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Original Article

In vitro evaluation of marginal and internal gaps of materials used for onlay and occlusal veneer restorations

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Abstract

Purpose: This study compares the marginal and internal gaps for four restorative materials produced by two fabrication methods in both minimally invasive occlusal veneer and conventional onlay cavities.

Methods: Eighty mandibular molars prepared as occlusal veneer and mesial-occlusal-distal-lingual onlays and restorations were produced using lithium disilicate glass ceramic, hybrid ceramic, nanohybrid composite, and laboratory composite materials. A silicone replica method was used to examine the marginal gap and internal gap with a stereomicroscope. Two-way analysis of variance (ANOVA) was used to analyze the effects of the material and design, and one-way ANOVA was used to analyze the effect of the fabrication method.

Results: The marginal gap significantly differed in relation to the material, and the internal gap significantly differed in relation to the material and design. Gaps were significantly smaller for the laboratory composite groups than for the other groups. Comparison of fabrication methods showed that internal and marginal gaps were significantly smaller for the conventional procedure.

Conclusion: The less complicated designs yielded a better fit. In particular, because of the greater number of intaglio surfaces, internal gap values were worse when cavity design complexity increased.

Keywords: internal gap, marginal gap, occlusal veneer, onlay, silicone replica

Introduction

The rapid pace of change in science and technology in this increasingly global society requires clinicians to constantly update their knowledge and techniques [1]. In adhesive dentistry, restorative and preventive dental care has been revolutionized by minimally invasive treatments and long-lasting restorations [2]. Indeed, the field has undergone a fundamental transformation from complex multistep procedures to simplified, highly efficient techniques. Advances in intraoral scanning and computer-aided design-computer-aided manufacturing (CAD-CAM), along with the introduction of new materials for dental CAD-CAM, have simplified patient care [3]. In addition to improving accuracy, cost, and time efficiency, CAD-CAM technology enables use of materials that cannot be fabricated using traditional laboratory-based workflows [4].

Adhesive restorations of posterior teeth not only improve aesthetics; they increase the biomechanical strength of the remaining tooth structure. The criteria used by clinicians to select materials and techniques can be classified as general and localized. General parameters include patient age, oral hygiene, motivation, caries risk, nutritional habits, functional activity, ergonomics, and financial resources. Local parameters include the shape of the cavity, the thickness of the remaining walls, the location of the cervical edges, the presence of cervical lesions, the presence of cracks, the position of the tooth, and the presence of pulp disease or periodontal lesions [5]. The materials used for manufacturing posterior indirect adhesive restorations—ceramics, resin composite materials, and hybrid materials—differ in composition, mechanical and optical properties, manufacturing techniques, and survival rates [6].

The lifespan and success of indirect restorations are directly related to patient characteristics and clinician-based factors. Patients' oral hygiene, diet, and functional habits govern clinicians' preferences in tooth preparation, impression, and cementation procedures [7,8]. Restoration fit is another important factor in the long-term success of dental restorations [9]. A specific distance is required for optimal fit between the inner surface of the restoration and the tooth [10,11]. Some researchers maintain that a marginal gap of 50 to 120 μm is acceptable, while others reported values of 120 to 250 μm [12-14]. Regarding the internal fit of the restoration, gap values of 100 to 350 μm have been reported [14,15]. In addition, there is no consensus regarding the number of measurement fields needed to assess the marginal gap and internal gap [16].

This study compared marginal gap and internal gaps for four restorative materials produced by two fabrication methods in both minimally invasive occlusal veneers and conventional onlay cavities. The first hypothesis was that marginal and internal gap values would be lower for occlusal veneers (OV) than for mesial-occlusal-distal-lingual (MODL) onlays. The second hypothesis was that marginal and internal gap values would be lower for conventionally fabricated restorations than for restorations fabricated with a milling machine. The third hypothesis was that marginal and internal gap values would be lower for restorations produced with composite resin-based materials than for those produced with ceramic-based materials.

Materials and Methods

Eighty extracted mandibular first molars of uniform size were selected and numbered sequentially. Molars extracted because of periodontal problems or orthodontic needs, and that retain some root structure from the enamel-cement border apically, were included in the study. Teeth with fractures or cracks from trauma, teeth with morphological deformities (eg., rudimentary teeth, "peg-shaped" teeth), and teeth with caries or restorations were not included.

Eight groups comprising 10 teeth each were selected in order of the predesignated numbering (Table 1). Digital scans (CEREC InEos Blue, Sirona, Bensheim, Germany) acquired for each tooth before preparation were used for the design of the ceramic restoration. The preparation was performed by the same experienced prosthodontist. Odd-numbered groups were prepared in the form of a nonretentive occlusal veneer with two separate flat surfaces from the central fossa to the tubercle crests; an angle of approximately 120 degrees was made by completely removing the occlusal enamel (Figs. 1a, 2) [17-19]. Even-numbered groups were prepared as a mesial-occlusal-distal-lingual onlay cavity. A 2-mm occlusal reduction from both the functional buccal and non-functional lingual cusps was made with a 90-degree finishing line. The mesial and distal box depth was 1.5 mm, the cavity depth was 2 mm, and the isthmus width was 3 mm (Figs. 1b, 3) [5,20-22]. To control the occlusal reduction, mesial and distal box depth, cavity depth, and isthmus width, lines for the appropriate depths and widths were marked before preparation. After preparation, all measurements were controlled with a periodontal probe (Hu-Friedy, Chicago, IL, USA).

After preparation, the teeth to be restored with lithium disilicate glass ceramic (LDGC) (IPS e.max CAD, Ivoclar Vivadent AG, Schann, Liechtenstein), hybrid ceramic (HC) (Vita Enamic, Vita Zahnfabrik, Bad Sackingen, Germany), and nanohybrid composite (NHC) (Grandio Blocs,

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Table 1 Restorative materials and study groups

Product name	Manufacturer	Lot number	Specimen type
IPS e.max CAD	Ivoclar Vivadent AG, Schann, Liechtenstein	U200232	group 1: occlusal veneer group 2: mesial-occlusal-distal-lingual onlay
SR Nexco Paste	Ivoclar Vivadent AG	W09842	group 3: occlusal veneer group 4: mesial-occlusal-distal-lingual onlay
Grandio Blocs	Voco, Cuxhaven, Germany	2014240	group 5: occlusal veneer group 6: mesial-occlusal-distal-lingual onlay
Vita Enamic	Vita Zahnfabrik, Bad Sackingen, Germany	51731	group 7: occlusal veneer group 8: mesial-occlusal-distal-lingual onlay

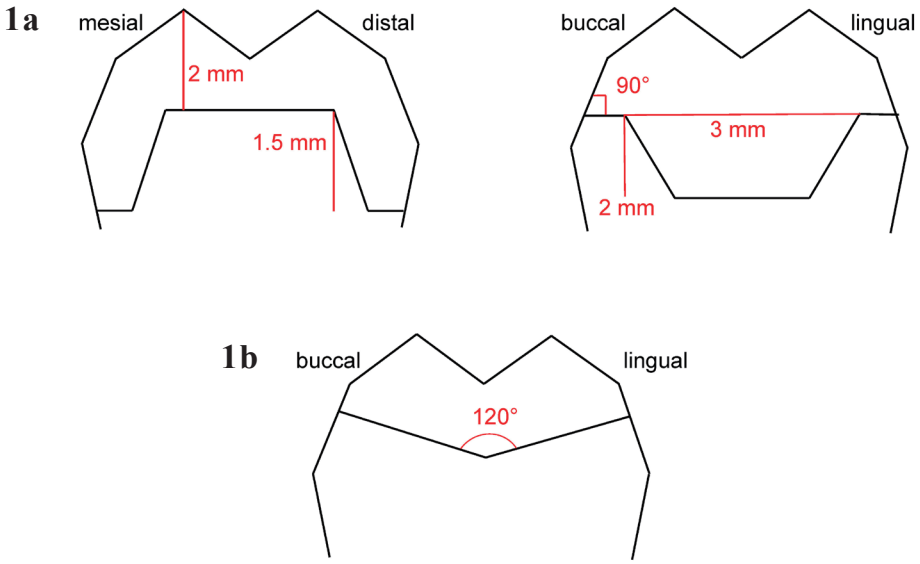

Fig. 1 Illustrations of preparation parameters
1a. mesiodistal and buccolingual section preparation parameters of MODL; 1b. preparation parameters of OV

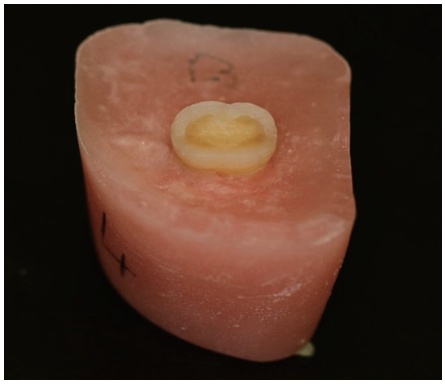

Fig. 2 An example of an MODL sample



Fig. 3 An example of an OV sample

Voco, Cuxhaven, Germany) were digitized directly with a laboratory model scanner (CEREC InEos Blue, Sirona). CAD software (CEREC 3D inLab, Sirona) was used to design restorations based on prior scans. The restorations were milled with a 5-axis milling machine (CEREC inLab MC XL, Sirona). The luting space were set at 100 µm [23,24]. Final sintering of the lithium disilicate restorations was performed after milling, in accordance with the manufacturer's instructions.

Fabrication of laboratory composite (LC) (SR Nexco Paste, Ivoclar Vivadent AG) restorations was done by a single experienced laboratory technician using the direct application method on the prepared teeth. The layer thickness of the liner was set to at least 150 µm, and the liner thinned out towards the preparation margin. The inhibition layer was removed with a disposable sponge. Then, the laboratory composite was layered, and each segment was precured with a curing unit for 40 s. Before final polymerization, gel (SR Gel, Ivoclar Vivadent AG) was applied to all surfaces, and final polymerization was performed for 5 min by using a curing unit with a light spectrum with peaks at 405 nm (86 mW/cm^2) and at 460 nm (68 mW/cm^2). Finishing and polishing of the restorations were performed in accordance with the manufacturers' instruction. The minimum occlusal thickness of all restorations was set at 2 mm.

Using the silicone replica method, the same experienced prosthodontist examined the marginal gap and internal gap with a stereomicroscope (Leica EZ4, Leica Microsystems, Weltzar, Germany) at a magnification of 35×. The silicone replica technique was used by loading a low-viscosity silicone impression material (Elite HD+, Zhermack SpA, Badia Polesine, Italy) on the inner surface of the restorations and then seating the restorations with a 50-N load. Then, heavy body silicone impression material (Elite HD+, Zhermack SpA) was used to stabilize the thin layer of the light body impression material for easy handling and to measure the gaps. All replicas were sectioned with a razor blade in the midplane of the buccolingual and mesiodistal surfaces.

The fit of onlay restorations was measured at 11 points in the mesiodis-

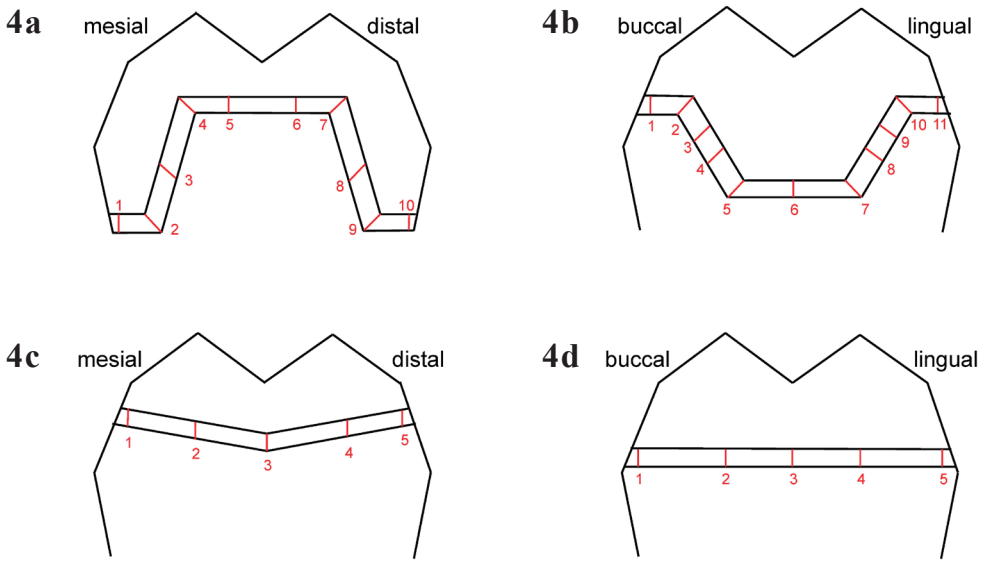

Fig. 4 Illustrations of measurement points
4a. mesiodistal section measurement points of MODL; 4b. buccolingual section measurement points of MODL; 4c. mesiodistal section measurement points of OV; 4d. buccolingual section measurement points of OV

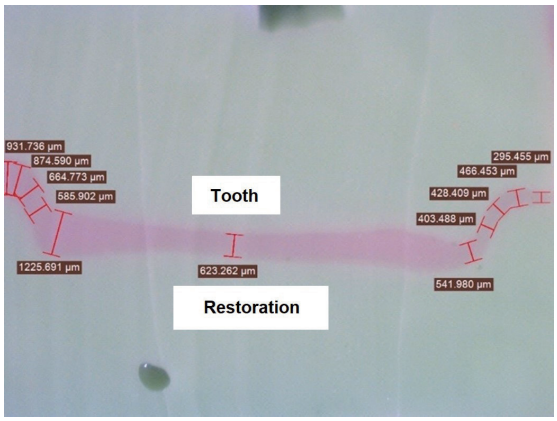

Fig. 5 Mesiodistal section measurement of MODL

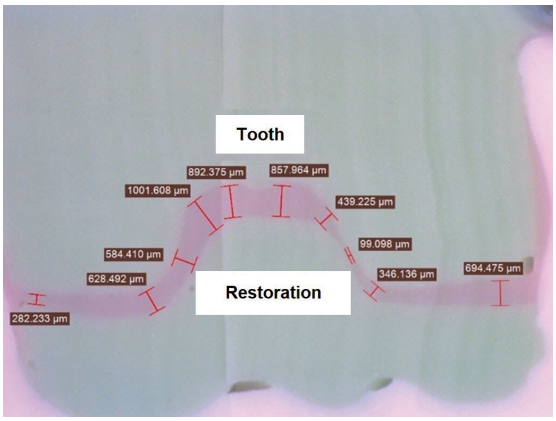

Fig. 6 Buccolingual section measurement of MODL

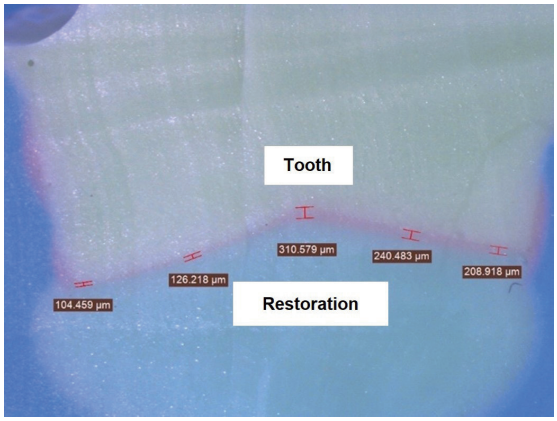

Fig. 7 Mesiodistal section measurement of OV

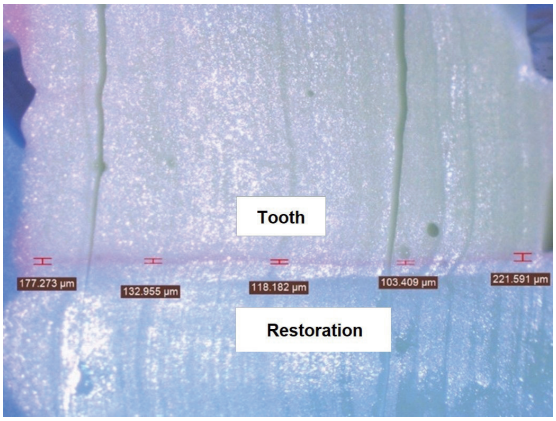

Fig. 8 Buccolingual section measurement of OV

tal section and at 10 points in the buccolingual section (Figs. 4b, 5). The fit of occlusal veneer restorations was measured at 5 points in both sections. To minimize measurement error, three measurements were obtained at each point and the average was recorded.

For MODL cavities, mesiodistal section measurement point 1 represents the mesial MG, and measurement point 10 represents the distal MG (Figs. 4a, 6); buccolingual section measurement point 1 represents the buccal MG, and measurement point 11 represents the lingual MG (Figs. 4b, 6). For OV cavities, mesiodistal section measurement point 1 represents the mesial MG, and measurement point 5 represents the distal MG (Figs. 4c, 7); buccolingual section measurement point 1 represents buccal MG, and measurement point 5 represents lingual MG (Figs. 4d, 8). After these measurements were obtained, the mean (SD) MG for each specimen was calculated.

For both cavity designs, other measurement points referred to internal gap values. For MODL cavities, mesiodistal measurement points 2 through 9 are referred to as mesiodistal IG values (Figs. 4a, 5), and buccolingual measurement points 2 through 10 are referred to as buccolingual IG values

(Figs. 4b, 6). For OV cavities, the mean of mesiodistal measurement points 2 through 4 is referred to as the mesiodistal IG (Figs. 4c, 7). Buccolingual measurement points 2 through 4 are referred to as the buccolingual IG (Figs. 4d, 8). The mean (SD) of IG values for each specimen was calculated.

Statistical analysis

Sample size determination and power analysis were performed with the G*Power software package, which indicated a sample size of 10 for each group. SPSS (Statistical Package for Social Sciences) for Windows 20.0 was used for statistical analysis. Statistical significance was defined as a *P* value of <0.05 within the 95% confidence interval. Means (SD) were used as descriptive statistics. Two-way analysis of variance (ANOVA) was used to analyze the two-factorial effect of material and cavity design for the marginal and internal gaps, and the Tukey HDS test was used to identify significant differences among multiple groups. Because the fabrication method used depends on the material, one-way ANOVA was used to analyze the effect of fabrication method.

Results

The mean marginal and internal gaps for all study groups are shown in Table 2. The LC-MODL group had the smallest marginal and internal gaps (166.8 ± 26.3 μm and 156.3 ± 20.7 μm, respectively), and the NHC-MODL group had the largest marginal and internal gaps (379.2 ± 110.2 μm and 549.0 ± 128.8 μm, respectively). Restoration material had a significant effect on marginal gap values, which were significantly lower in the LC group than in the other groups ($P = 0.05$ vs HC; $P < 0.001$ vs LDGC and NHC) and significantly lower in the HC group than in the NHC group ($P < 0.001$) (Table 3). The restoration material and cavity design both had a significant effect on internal gap values, which were significantly lower in the LC group and OV group than in the other groups ($P = 0.009$ vs HC; $P < 0.001$ vs LDGC and NHC) and significantly lower in the HC group than in the NHC group ($P < 0.001$). OVs had significantly smaller internal gaps than did MODLs ($P = 0.002$) (Table 4). Comparison of fabrication methods showed that conventional fabrication yielded significantly smaller marginal ($P < 0.001$) and internal ($P < 0.001$) gaps, as compared with the CAD-CAM method (Tables 3, 4).

Table 2 Mean marginal and internal gaps, in μm

		Marginal gap		Internal gap	
Study groups	*n*	Mean	SD	Mean	SD
LDGC-OV	10	315.9 ± 96.9^{Bc}		285.9 ± 61.6^{Bc}	
LDGC-MODL	10	251.8 ± 52.5^{B}		323.7 ± 121.2^{Bd}	
LC-OV	10	190.3 ± 81.9^{A}		194.4 ± 79.7^{Ab}	
LC-MODL	10	166.8 ± 26.3^{A}		156.3 ± 20.7^{Aa}	
NHC-OV	10	288.4 ± 66.2^{C}		273.7 ± 64.6^{Cc}	
NHC-MODL	10	379.2 ± 110.2^{D}		549.0 ± 128.8^{Ce}	
HC-OV	10	256.6 ± 35.4^{B}		283.0 ± 46.0^{Bc}	
HC-MODL	10	217.8 ± 50.2^{A}		231.4 ± 48.0^{Bb}	

Different uppercase letters indicate significant differences among restoration materials ($P < 0.05$). Different lowercase letters indicate significant differences among preparation designs ($P < 0.05$)

Table 3 Comparison of marginal gap values

		P
Material and design*		0.005
Material		<0.001
LC	HC	0.05
	LDGC	<0.001
	NHC	<0.001
HC	LDGC	0.167
	NHC	<0.001
LDGC	NHC	0.123
Cavity design*		0.574
Fabrication method**		<0.001

*Two-way ANOVA, **One-way ANOVA, sig. $P < 0.05$

Table 4 Comparison of internal gap values

		P
Material and design*		<0.001
Material		<0.001
LC	HC	0.009
	LDGC	<0.001
	NHC	<0.001
HC	LDGC	0.240
	NHC	<0.001
LDGC	NHC	<0.001
Cavity design*		0.002
Fabrication method**		<0.001

*Two-way ANOVA, **One-way ANOVA, sig. $P < 0.05$

Discussion

The first hypothesis of the study is partially accepted: only occlusal veneers had internal gaps smaller than those for MODL onlays. The second hypothesis of the study is accepted: internal and marginal gaps were smaller for the laboratory composite material than for the other materials. The third hypothesis of the study is partially accepted: although the internal and marginal gaps for restorations fabricated with laboratory composite material were smaller than those for other materials, gaps for the nanohybrid composite material were larger than those for the HC material.

No comprehensive study has defined when onlay, overlay, and occlusal veneer restorations can be used. The glut of available information confuses clinicians and leaves them having to determine their own criteria for distinguishing the types of posterior indirect restoration. After the best treatment option is identified, the clinician must consider the mechanical properties of the restorative materials when designing the geometric configuration of their cavities [8,16]. The present comparative study of cavity designs used occlusal veneer and extensive onlay cavities with structurally comparable designs involving both buccal and lingual cusps.

Differences in the mechanical properties of composite resin-based and ceramic materials raise the question of material longevity, especially in high-load-bearing posterior regions of the oral cavity. The success rates and duration of use of ceramic and composite resin materials have been investigated, but the optimal material for posterior indirect restorations has not been identified. This study sought to answer that question by examining indirect posterior restorations produced with the most frequently used materials in daily clinical routine, namely, LDGC, HC, NHC, and LC materials.

Ensuring that marginal and internal gaps are within clinically acceptable limits directly affects the success of a posterior indirect restoration. The most frequently used approaches to assess the fit of prosthetic restorations are the embedded and replica methods. The former is considered the most accurate but results in destruction of the material. In the present study, maximum accuracy was achieved by using the nondestructive and repeatable silicone replica method with a low-viscosity impression material [9]. Limitations of the silicone replica method are that it requires technical skill and that its multistage structure increases the risk of error. Elbadawy et al. and Swaid both reported that higher luting spaces resulted in smaller marginal and internal gaps in materials fabricated with milling procedures [23,24]. However, Swaid found that higher luting spaces may be problematic in a nonaxial seating [24]. Therefore, the digital luting space was set at 100 μm in this study.

Preparation can significantly affect internal gap values of restorations. Similar to the present results, Hasan et al. found that conventional design with boxes resulted in larger gaps [25], and Yang et al. suggested that fit was adversely affected when shoulder preparation was preferred in buccal and lingual cusps [22]. Some studies noted that MODL designs had a more complex geometry and internal angles that increased the risk of error during scanning and milling [22,26-28]. This may explain the smaller internal gaps of occlusal veneers in the present study.

A marginal gap of ≤120 μm is considered clinically acceptable, especially for crown restorations, but marginal gaps of 120-250 μm have been reported. Several studies reported that an internal gap of 200-300 μm is clinically satisfactory for cemented restorations [13,29-31]. LDGC, HC, NHC and LC materials yield different marginal and internal gap values. Although laboratory composite restorations resulted in better fit in some studies, other studies reported similar or worse results when comparing CAD-CAM materials [11,14,28,32,33]. In this study, results were better for the LC groups than for the other materials, perhaps because of the material itself or the conventional fabrication method.

Hassan et al. found that LDGC and NHC perform similarly, as did the current study [34]. However, El-Din et al. reported that the marginal and internal gaps of NHC exceeded clinically acceptable limits and that the gaps were significantly larger than those for ceramic material [35]. In addi-

tion, the present NHC group had significantly worse marginal and internal gap values, as compared with the HC group. In addition, gaps were larger for resin-based CAD-CAM materials than for ceramic-based CAD-CAM materials, perhaps because the high modulus of elasticity and flexural strength of glass ceramic materials, as well as their resistance to fracture and crack propagation during milling, are related to their mechanical properties and structural composition. The low hardness and modulus of elasticity of resins result in the removal of more material during milling.

The limitations of this study include its use of molar teeth without cavities, fractures, prior endodontic treatment, or preexisting restorations. These clinical variables affect the choice of preparation design. The finishing line is typically tailored to the tooth region. The present study protocol used a standard preparation procedure for all tooth specimens; however, in clinical practice preparation design is individualized. In addition, this study may not have adequately simulated the intraoral environment of restorations.

No previous study has used the present cavity designs to compare the fit of the materials used in the study. However, the present values are similar to those in previous studies that compared these materials separately. Because of the in vitro nature of the study and its limitations, the present results require confirmation in long-term clinical follow-up studies.

In conclusion, less complicated cavity designs resulted in a better fit. In particular, internal gap values were worse when cavity design complexity was increased by the increased number of intaglio surfaces. Marginal and internal gap values were better for conventional fabrication than for milling.

Abbreviations

ANOVA: analysis of variance; HC: hybrid ceramic; IG: internal gap; LC: laboratory composite; LDGC: lithium disilicate glass ceramic; MG: marginal gap; MODL: mesial-occlusal-distal-lingual; NHC: nanohybrid composite; OV: occlusal veneer; SD: standard deviation

Ethics Statements

The study was approved by the Ethics Committee of the Health Sciences Institute, Marmara University, Turkey (number 16; dated November 30, 2015).

Conflicts of Interest

The authors declare no conflicts of interest.

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Author Contribution Statement

ŞCA: Conceptualization, Methodology, Formal Analysis, Investigation, Writing - Original Draft, Writing - Review and Editing, Visualization; EK: Conceptualization, Methodology, Resources, Writing - Review and Editing, Supervision, Project Administration.

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Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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