension, strength and bending. It has entered dentistry as a dental CAD/CAM material [3]. Since the early 1990s, titanium frameworks have been used as an alternative to gold and other metal-ceramic alloys. Titanium is used as a coping for FDPs [13]. Low material costs, good mechanical properties, low thermal conductivity and biocompatibility make titanium an attractive material as an alternative to gold alloy [14]. The first production problem with titanium was the formation of a reactive layer on the surface due to the investment affinity of highly molten titanium as a casting metal [15]. This leads to an inadequate bonding of ceramics to titanium and clinical failures. In addition, cast titanium restorations are more susceptible to corrosion than milled titanium restorations [16]. Furthermore, it is difficult to cast on thin, brittle wax areas of crown and to combine separate parts with welding [17].

Commercially specific manufacturing methods have been developed for the dental laboratory to prevent such natural problems. Currently, copings can be milled from industrial prefabricated blocks using machines or produced by electron discharge along with the milling technique [18]. Titanium crowns produced with milling method showed clinically acceptable marginal discrepancies in many different studies [19].

There is no research that examines the internal and marginal adaptation of the copings obtained from prefabricated PEKK, Co-Cr, Zr, Ti blocks and selective laser technology. Our null hypothesis (H^0): ‘‘ Regardless of the different manufacturing techniques and CAD/CAM blocks used, there are no significant marginal and internal gap values between the copings obtained by CAD/CAM milling and DMLS methods ’’. The results of this study will reveal the advantages and disadvantages of the copings obtained from different CAD/CAM blocks and DMLS method and provide guidance for successful long-term crown restorations.

2. Material and Methods

An Acrylic maxillary right molar tooth (frasaco GmbH) prepared according to the preparation rules for the all-ceramic crown. All-round and 1-mm wide chamfer finish line was performed in the cervical of tooth. The metal master die obtained from the prepared acrylic tooth with laser sintering technique.

The silicon pattern was obtained by duplication of this metal master die with duplication silicone (Elite Double 32 Fast, Zhermack GmbH). This silicone guide was copied hundred times with scannable type-4 CAD/CAM stone (Rocky Mountain, Klasse4 Dental) and stone dies were produced. Produced stone dies were divided into 5 groups. Dies in each group were assigned numbers from 1 to 20 and then scanned with a laboratory scanner (Yenascan, Yenadent Ltd.). Copings were designed by one operator in exocad V 2.2 (exocad GmbH) program with thickness of 0.5 mm. The cement space was set to 35 µm. Eighteen CAD/CAM milling copings were fabricated from prefabric blocks shown in Table 1 using Yenadent D40 5-axis milling machine (Yenadent Ltd.). Twenty DMLS Co-Cr copings (LSC) were fabricated from the Co-Cr powder (Remanium® star CL, Dentaurum GmbH & Co.) with laser sintering system (Concept Laser Mlab cusing 200R, Concept Laser GmbH). Each coping was cemented with dual resin cement (NOVA Resin Cement, Imıcrly) on the stone dies with a force of 50 N (~5kg) applied to the occlusal central fossa and waited for 5 minutes (Figure 1).

Table 1. Used prefabricated CAD/CAM blocks

Material name	Content	Supplier
Starbond Ti5 Disc	TiAl6V4	S & S Scheftner GmbH, Mainz, Germany
Starbond CoCr Disc	Co-Cr	S & S Scheftner GmbH, Mainz, Germany
PEKKTON® Polimer Disc	Polietheretherketon	Cendres + Métaux SA, Bienne, Switzerland
DD Bio ZX [2]Zirconia Disc	HP zirconia	Dental Direkt GmbH, Spenge, Germany

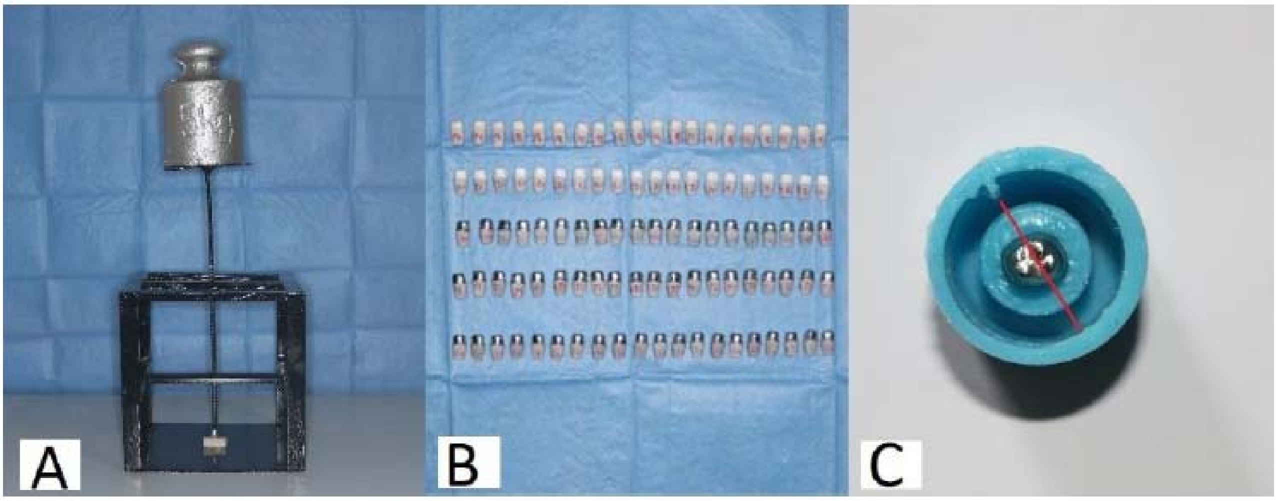

Figure 1. A = Cementation with 50N force, B = Cemented Specimens, C = Silicon pattern and cutting line

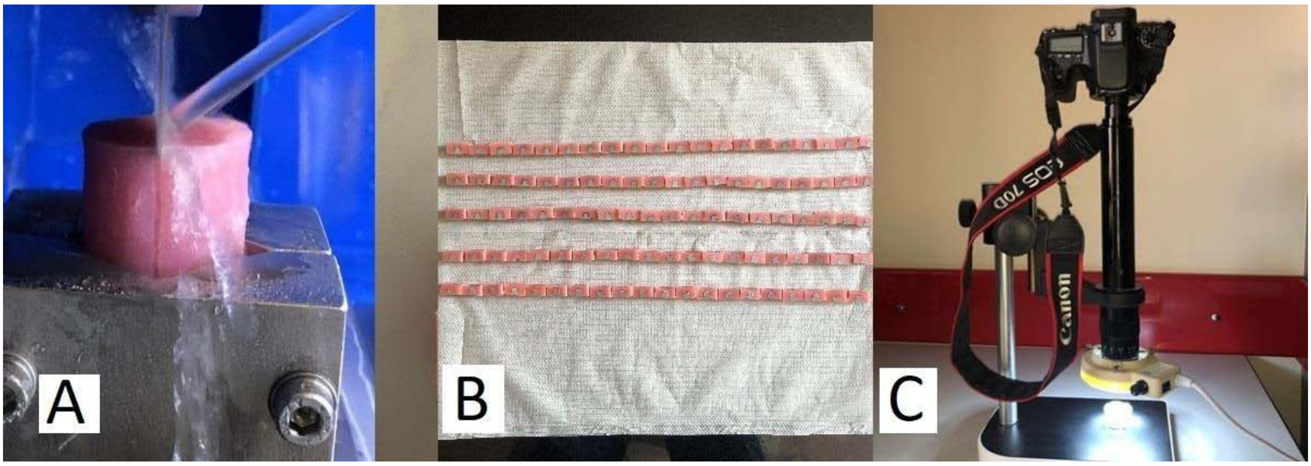

Figure 2. A = cutting of specimens, B = cut all specimens, C = video microscope

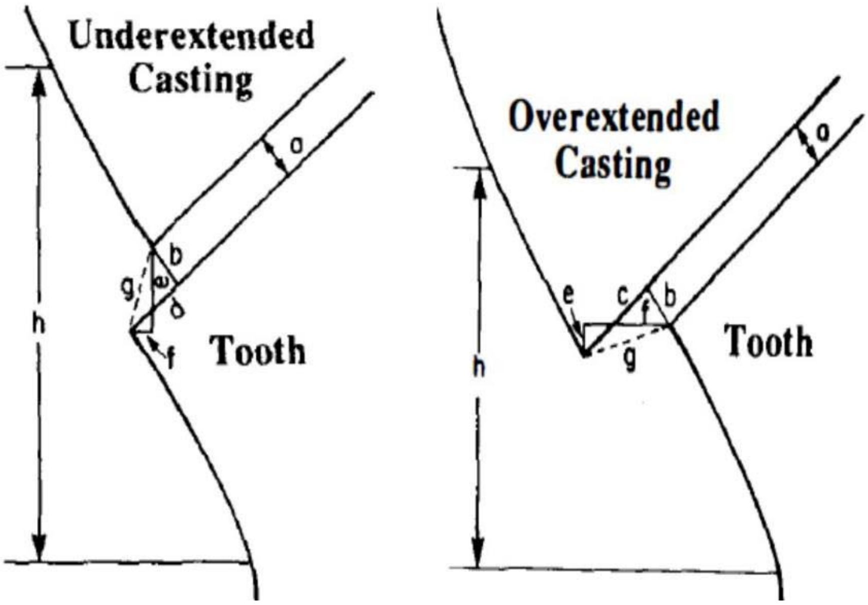

Figure 3. Casting misfit terminology. a = internal gap, b = marginal gap (measured in the this study), c = overextended margin, d = underextended margin, e = vertical marginal discrepancy, f = horizontal marginal discrepancy, g = absolute marginal discrepancy, h = seating discrepancy

All the cemented samples were placed in a specially prepared silicone guide in the same position one by one and embedded in acrylic (Meliodent, Kulzer GmbH) for preventing decemantation during cutting processes. The silicone guide was specifically designed to ensure that the specimens were in the same position and the incision line was in the same location (Figure 1). Embedded specimens cut mezio-distally with precision cutting machine (MKC-100, Mod Dental) (Figure 2). For the standardization of the measurement points, the occluso-axial angle was taken as the reference and 1.5-mm in the axial and 1-mm in the occlusal markings were made with pencil.

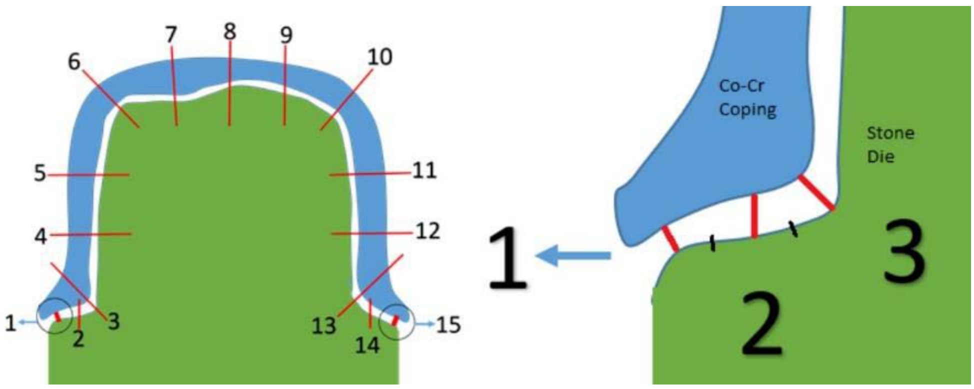

Figure 4. Marginal Gap (MG)(1. and 15. points), Chamfer step gap (CSG)(midpoint of step) (2. and 14. points), Chamfer Angle Gap (angle bisector) (CAG) (3. and 13. points), Axial Wall Gap (AWG) (4.,5.,11. and 12. points), Axio-occlusal Angle Gap (AOG), Occlusal Gap (OG) (7.,8. and 9. points)

Figure 5. Measurements in Image J software

The adaptation of the copings was observed with a 22 MP camera (Canon 70D, Canon) integrated video microscope (Lapsun, Lapsuntech) at x 180 magnification in Figure 2. All photographs (5427 x 3648 resolution) were taken using a precision micrometre with 0.01mm spacing for calibration. Marginal and internal gap values were measured in six regions at 15 points determined by Holmes et al. (Figure 3). Five measured values for each point in Figure 4 were determined and averaged. Thus, 75 measurements for each sample and 7500 measurements in total were performed. All measurements were made with Image J software (Wayne Rasband, NIH) (Figure 5). SPSS 22 program (SPSS Inc.) was used for statistical analysis. The data evaluated with descriptive statistical methods and post hoc test (Tukey and Bonferroni) and one-way analysis of variance (ANOVA) test were used for comparison of multiple groups. The results were evaluated at $P < 0.05$ significance level.

3. Results

The mean and standard deviation (SD) values of the total gap avarage measurements of the copings produced by two different manufacturing systems are in Table 2 and Table 3. There was a statistically significant difference between the groups in the AOG values ($P < 0.05$, F = 39.566) and MG values ($P < 0.05$, F = 20.335) and OIG values ($P < 0.05$, F = 23.984) and CSG values ($P < 0.05$, F = 15.391) and AWG values ($P < 0.05$, F = 20.414) and OG values ($P < 0.05$, F = 12.796).

There was a statistical variation change between LSC group and CAM/CAD milling groups (CMG) and it was found that LSC group had higher fitting ($P > 0.05$). CZ group had the higher fit, CC and CP group, CZ and CT group were similar in the CMG ($P > 0.05$). Marginal gap was similar between the LSC group and the CZ group ($P > 0.05$). Between the CMG, a higher marginal fit was found in the CZ group. The internal gap was different between the LSC group and CMG. CZ group had a higher internal fit in CMG. The CSG was similar between LSC group and CZ group ($P > 0.05$). In the LSC group, it was found that the CSG fit was higher than the CMG and there was a difference between them ($P < 0.05$). In the CAD/CAM milling group, the higher gap was found to be in the CZ group. AWG in the LSC group and the CP group was found to be similar ($P > 0.05$). The axial gap fit was higher in the LSC group than the CMG and there was a statistically difference between them ($P < 0.05$). The higher axial fit in the CAD/CAM milling group was found to be in the CP group. There was no statistically significant difference between the groups in AOG values ($P > 0.05$, F = 3.106). It was shown that the fit of the AOG in the LSC group was similar to the CMG ($P > 0.05$). CC and CT group were having the higher axio-occlusal fit in the CMG. The OG was found to be similar in the LSC group and the CZ group ($P > 0.05$). In the LSC group, the OG was higher than the CMG and there was a statistically significant difference between them ($P < 0.05$). In the CAD/CAM milling group, the higher axial fit was found in the CZ group.

Table 2. Overall gap values

	OAG		MG		OIG	
Group	Mean	SD	Mean	SD	Mean	SD
LSC	70.19	36.23	44.78	20.49	74.53	37.84
CC	105.56	46.51	82.22	32.22	108.36	48.33
CT	93.26	45.93	72.69	33.98	96.30	47.81
CZ	86.47	37.76	58.72	29.39	94.76	46.07
CP	92.06	51.28	102.82	37.02	103.76	49.07
	p < 0.05		p < 0.05		p < 0.05	

LSC: Laser sintering Co-Cr coping, CC: CAD/CAM Co-Cr coping, CT: CAD/CAM titanium coping, CZ: CAD/CAM zirconia coping, CP: CAD/CAM PEKK coping, OMG: Overall mean gap, SD: Standart deviation.

Table 3. Internal gap values by groups

	Internal Gap									
	CSG		CAG		AWG		AOG		OG	
Group	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
LSC	61.49	27.92	68.71	32.65	47.4	19.72	68.71	32.65	109.86	34.82
CC	101.13	29.05	124.7	63.37	92.04	40.33	124.70	63.37	138.55	38.16
CT	90.94	36.13	101.25	40.18	71.47	44.55	101.25	40.18	133.17	35.27
CZ	75.97	28.36	84.85	32.48	65.98	25.4	84.85	32.48	121.81	33.25
CP	108.56	31.25	106.7	29.11	59.34	26.37	106.70	29.11	148.06	43.22
	$p < 0.05$		$p < 0.05$		$p < 0.05$		$p > 0.05$		$p < 0.05$	

4. Discussion

The number of studies examining the internal and marginal adaptation of FDPs produced with DMLS technique is little [20]. Some researchers evaluated the restoration adaptation in points, others divided the measurement points into regional groups and made evaluations on these regions [21]. Beuer et al. examined marginal and internal adaptation of zirconia crowns. They were divided into four groups as marginal, chamfer, axial and occlusal regions [22]. Anunmana et al. examined the sections in 6 regions and performed a single measurement for each region [23]. In this study, 5 measurements were made with 15 different points into six regions on digital photographs of mesiodistal cross-section image which were obtained through a video microscope.

Park et al. reported that the average marginal gap of single-unit metal frameworks was 36.96 µm in the casting group, 63.21 µm in the CAM/CAD group (Datron D5) and 70.98 µm in the DMLS (Eosint M270) group. Ortorp et al. reported that marginal value of three-unit Co-Cr copings was found in DMLS group: 84 µm, wax milling group: 117 µm, casting group: 133 µm and CAM/CAD metal group: 166 µm. The lower marginal gap value was 84 µm in the DMLS group [20]. Kim et al. reported that the average marginal gap values of three-unit crowns were 130.6 µm for the premolar in the DMLS Co-Cr group, 133.1 µm for the premolar, and 81.7 µm for the premolar in the cast group (Ni-Cr). They measured 81.8 µm for the molars [9]. Nesse et al. stated that CAM/CAD technique had better fitting than laser sintering and traditional casting techniques [24]. Many factors such as scanning, design and milling can affect the marginal and internal fit of crowns produced with CAM/CAD technology [25]. Sometimes the diameter of burs milling the inner surface of the restoration may be larger than some surfaces of the prepared tooth, such as the finish line. In this study, more internal gap values were obtained than DMLS copings conrad [26]. The highest marginal discrepancy values were observed in the occlusal region in all crown copings. Similar results have been found in different studies and one of the reasons for this is said to be “total occlusal preparation angle”[12].

May et al. were reported 49-64 µm for crowns produced with Procera CAD/CAM system [27]. The average marginal gap for single zirconia ceramic crowns produced with the Cercon CAD/CAM system was reported to be 66.4 mm. Baig et al., Lins et al. in the Ceramill, Lava and Leoshape systems, the mean (SD) for the marginal gap was 65.8 (7.62), 70.0 (15.9) and 74.5 (6.80) µm, respectively [28]. However, it is not correct to compare these values with the results of this study because such values were obtained by evaluating marginal and internal fitting by two-dimensional methods using optical or scanning electron microscopes. The mean marginal fit was 69.62 µm for canine and 55.7 µm for molar in zirconia single copings. The internal fit of the zirconia single coping was 41.6 µm for canine and 40.36 µm for molar. May et al. reported that these discrepancy values produced for zircon crowns with CAD/CAM system were similar. Furthermore, similar values were found to be close to those measured by similar methods from CAD/CAM restorations [29].

The mean marginal gap of PEKK group was 62.04 µm for canine and 51.64 µm mm for molar. These values were reported by Yao et al. They were smaller than the values indicated in the studies where the average marginal adaptation of restorations was made with polymer type CAD/CAM materials including polymethylmethacrylate (PMMA). The gap values of PEKK-like acrylate polymer were observed to be 150 -160 µm [30]. The marginal fit of long-term temporary FDPs made with a PMMA block was on the average 87.9 µm in a study by Pente et al. This value was smaller than the value of this study for PEKK copings. Tsitrou et al. reported that the marginal gap was 77-105 µm in resin composite crowns produced by chairside systems.

The copings produced from PEKK showed more misfit internally and marginally compared to zirconia copings in this study. Such marginal and internal discrepancies may be considered as part of the overall accuracy of the clinical digital workflow of two groups. This can be explained by the fact that potential stress is concentrated in the region of severe curvature, such as the finish line, as well as errors associated with marginal adjustment during production, measurement, CAD design, CAM and final sintering. The milling is required for the convex region since the location of a rapid change in inclination is in the concave region. However, the present milling drill causes a problem because it leaves a concave cutting path in the form of diamond milling between the concave surfaces. Such a path leads to negative differences as it is milled in a smaller size [31].

In this study, it was observed that the values obtained were higher in the chamfer region where there was a sudden slope change in the prepared tooth and in the central fossa of occlusal region. Gap values vary according to the type of support tooth. So-Yeon Bae et al.

reported that the gap value shows significant differences compared to canine and molar teeth. This was consistent with the results of Rudolph et al's study of different types of teeth [32].

Many previous studies have reported that the accuracy of restorations may depend on the mill size of machine [23]. The same size bur (YT201 : 2-mm and YT202: 1-mm) was used for each group in this study. The larger bur ensures higher impact resistance during milling, higher milling speed and excellent cutting efficiency. A smaller diameter bur is required for the production of dental restorations. It is necessary to produce edges and grooves in detail. Excessive milling may occur due to serious curvatures and the size of the bur [2]. The excess of the gap in the chamfer and occlusal fossa area is due to excessive drilling. Boening et al. found a marginal gap of 53 µm in titanium copings produced using CAD/CAM. Leong et al. observed marginal spaces of 54 µm with CAD/CAM titanium and 60 µm with cast titanium crowns. In another study using commercially pure titanium and Ti-6Al-4V alloy crowns, the marginal gap was 83 µm and 50 µm, respectively [33]. The study comparing the vertical marginal gap of CAD/CAM titanium and conventional cast restorations found that cast restorations had a marginal gap of 24 µm smaller than 79 µm for CAD/CAM restorations. Other studies evaluating various titanium coping manufacturing systems have reported an average marginal gap of 53-70 µm [34].

Although these values seem to be below the values in this study, when manual adjustments are made, the adaptation of the copings will be close to these values. Limited to this study, PEKK copings were found to have statistically different marginal and internal adaptation when compared with zirconia copings. The values presented for PEKK and zirconia copings are clinically acceptable. This study was carried out under similar conditions in the mouth but there were many differences such as the structure and quality of soft tissues, saliva, non-ideal tooth preparations. The variability of marginal and internal adaptation after porcelain firing and glazing process, which is one of the all-ceramic manufacturing steps, is the missing step of this study. There is a need for new studies including these procedures.

5. Conclusion

The marginal and internal adaptation of crown copings produced by DMLS system and CAD/CAM milling system was found to be within acceptable limits and fitting with the values obtained in previous studies.

The internal gap of crown copings produced by DMLS method was found to have more adaptation than copings produced by milling system. DMLS method can provide accuracy restorations compared to CAD/CAM milling systems for Co-Cr crown coping manufacturing. Copings fabricated with CAD/CAM technology have clinic fitting with an acceptable range. The material type did not influence the fit significantly

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