



## ADAPTATION OF COMPOSITE CAD/CAM INLAYS FABRICATED BY DIFFERENT METHODS: AN IN VITRO MICRO-CT STUDY

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### ABSTRACT:

**Purpose:** Indirect restorations can be performed using different impression techniques (conventional, laboratory, or intraoral scanners). Their accuracy determined their longevity. This study compares the marginal and internal adaptation of milled CAD/CAM composite inlays fabricated by conventional, hybrid, and digital methods.

**Material and methods:** Thirty human premolars were prepared for MOD composite inlays (CI). They were divided into three equal groups depending on the process of fabrication: Group 1 (conventional group)—impression and laboratory-fabricated CI, Group 2 (hybrid group)—impression, laboratory scanner and milled CAD/CAM CI, and Group 3 (digital group)—digital impression (intraoral scanner) and milled CAD/CAM CI. The marginal gap (MG), absolute marginal discrepancy (AMD), and internal gap (IG) were measured at 120 different points per CI using X ray microtomography. The data were analyzed using Kolmogorov–Smirnov and Mann–Whitney U tests.

**Results:** The conventional and digital composite inlays present significantly smaller marginal and internal gaps than the CAD/CAM group manufactured by hybrid methods.

**Conclusions:** Within the limitations of this in vitro study, we concluded that the CAD-CAM composite inlays fabricated by digital method exhibited statistically better marginal and internal adaptation results than composite CAD-CAM inlays by hybrid methods. The composite CAD-CAM inlays made by digital methods are an alternative to those made by a conventional methodology.

**Keywords:** inlays, CAD/CAM dental materials, in vitro micro-CT, marginal adaptation, internal adaptation, digital dentistry,

### INTRODUCTION

Aesthetic restorations have attracted increased interest among dental practitioners. Along with the ceramic materials used for indirect restorations, hybrid-composite materials with improved quality have been introduced into the market. The latter exhibits numerous advantages, such as a high fracture resistance (even at a thickness of 1–1.5 mm), abrasion resistance similar to hard dental tissues, and a lower price [1, 2].

Indirect restorations of hybrid-composite materials could be laboratory-fabricated or produced by milling computer-aided design/computer-aided manufacturing (CAD/CAM) technology [3, 4]. Modern laboratory composites are second-generation and characterized by a high content of ceramic filler particles. To achieve the complete polymerization of laboratory hybrid-composite materials for indirect restorations, the following requirements should be present: polymerization conducted in an oven, additional pressure, and a vacuum and oxygen-free environment [2, 5]. This results in less material shrinkage, improved accuracy, and reduced marginal and internal gaps in the inlays.

Over the past 20 years, digital technology utilized in dental practice has rapidly evolved. Different scanners and CAD/CAM milling machines (3-, 4-, and 5-axis) have been used. The research conducted by Alajaji et al. observed that the most incredible precision of fabricated inlays is achieved by five-axis milling machines [6]. Hybrid-composite blocks are used for different milling types of constructions [3, 4]. They possess excellent mechanical and aesthetic qualities.

The longevity of tooth-colored restorations using composites or ceramics depends on the quality and stability of their marginal and internal fits. The marginal fit is related to and measured by the marginal gap. It is defined as the distance between the edge of the inlay and the outer edge of the cavity. The smaller it is, the less the possibility of micropenetration. Hence, the risk of developing secondary caries and subsequent damage to the dental pulp is reduced. There are discrepancies in the literature regarding the marginal gap values. According to Fonseca et al., Nguen et al., Lauvahutanon et al., and Maroiu, a marginal gap of up to 120  $\mu\text{m}$  is clinically acceptable [7, 8]. Other

authors claim that the best results are demonstrated when the gap is no bigger than 100  $\mu\text{m}$  [6, 9], whereas according to Schaefer et al. and Addi et al., these values are between 50 and 150  $\mu\text{m}$  [10, 11].

The internal fit is the distance between the inner surface of the restoration (inlay) with the pulp and axial cavity wall. It is essential for the equable stress distribution during chewing [12, 13]. In the literature, the information about the marginal and internal fits of laboratory-fabricated and CAD/CAM composite inlays is insufficient and ambivalent [14, 15].

Clinicians used three methods to fabricate composite inlay (CI). Conventional methods impression and laboratory-fabricated CI. Hybrid approach – impression, laboratory scanner, and CAD/CAM CI. Digital method impression with intraoral scanner and CAD/CAM CI.

The aim of this study is to compare the marginal and internal adaptation of CAD/CAM inlays fabricated by different (conventional, hybrid and digital) methods. The null hypothesis is that there is no significant difference between the groups.

## MATERIALS AND METHODS

Thirty intact human premolars, extracted for orthodontic reasons, were selected for the study. According to the Medical University- Sofia Commission on the Ethics of Scientific Knowledge, all patients signed informed consent before extraction. The teeth were ultrasonically cleaned from soft tissues and plaque. The teeth were examined by stereomicroscope Leica S6 (*Leica Microsystems, Wetzlar, Germany*) at 9x magnification to detect cracks and hypoplastic defects and stored in a 0.1% thymol solution at room temperature until the study was performed. The specimens were placed in gypsum blocks (class IV gypsum, Octarock (*Heraeus Kulzer, Hanau, Germany*) by adding a light body of silicone material type-A Light-Flow Variotime (*Heraeus Kulzer, Hanau, Germany*) between the gypsum and tooth.

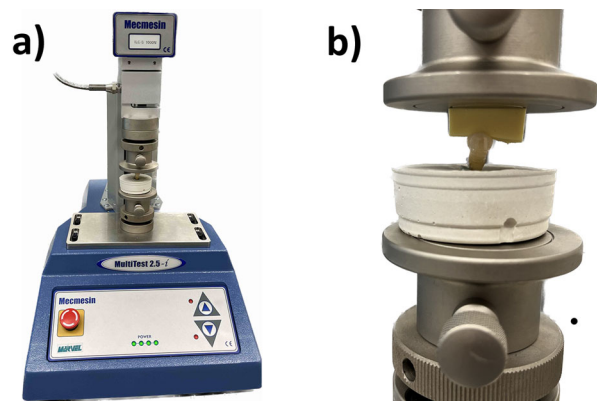
**Cavity preparation.** Mesio-occlusal-distal cavities for inlays were created with the following dimensions: 2 mm wide and 2 mm deep in the occlusal part of the teeth, 4 mm deep and 4 mm wide in the proximal portions. No bevel was prepared on the enamel edges. The degree of divergence of the cavity walls was  $12^\circ$  made by appropriate bur – Expert set 4562, *Komet, Germany*. The teeth were divided into three equal groups: Group 1—conventional inlay, Group 2—hybrid inlay, and Group 3—digital.

**Impression technique.** Groups 1 and 2: Standard one-stage, two-phase impressions with A-silicone Easy putty Variotime (*Heraeus Kulzer, Germany*) and Light-Flow Variotime (*Heraeus Kulzer, Germany*) were obtained. The impressions were poured using a type-IV dental stone (Octarock, *Heraeus Kulzer, Germany*). The teeth were divided into two groups, 10 ( $n = 10$ ). For Group 2, the samples were scanned with an Evolution Zfx (*Zimmer Biomet, Palm Beach Gardens, FL, USA*) laboratory scanner using

the Multi-Die method (simultaneous scanning of all samples) like other similar studies [4, 12]. Group 3—the pieces were scanned with intraoral Intra scan Zfx (*Zimmer Biomet, Palm Beach Gardens, FL, USA*).

**Inlay fabrication.** Group 1: Inlays of the laboratory composite Signum ceramics (*Heraeus Kulzer, Hanau, Germany*) were produced on the models the Technician prepared. The material was applied in layers of A3 color using a C&B liquid modeling fluid (*Heraeus Kulzer, Hanau, Germany*). After applying each layer of laboratory composite for complete polymerization, the model was placed in a Hi-Light power 3D (*Heraeus Kulzer, Hanau, Germany*) oven for 6 seconds with a final treatment of 90 sec. The complete polymerization of the investigated inlays was conducted by exposure to a wavelength of 460 nm and a thermal effect. Groups 2 and 3: Composite CAD-CAM Inlays were designed using Zfx Exocad software (*Zimmer Biomet, Palm Beach Gardens, FL, USA*). The distance between the cavity and the restoration was 50  $\mu\text{m}$ . The 5-axis Zfx in-house 5x milling machine (*Zimmer Biomet, Palm Beach Gardens, FL, USA*) of CERASMART composite blocks (*GC, Corp. Tokyo, Japan*) was milled in the inlay. According to the manufacturer's instructions, all indirect inlays were cemented with self-adhesive cement i-CEM Self-adhesive (*Heraeus Kulzer, Hanau, Germany*). The cavity was treated with a 2% chlorhexidine solution for 30 s and dried. The inner surface of the inlays was sandblasted (50 $\mu\text{m}$   $\text{Al}_2\text{O}_3$ ), and a silane agent was applied. The dental surface was rinsed and dried; the prepared cement was applied to the finished restoration and placed in the cavity. The inlays were seated on the cavities using an applied force of 20 N with a universal material testing machine (MultiTest 2.5 i (*Mecmesin GmbH, Freiburg in Breisgau, Germany*), as shown in Figure 1. Then, the cement was polymerized with light for 1–2 seconds, and the excess material was removed. Subsequently, the final polymerization was performed for another 30 seconds. The final curing of the cement was obtained without light for 2.5 minutes under the slight pressure of the inlay to the cavity.

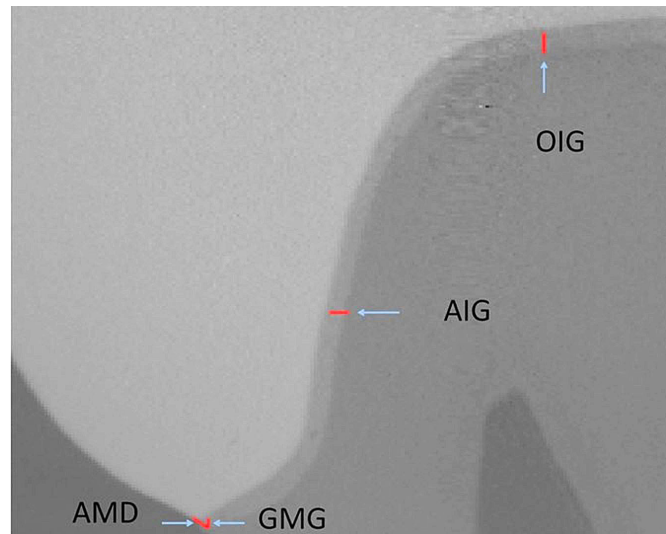
**Fig. 1.** A. Universal materials testing machine. B. Inlay seating on the cavity using a universal materials testing machine.



**Micro-CT evaluation.** The micro-CT scanning was performed on a Nikon XT H 225 (Nikon Metrology, Inc., Americas) system developed by Nikon Metrology. The system has a 225 kV microfocus X-ray source, a 5-axis manipulator, and a Varian 2520 flat panel detector with a pixel size of 127  $\mu\text{m}$ . The Inspect-X software was used for image acquisition. The data were collected at 100 kV and 100  $\mu\text{A}$  X-ray power. The sample was continuously rotated during the scan. Three thousand projections were collected over 360 degrees with a 500 ms exposure time per projection. Following the acquisition, the software CT Pro 3D was used for a 3D volume reconstruction. The VGStudio MAX 2.2 software (Volume Graphics GmbH) was used to visualize the micro-CT data.

**Measure.** Five equal cuts were made at 100 sections from the tooth's center in the buccolingual direction. Two absolute marginal discrepancies (AMDs) – the distance between the internal surface of the inlay margin and the preparation finish line and two occlusal marginal gaps (OMGs) were measured for each slice, yielding 20 values. The absolute marginal discrepancy is the distance between the cavity and inlay edges. In the mesiodistal direction, five cuts were made of 50 sections of each other. A total of 12 points were measured on each of the samples obtained: 2 for the absolute marginal discrepancy (AMD), 2 for marginal gingival gap (GMG), 4 for the internal occlusal gap (OIG), and 4 for the axial inner gap (AIG)—60 in total. A total of 5 transverse cuts were made in the occlusal gingival direction, 75 sections apart. A total of 8 points were measured on each sample—4 for the absolute marginal discrepancy (AMD) and 4 for the proximal marginal gap (PMG)—40 in total. The results were measured according to the methodologies proposed by Holmes et al. and Alajaji et al. [6,12]. 120 points were calculated for each inlay (Figure 2).

**Fig. 2.** Casting misfit terminology: absolute marginal discrepancy (AMD), gingival marginal gap (GMG), axial internal gap (AIG), and occlusal internal gap (OIG).



**Statistical analyses.** The study used a descriptive statistical method: one Kolmogorov–Smirnov, non-parametric test in two independent samples (Mann–Whitney U test). The statistical methods were applied with IBM SPSS Statistics 24, and the graphical representation was performed using Excel 2010.

## RESULTS

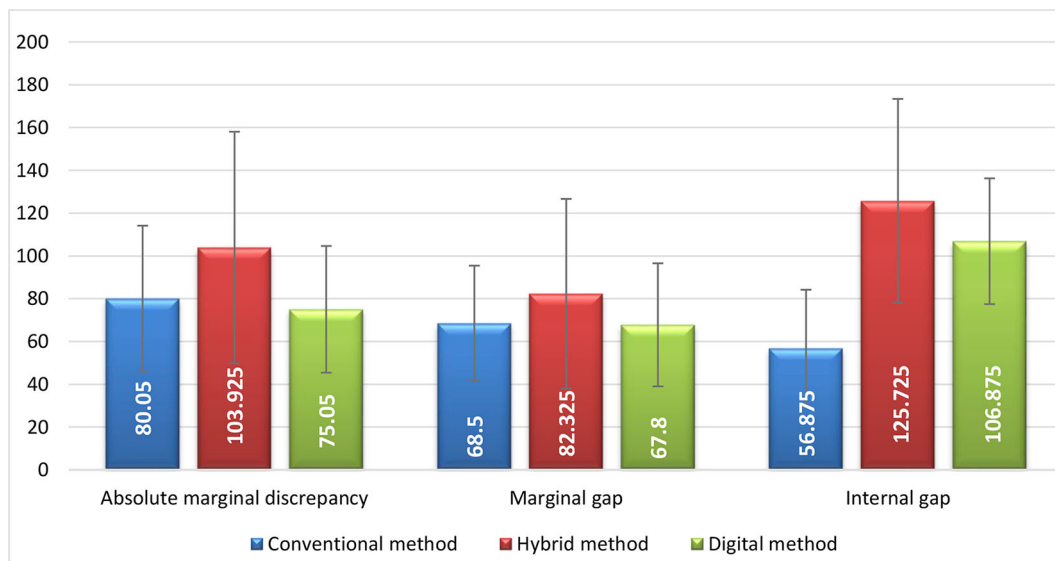
The summary results for the absolute marginal discrepancy (AMD), marginal gap (MG), and internal gap (IG) are presented in Table 1 and Figure 3. Groups 1 and 3 statistically present significantly better results than Group 2 for the absolute marginal discrepancy and marginal gap.

**Table 1.** Descriptive statistics of an absolute marginal discrepancy, marginal gap, and internal gap between three groups in  $\mu\text{m}$ .

Groups		Absolute marginal discrepancy	Marginal gap	Internal gap
<b>Laboratory composite Conventional Group</b>	Median	<b>80.05<sup>a</sup></b>	<b>69<sup>a</sup></b>	<b>57<sup>a</sup></b>
	SD	$\pm 34.01$	$\pm 26.95$	$\pm 27.34$
	N	400	400	400
<b>Composite CAD-CAM inlay Hybrid Group</b>	Median	<b>103.93<sup>b</sup></b>	<b>82<sup>b</sup></b>	<b>126<sup>b</sup></b>
	SD	$\pm 54.12$	$\pm 30.72$	$\pm 47.67$
	N	400	400	400
<b>Composite CAD-CAM inlay Digital Group</b>	Median	<b>75.05<sup>a</sup></b>	<b>68<sup>a</sup></b>	<b>107<sup>c</sup></b>
	SD	$\pm 29.61$	$\pm 28.76$	$\pm 29.39$
	N	400	400	400
<b>Total</b>	N	1200	1200	1200
<b>Mann–Whitney U test</b>	P	<b>p&lt;0.01</b>	<b>p&lt;0.01</b>	<b>p&lt;0.01</b>

\* Groups with statistically significant differences were marked with different letters.

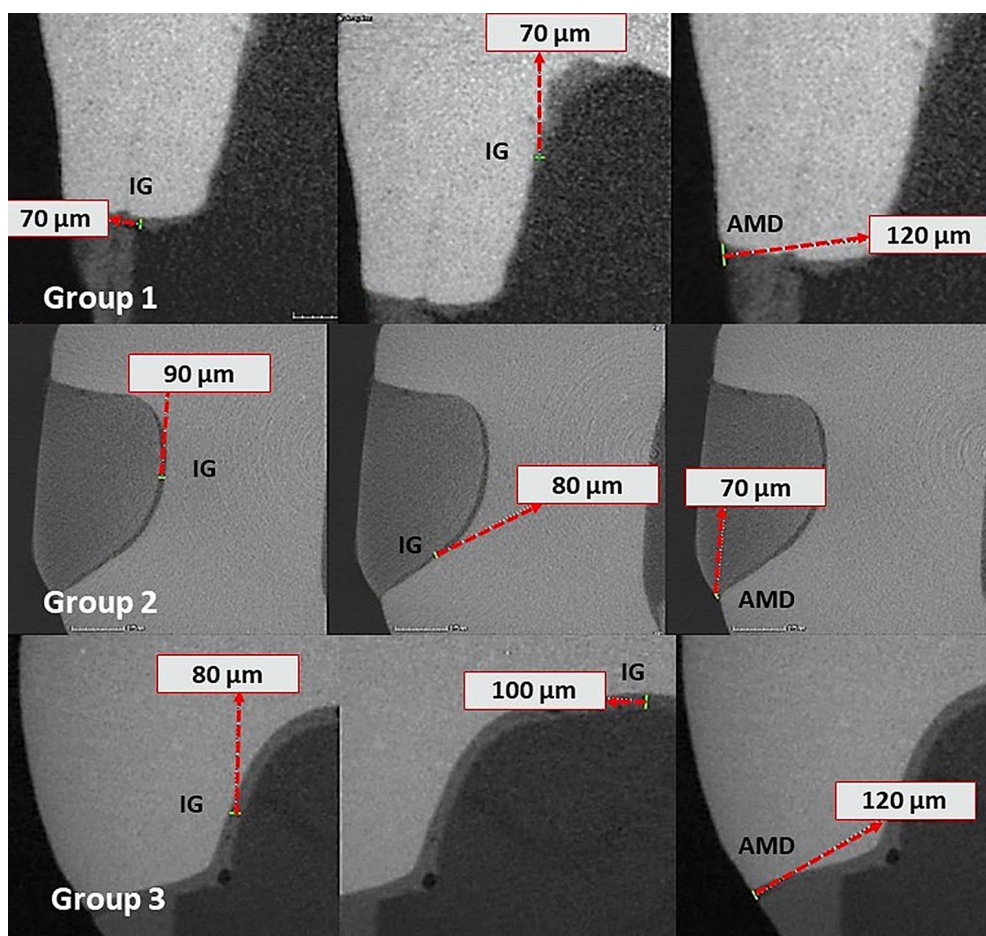
**Fig. 3.** Average Gap values ( $\mu\text{m}$ ) for the three groups of inlays. Laboratory composite inlays are in blue; CAD-CAM composite inlays (hybrid group) are in red; CAD-CAM composite inlays (digital group) are in green.



Regarding the accumulated data for the marginal and internal gaps, Groups 1 and 3 perform statistically better than Group 2. There is a statistically significant difference between a conventional and digital CAD-CAM inlay for the inner gap.

Figure 4 presents the sections with measured values in the studied groups.

**Fig. 4.** Digital slices with a measured gap. Group 1–laboratory composite inlays (conventional group); Group 2–composite CAD-CAM inlays (hybrid group); Group 3–composite CAD-CAM inlays (digital group). AMD is the absolute marginal discrepancy; IG is the internal gap.



## DISCUSSION

The conventional and digital groups demonstrate statistically better results than those prepared with a standard impression and CAD/CAM technology—the hybrid method. This could be because the second group has the potential to experience more procedural errors and inaccuracies associated with transferring the prosthetic field into a plaster model, followed by the additional scanning conducted with a laboratory scanner into a digital copy. There are several problems with this type of restoration: the deformation and contraction of the impression, the enlargement of the gypsum, and the image deformation when scanning the model. From a clinical perspective, the difference between the three groups is irrelevant since the results are within the limits of the clinically acceptable values (Marginal gap (Group 1) –  $69.05 \pm 29.65 \mu\text{m}$ , Marginal gap (Group 2) –  $82.00 \pm 30.72 \mu\text{m}$ , and Marginal gap (Group 3) –  $68 \pm 28.76 \mu\text{m}$ ). Although clinically acceptable marginal gap values have been previously described in the literature, no internal gap values were reported [16].

Some authors measure only the marginal gap [10, 11], while others [12, 16] report absolute marginal discrepancy and marginal gap values. The total marginal discrepancy gives information about the overcontour or undercontour of the restorations.

There are two possibilities for building 3D images in dentistry: directly through an intraoral scanner or indirectly through a laboratory scanner [16]. The intraoral scanner used in the present study works on the principle of confocal microscopy. It is of the modern generation of digitizers that do not need a coating agent when scanning an object. This increases the accuracy of the obtained image, hence the future restoration [17].

Park et al. investigated the marginal and internal adaptations of two CAD/CAM block types—Lava Ultimate (LU, 3M ESPE, St. Paul, MN, USA) and nanoceramic composite blocks. The results of the first type are better for an OIG of  $175.44 \pm 5.85 \mu\text{m}$ , an AIG of  $111.05 \pm 5.29 \mu\text{m}$ , and for a GMG of  $48.72 \pm 4.07 \mu\text{m}$ . The milled CAD/CAM mills values for GMG and AIG followed their results, but higher values were registered for GMG. This was probably due to the differences in the methodology used. In their in vitro study, Park et al. investigated CAD/CAM inlays with digital impressions. Additionally, the gap was measured through digital images, where the possibility of error was more significant [16].

Chang et al. examined the marginal gap of Co-Cr-Mo metal crowns fabricated using wax molding and CAD/CAM techniques. The former performed statistically better, which is confirmed by the results of the current study. The average values of MG for standard crowns were  $76 \pm 61 \mu\text{m}$  and  $121 \pm 98 \mu\text{m}$  for CAD/CAM [18].

Other authors used an intraoral scanner to examine the accuracy of standard crowns created through traditional impression and wax techniques and CAD/CAM crowns [19, 20]. Haddadi et al. conducted a clinical trial of ceramic crowns' marginal and internal adaptations using a silicone-duplicate technique. The results obtained for the marginal gap in crowns fabricated by standard impressions are simi-

lar to those reported for conventional inlays in the present study ( $78 \mu\text{m}$ ). In their experiment, Haddadi et al.'s use of CAD/CAM technology demonstrated significantly better results when using an intraoral scanner [19]. Zaraus et al. also investigated the accuracy of crowns using standard and digital (iTERo) impressions. The latter was significantly more accurate and presented a smaller marginal gap [20]. Similar to the present investigation, several studies claim that the direct digitalization of a prepared cavity produces better results. The measured values for marginal and internal gaps were significantly lower [21, 22]. This is likely why conventional inlays are more precise than CAD/CAM milled inlays using a laboratory scanner. Our results confirm the data obtained from some of the studies observed in the literature [6,18].

Reich et al. compared the marginal gap in conventional and CAD/CAM ceramic inlays. The former was created using two-phase, one-stage A silicone, and the latter was created using CEREC 3D. The traditional inlay presented better results than the results obtained in this study [9]. Boitelle et al. analyzed the available literature data on the accuracy of indirect restorations. They observed that the mean values for the marginal gap ranged between  $39.1$  and  $210 \mu\text{m}$  and  $23$  and  $230 \mu\text{m}$  for the internal gap [23].

The conventional inlay group showed statistically significantly better results than the other two groups in the present study. There is a pre-set distance for inlays created using hybrid and digital methods. This was a possible reason for the larger internal-gap values in these constructions compared to the conventional ones. In most studies, the values for this distance vary between  $20 - 50 \mu\text{m}$  [6, 23], with current milling block manufacturers recommending specific parameters. Similar to our research, all studies on the accuracy of CAD/CAM restorations reported higher gap measurement values than pre-set distance [6, 23].

Some studies were performed before the cementation of the restorations [18, 19] and others after [24], similar to the present study. It is possible to form a more significant internal gap due to the viscosity of the cement [25, 26].

There are several methods used for measuring marginal and internal adaptations—microtomography and light microscopy, silicone duplicates of the space between the restoration and cavity, the measurement of the weight and density of the silicone duplicate [18], virtual 3D scanner and special software, and computer microtomography [27, 28]. They can be divided into destructive and non-destructive. The first ones are related to the destruction of the specimen, where it can be damaged, and wrong measurements can be obtained. Usually, in destructive methods, the measurement is done under a microscope, where the magnification is not high enough to measure values in  $\mu\text{m}$ . Micro-CT is a non-invasive approach, allowing many digital sections to be created without destroying the specimen [29, 30]. In addition, this method makes it possible to examine three-dimensional samples, which increases their accuracy. Schonberger et al. compared the measurement accuracy of two methods for reading marginal and internal gaps using a silicon duplicate and under a microscopic evaluation of the cross-sections [31]. The two methods per-

formed equally well. Thus, the conventional methods used for obtaining gap measurements might also be reliable, and we can compare our results with those obtained via these methods. Micro-computed tomography is a newly introduced method in the research for measuring marginal adaptation values. The main advantage of this technique is the reliability of the results obtained by the numerous measurements of the studied objects. Nevertheless, this approach is expensive and time-consuming.

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#### CONCLUSIONS

Within the limitations of this in vitro study, we concluded that the inlays fabricated by the digital method exhibited statistically better marginal and internal adaptation results than the hybrid method. Thus, the null hypothesis was rejected. The composite CAD-CAM inlays made by digital methods are an alternative to those produced conventionally.

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