Evaluation of marginal fit of conventional, milled, and direct metal laser sintered cobalt chromium crowns: A comparative study

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ABSTRACT

Introduction: A close marginal adaptation of a fixed partial denture is crucial for its long-term functionality without any adversity. Human errors and casting defects are common with conventional techniques. The latest techniques, direct metal laser sintering (DMLS), and computer-aided design and manufacturing (CAD/CAM) tend to overcome these errors.

Methods: 33 dies were fabricated from similar number of impressions of a tooth based on standardized measurement and were equally distributed in 3 groups (11 each). Crowns were fabricated using conventional, DMLS, and CAD/CAM methods using chrome-cobalt. All the fabricated crowns were cemented onto the die using resin cement and 50 N force, followed by leaving them for 12 hours at room temperature. Then, each crown was sectioned into two halves, and a stereomicroscope was used to evaluate the cement thickness at three different reference points.

Results: The marginal fit of conventionally fabricated crowns, DMLS, and CAD/CAM crowns were in the clinically acceptable range. Marginal discrepancy remained more in conventionally fabricated crowns than in CAD/CAM and DMLS crowns. However, the axial discrepancy in crowns fabricated by the conventional method was lesser than in CAD/CAM and DMLS fabricated crowns. The occlusal discrepancy in DMLS-fabricated crowns was more than that of the other two methods.

Conclusion: The DMLS group displayed better marginal accuracy with respect to the marginal reference point. On the other hand, the convention group exhibited superior adaptability when the buccal and occlusal reference points were considered. Similarly, statistically significant results were observed when the conventional group's 'margin reference point' was compared with the CAD/CAM or DMLS group. The margin reference point of the CAD/CAM group was comparable with DMLS cobalt-chromium crowns.

Key words: Buccal fit; Cobalt-chromium crown; Computer-aided design and manufacturing; Direct metal laser sintering; Marginal; fit; buccal fit; Occlusal fit.

Conflict of Interest: None

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INTRODUCTION

Marginal fit is one of the most critical criteria for fixed dental restoration adaptability and long-term survivability.[1] The discontinuous junction or marginal discrepancy between the prepared tooth and the restoration leads to the formation of an interphase, which enhances plaque accumulation along the gingival margins, leading to localized gingivitis.[1,2]

McLean and Von Fraunhofer have concluded that the degree of acceptable marginal discrepancy is up to 120 microns.[3] Further, Shillingburg had suggested that for a better fit of metal restorations, the margin of preparation should be acute in cross sections to facilitate a tight fit.[6] An acute edge of metal restoration can be burnished against the tooth to improve marginal fit further. The margins must have an angle of 10 to 20 degrees before the dental prostheses can fulfill their intended fit.[4,7] Donovan et al. had stated that the shoulder can be used with a metal margin, which can be highly polished, critical to long-term periodontal health because rough materials accumulate and retain plaque more readily than smooth materials.[5]

Co-Cr alloys are mainly used for fixed partial denture (FPD) fabrication because of their strength, corrosion resistance, and affordability.[9] Cobalt provides hardness to the prosthesis, while chromium prevents corrosion and improves the mechanical properties.[9] However, the manufacturing processes for these alloys are usually difficult because of their great melting points, limited ductility, and hardness. Cobalt chromium structures are frequently associated with issues related to poor marginal fit. Problems in conventional techniques, primarily human errors, and casting defects, are the main reasons for the marginal fitting discrepancies.[8]

Computer-aided design and milling (CAD/CAM) is a subtractive method for fabricating FDPs utilizing computer-aided design data to mill the Co-Cr alloy blank. The main advantages of this method are that the predesigned restorations can be made in a short time, and the construction of the restorations can be standardized.[9] Laser sintering, on the other hand, is a newer and more advanced additive dentistry technique based on the rapid prototyping (RP) system, which uses a high-power laser to make a 3D metallic framework based on the CAD restoration software. Shellabear et al. stated that copings are densely sintered up to a density of 99.9% with practically no voids, resulting in improved strength and accuracy of the restorations[9] Zeng et al. have also stated that fabricated FDPs demonstrate better anti-corrosion properties, which expressively aid in sustaining the integrity of the margins of fabricated FDPs for longer periods.[10]

Many previous studies assessed this important criterion of metal prosthesis produced by CAD/CAM and direct metal laser-sintered (DMLS) utilized replica systems, weighing methods, direct sectioning of the crown and die after cementation, or micro-CT methods to measure the marginal discrepancy.[11-13]

The weighing method is another destructive but technique-sensitive method that does not represent point measurement.[14] Micro CT is a newer method but it requires expensive equipment.[14] The replica method is less destructive but can yield false results due to material polymerization and less force applied.[15] Therefore, the direct sectioning method is more accurate for evaluating marginal discrepancy even though it is more destructive than other methods.[16] Few studies are available to assess the marginal fit of metal crowns produced by these newer methods.[17,18] Considering the above limitation, the present study has evaluated and compared the marginal fit of the conventional, milled, and DMLS cobalt-chromium crown.

METHODS

A typodont model of a maxillary first molar crown mounted on an acrylic resin block. The crown had a height of 6 mm, an even heavy chamfer line of 1 mm, and an occlusal convergence of 5 degrees. The occlusal reduction was performed using a high-speed air rotor handpiece. In contrast, the axial reduction was achieved using Paraskop M-BA-85744-

04 milling machine (Bremer Schlagerei Will Herbst-BEGO Gmbh & Co KG; Bremen, Germany) to ensure parallelism and uniform finish lines across the models. Thirty-three single all-metal crowns were fabricated and examined for this study.

Three groups were created, each with eleven samples, with crowns constructed using three different methods. In the conventional method (Group I), polyvinyl siloxane impressions of the model were made followed by pouring type IV die-stone, with no die spacer applied to create variations in the casting fit. Type IV die-stone was used for pouring the siloxane impression as it is a high strength, low expansion stone that produces smooth, hard, and accurate surfaces. The wax coping was refined, spread, and vacuum-invested in a phosphate-bonded investment material (Wirocer®, BEGO Gmbh & Co KG; Bremen, Germany), and metal castings were subsequently made from Co-Cr pellets (Wironit®, BEGO Gmbh & Co KG; Bremen, Germany). The internal surface of the crown was sandblasted with 100µg alumina (Easyblast Blaster, BEGO Gmbh & Co KG; Bremen, Germany) before cementing it onto a die. For the CAD/CAM milled method (Group II), eleven specimens were prepared similarly to obtain the master die, which was then scanned, transferring the data into the 3D CAD (Exocad Dental CAD, exocad GmbH, Darmstadt, Germany) process, with parameters set for milling a Co-Cr disc. These discs were milled using a 1mm diameter milling bur. In the Direct Metal Laser Sintering (DMLS) method (Group III), eleven specimens were fabricated, and data were sent to the production unit to fabricate the crown with cobalt-chromium powder in a laser sintering machine (LSM) with a laser processor (EOSINT M 270, Electro Optical Systems GmbH, Munich, Germany).

All the dies were inspected for surface abrasion, and the crown was seated on the die for evaluation. Crowns were cemented onto their corresponding dies using luting resin cement (RelyX™ Universal Resin Cement, 3M, MN, USA) as per the manufacturer's instruction. The crowns were then seated initially with firm finger pressure for 10 sec followed by a seating force of 50N for 60 seconds per tooth which was delivered to the tooth specimen using a stylus mounted on to the Universal Testing Machine. Excess cement was cleaned from the margins. All cemented specimens were kept at room temperature and left for 12 hours before sectioning these samples. Sectioning of samples was carried out with a slow-speed handpiece in a mesiodistal direction, this will prevent distortion of the samples during sectioning.[19,20]

Half of the sectioned specimen was used for testing. The reference point was marked at the crown's margin, buccal, and occlusal aspects. The sectioned sample was mounted on a stereomicroscope (Leica DM2500M, Leica Microsystems GmbH, Wetzaiar, Germany) at 5X magnification, and the thickness of cement was measured at the respective reference points with the help of measurement software (Leica Application Suite version 4.2.0, Leica Microsystems GmbH, Wetzaiar, Germany) (Fig.1,2, and 3). The mounted sectioned samples were analyzed for accuracy at all the reference points. The sample with distorted reference points was excluded from the study.

STATISTICAL ANALYSIS

Statistical analysis was carried out for crown margins among three different fabrication methods. Our null hypothesis postulated no significant difference between the methods. We applied ANOVA with a significance level of $\alpha = 0.05$ to test this hypothesis, with a decision criterion of rejecting it if the p-value was less than 0.05. In cases of significance, we conducted post-hoc Tukey using the Bonferroni procedure to identify specific method pairs that differed.

RESULTS

Data derived in the present study is presented in tabular forms to make the group comparison easy to understand.

Table 1. presents the descriptive statistics for three fabrication methods: Conventional, CAD/CAM, and DMLS, focusing on the margin measurements. It also includes statistics for buccal and occlusal margins. These statistics provide insights into central tendencies and variability associated with each method.

Table 2. displays the results of the ANOVA analysis for different margin types and fabrication methods. For the Conventional margin type, there is a significant difference among the methods, while for the buccal and occlusal margin types, there is no significant difference. The F-value represents the ratio of between-group variation to within-group variation, and the p-value indicates whether this difference is statistically significant.

Table 3. shows the post hoc Turkey test results, which compare different groups to determine statistically significant differences. The conventional method showed a significant difference compared to the CAD/CAM method ($P < 0.001$). However, there was no significant difference between the CAD/CAM and DMLS methods for the buccal margin, occlusal Margin, DMLS comparison, and occlusal margin. The results suggest no significant differences between the two methods.

Table 1: Descriptive statistics related to the three fabrication methods (i.e., Conventions, CAD/CAM, and DMLS) focused on the marginal measurements.

		N	Mean	Std. Deviation Lower Bound	95% confidence interval for mean		Minimum	Maximum
					Upper Bound			
Margin	Conventional	11	252.715273	80.3070210	198.764282	306.666264	140.7110	413.8590
	CAD/CAM	11	122.917909	51.7973689	88.119963	157.715855	20.5710	209.7000
	DMLS	11	93.430455	34.2681055	70.408828	116.452081	18.6000	150.5290
	Total	33	156.354545	90.3216677	124.327875	188.381216	18.6000	413.8590
Buccal	Conventional	11	56.901091	29.8952796	36.817169	76.985013	20.5710	107.8610
	CAD/CAM	11	58.364091	33.9616249	35.548361	81.179821	16.7640	128.0190
	DMLS	11	67.869818	52.8792287	32.345069	103.394567	15.5890	179.2680
	Total	33	61.045000	39.2164015	47.139469	74.950531	15.5890	179.2680
Occlusal	Conventional	11	317.694636	142.2315127	222.142206	413.247067	69.5740	596.2860
	CAD/CAM	11	360.903545	230.4621590	206.076960	515.730131	98.3060	747.3980
	DMLS	11	372.446818	188.1123509	246.071221	498.822415	123.4480	685.5700
	Total	33	350.348333	185.8775537	284.439019	416.257648	69.5740	747.3980

Table 2: The outcome of the ANOVA analysis for the different fabrication methods and the marginal type.

Dependent Variable		Mean	Std. Deviation	F- value	p- value
Margin	Conventional	252.715273	80.3070210	22.994	<0.001**
	CAD/CAM	122.917909	51.7973689		
	DMLS	93.430455	34.2681055		
Buccal	Conventional	56.901091	29.8952796	0.242	0.787
	CAD/CAM	58.364091	33.9616249		
	DMLS	67.869818	52.8792287		
Occlusal	Conventional	317.694636	142.2315127	0.253	0.778
	CAD/CAM	360.903545	230.4621590		
	DMLS	372.446818	188.1123509		

Table 3: Post hoc Turkey test results comparing the different experimental groups.

Dependent Variable	(I) Group	(J) Group	Mean Difference (I-J)	Sig.
Margin	Conventional	CAD/CAM	129.7973636*	.000**
		DMLS	159.2848182*	.000**
	CAD/CAM	DMLS	29.4874545	.474
Buccal	Conventional	CAD/CAM	-1.4630000	.996
		DMLS	-10.9687273	.799
	CAD/CAM	DMLS	-9.5057273	.845
Occlusal	Conventional	CAD/CAM	-43.2089091	.856
		DMLS	-54.7521818	.780
	CAD/CAM	DMLS	-11.5432727	.989

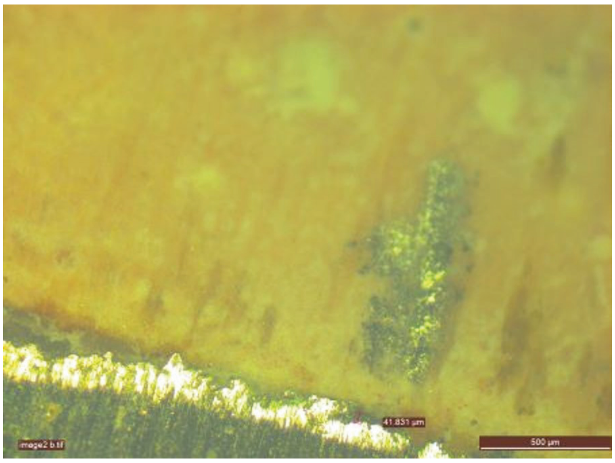

Figure 1: *Adaptation and fit of the crown at the marginal reference point under a stereomicroscope (5X).*

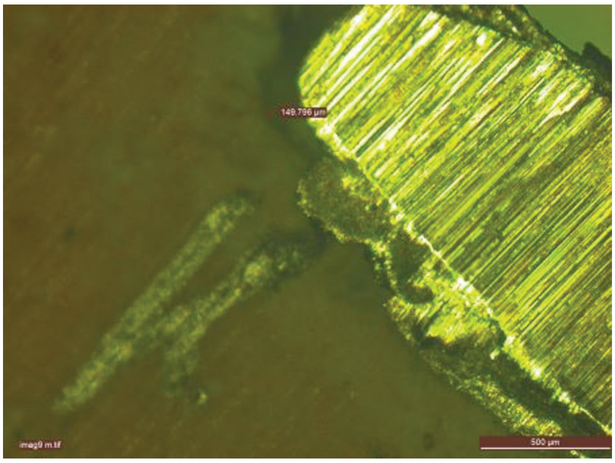

Figure 2: *Adaptation and fit of the crown at the occlusal reference point under a stereomicroscope (5X).*

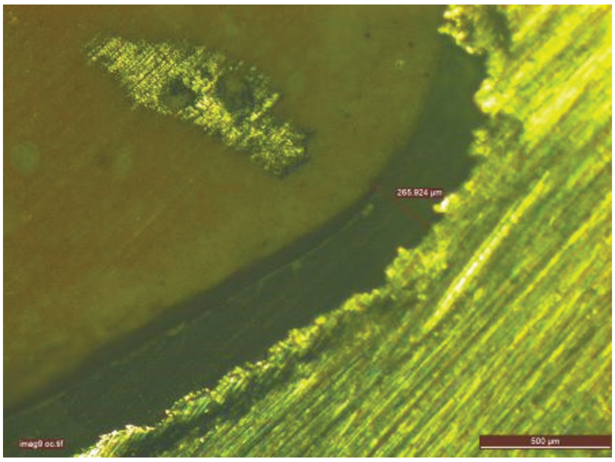

Figure 3: *Adaptation and fit of the crown at the buccal reference point under a stereomicroscope (5X).*

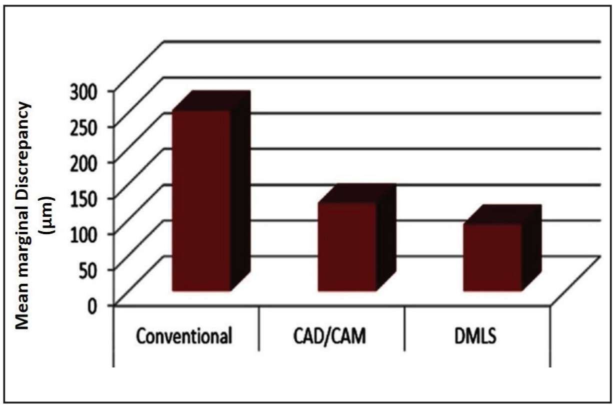

Figure 4: *Mean marginal discrepancy between the conventional, CAD/CAM, and DMLS fabricated crown (in µm).*

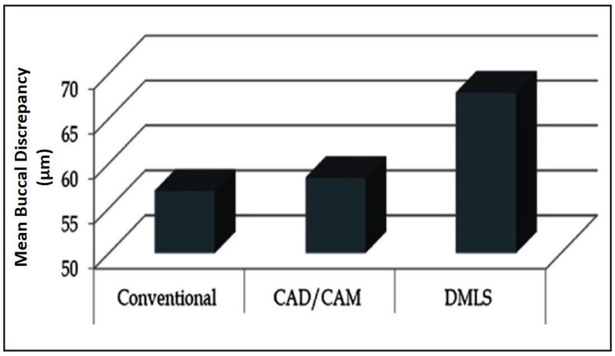

Figure 5: *Mean buccal discrepancy between the conventional, CAD/CAM, and DMLS fabricated crown (in µm).*

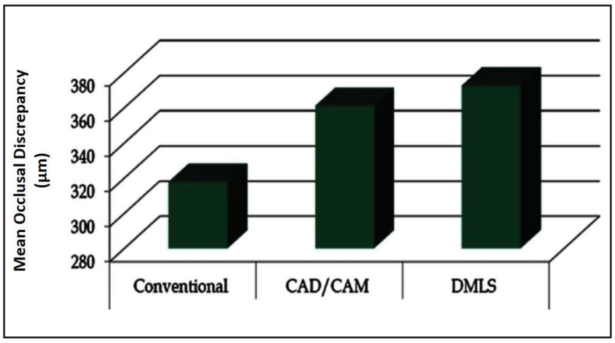

Figure 6: *Mean occlusal discrepancy between the conventional, CAD/CAM, and DMLS fabricated crown (in µm).*

DISCUSSION

An outstanding adaptation offers an enclosed seal to minimal plaque accumulation and reduces the chances of recurrent caries and periodontal inflammation, leading to the prosthesis's longevity. Mc Lean and Fraunhofer recommended that the clinically acceptable marginal gap after cementation be 150 to 200µm. In addition, a marginal gap of less than 80µm was difficult to detect under clinical situations.[5] According to American Dental Association (ADA) specification no. 8, the marginal gap width ranges between 25-40µm have been suggested as a clinical goal. However, this goal is rarely achieved; thus, a marginal gap width of less than 120µm can be clinically acceptable.[19,21-23]

In 1907, Taggart introduced the lost wax technique.[24] Chiefly, noble alloys were selected because of their good biocompatibility. The cost factor was considered for fabrication, so manufacturers chose cheaper alternatives to reduce costs. So, according to consideration, nickel-chromium and cobalt-chromium alloys are now used. These materials had less cost and ease of fabrication. Many attempts were made to evolve investing material, alloy composition, and casting techniques to improve the marginal adaptation and the seating of crowns fabricated by the conventional method.

Subtractive, as well as additive methods of fabrication, increase the efficiency and rapid production of dental restorations. The subtractive method includes computer-aided designing and computer-aided manufacturing (CAD/CAM). Additive methods include rapid manufacturing (RM) and rapid prototyping (RP), such as fused deposition modeling (FDM), stereolithography (SLA), selective laser sintering (SLS), or direct metal laser sintering (DMLS), particular electron beam melting (SEBM).[25-32]

The subtractive method consists of three basic components: a digital scanner, software processing data, and a production unit that transforms the data set into the desired production.[33] This technique has advantages such as fewer production steps and reduction of human error as compared to the conventional method.[25]

DMLS is an additive method for the fabrication of restoration.[33,34] It provides layers of powders, for example, polymers, ceramics, and metals. Later, it sintered using a focused laser beam. The technique starts by applying a thin layer of powder material to construct the platform, and a focused laser beam melts the powder, which gets sintered with the underlying layer. After focusing, laser beam material gets fused to form a bond with the layer below at certain points, resulting in a complex part. All welding lines generate a new micro-segment of the final part, piling all monitoring information on top of each other. Many factors, such as powder material, exposure parameters, inert gas flow, and temperature at the building platform, influence this system. With this process, the gradual building of restoration results in a high-density product. The density can be as high as 99.9%, preventing the restoration from getting distorted.[9] Further, studies have shown that the final restorations created will have a detailed resolution, good surface quality, and excellent mechanical properties.[21,33,34]

The present study assessed the marginal discrepancy of Co-Cr crowns fabricated by conventional, CAD/CAM, and laser metal sintering methods. The samples were standardized using a single model, and the preparation of the model was précised using a parallelometer. Many authors have advocated two techniques, cross-sectioning and silicone replica, to measure the marginal gap. Shearer et al. reported statistically significant differences in using both methods. They supported using the sectioning technique over the silicone replica technique.[35] Other methods available in the literature are micro-CT and weighing methods.

In research, marginal misfit was assessed for every Group under the stereomicroscope. The gap width was measured with computer software (Leica DM2500, Leica Microsystems GmbH, Wetzaiar, Germany) using a 500µm scale. The sample was placed under the stereomicroscope.

When Group I (Conventional Group) was compared with Group II (CAD/CAM group), Group II showed lesser marginal discrepancy (122.91µm) when compared to Group I (252.71µm) (Table 2; Fig. 4), which was statistically significant ($P<0.005$). At the same time, group II showed a marginal discrepancy within the clinically acceptable range, as mentioned by many authors in the previous studies.[36] The possible explanation for this result could be human errors, wax distortion, or casting errors (Fig. 1).

These errors can be eliminated by utilizing computer-aided manufacturing, which offers a reduction in processing steps, a reduction in human errors, ease in production, and better quality of materials used for the fabrication crowns, and, in turn, a much better degree of restoration. The use of virtual wax on a computer makes the production of the restoration efficient, convenient, and predictable. It introduces more standardization across restorations as compared to the conventional method.

When Group II (CAD/CAM group) was compared with Group III (DMLS group), group III had better marginal accuracy (93.43µm) as compared to Group II (122.91µm) (Table 2), which was statistically significant (P <0.005). In contrast, when these groups were compared at buccal and occlusal reference points, group II (CAD/CAM group) had better buccal and occlusal fit than Group III (DMLS group) (Fig. 2 and Fig 3.).

CAD/CAM is a subtractive method with certain shortcomings, like unnecessary wastage of materials, heat generation, and wear of milling, but the process of milling reduces the efficiency of the process.[26,30]

Certain aspects that determine the fit of the prosthesis are 1) the Scanning device's precision for dental bridge abutments, 2) the Software used for 'transforming the data points' to build a 3D model, and 3) Milling/Machining - the precision of fabrication. Another possible reason for the observed marginal discrepancies could be due to drilling compensation.[27] To overcome these disadvantages, the additive method of producing and carrying out dental restoration was helpful. In the DMLS method, layered sintering of metal (Co-Cr) alloys added to the overall metal density in the restoration.

When Group I (conventional Group) was compared with Group III (DMLS group), Group III displayed a better marginal fit: 252.71µm and 93.43µm, respectively. Studies have shown that microstructure and the alloys' mechanical properties greatly depend on the constituent metals' manufacturing techniques and chemical composition. DMLS alloy exhibits a homogenous microstructure, whereas cast alloy shows a typical dendritic microstructure.

Studies have shown that on heating, cobalt undergoes allotrophic phase transformation γ (FCC) phase to lower temperature phase ε (HCP) phase. The retained γ phase at room temperature provides superior physical and mechanical properties. This γ phase maintains the marginal integrity of restoration for a longer duration.[16] In the conventional casting, the γ phase transforms into the ε phase as the cooling process results in a weaker final restoration.[16]

Ucar et al. reported no significant difference between DMLS and cast Co-Cr sectioned crowns when focusing on the internal gap.[19] However, Ortorp et al. reported that the laser-sintered Co-Cr group showed lower discrepancies than the casting Co-Cr group for the conventional fixed restoration.[22]

When group II (CAD/CAM group) crown margin, buccal, and occlusal points were compared with group III (DMLS group), the mean difference was 29.487, -10.96, and -11.54, respectively (Fig.2 and Fig.3). This was statistically insignificant as the P-value was > 0.005. This finding is in line with the former study.[35] In this study, Group III (DMLS group) showed the largest mean buccal and occlusal discrepancy, 67.86 and 372.44, respectively, compared with the other two methods.

The present study evaluated the cobalt-chromium (Co-Cr) crowns fabricated using conventional, CAD/CAM, and DMLS methods at three reference points. The crowns were cemented onto the die to simulate the clinical scenario. The resultant restoration produced by the DMLS method is denser, biocompatible, and has observably better mechanical properties. A superior marginal adaptation was seen in DMLS fabricated crowns, indicating a better restoration success rate than other methods.

CONCLUSION

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

- The marginal fit of conventionally fabricated, CAD/CAM, and DMLS fabricated crowns was clinically acceptable.

- DMLS-fabricated prostheses displayed the best marginal fit, followed by CAD/CAM, and the conventionally fabricated crowns had a comparatively less accurate marginal fit.
- The axial discrepancy was less in crowns fabricated by conventional methods than in CAD/CAM and DMLS crowns. The occlusal discrepancy was more in DMLS-fabricated crowns than the discrepancies observed among milled CAD/CAM and conventional method-based fabrications of Co-Cr dental crowns.

Ethics approval and consent to participate

This paper did not use experimental data from human subjects. The Institute Review Board approved the original research via Ref No. 434/2015-16.

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