Additively Manufactured Definitive Crown Resins on Premolar and Molar Teeth: 2-Year Results of a Prospective Clinical Study

Ezgi Sonkaya, DDS
Gonca Zeliha Bek Kürklü, DDS, PhD
Department of Restorative Dentistry, Çukurova University, Adana, Turkey.

Purpose: To evaluate the 12- and 24-month clinical results of overlay and one-piece endodontic crown restorations applied with additively manufactured, 3D-printed, permanent ceramic-filled resin (PCR) according to the modified US Public Health Service (USPHS) criteria. ***Materials and Methods:*** A total of 33 indirect restorations (16 overlay, 17 endocrown; 4 premolar, 29 molar) produced using PCR (Formlabs) were applied in 30 patients by a single dentist. The restorations were evaluated according to the modified USPHS criteria at baseline (1 week), 12 months, and 24 months by two independent evaluators. For comparisons of the dependent criteria scores, related samples Cochran Q test was used, and in post-hoc paired comparisons, Bonferroni test was used. Fisher-Freeman-Halton test was applied in the comparisons of categoric variables according to the restoration type groups (α = .05). ***Results:*** No statistically significant difference was determined between the evaluation criteria scores at baseline, 12 months, and 24 months for marginal adaptation (P = .05), retention (P = 1), interproximal contact (P = .368), color match (P = 1), surface texture (P = 1), and patient satisfaction (P = 1). The only score criterion that showed a statistically significant difference between baseline and 24 months (P = .001) was marginal discoloration. This criterion's score change was from 100% A score to 69.7% A score. ***Conclusions:*** In the 2-year follow-up of indirect single-tooth restorations produced with 3D-printed PCR, all restorations showed acceptable clinical performance (≥ 99.5% A + B score at 2 years). *Int J Prosthodont 2025;38:279–289. doi: 10.11607/ijp.9200*

Current, minimally invasive treatment protocols in dentistry have been developed by combining low-cost treatment options with increasing esthetic expectations. As a result of these developments, two technologies have rapidly entered clinical practice in recent years: CAD/CAM and, more recently, additive manufacturing (AM).[1,2]

Compared to conventional composites, CAD/CAM hybrid resin blocks have higher resistance, and lower levels of wear, water absorption, and discoloration.[3,4] However, subtractive manufacturing can spoil most of the material during milling and cause various defects below the surface.[5] AM with CAD at a lower cost and with less waste has eliminated these disadvantages and started to come into use in dentistry practice.[5,6] AM resin materials are formed from acrylates and epoxy resin, which are composite-based resins, photo-initiators, and ultraviolet (UV) absorbents, which make light-activated polymerization possible.[1] In addition, content that includes inorganic particles such as silanized dental glass at the rate of 30% to 50% has been named hybrid-ceramic-filled methacrylate photopolymer in literature.[7]

AM is the most current method for constructing single-tooth, permanent indirect restorations. 3D resins, which were only used to produce interim crowns when they were first introduced to the market, have been developed further by improving their physical properties in recent years.[5]

Correspondence to:
Dr Ezgi Sonkaya
sonkayaezgi@yahoo.com

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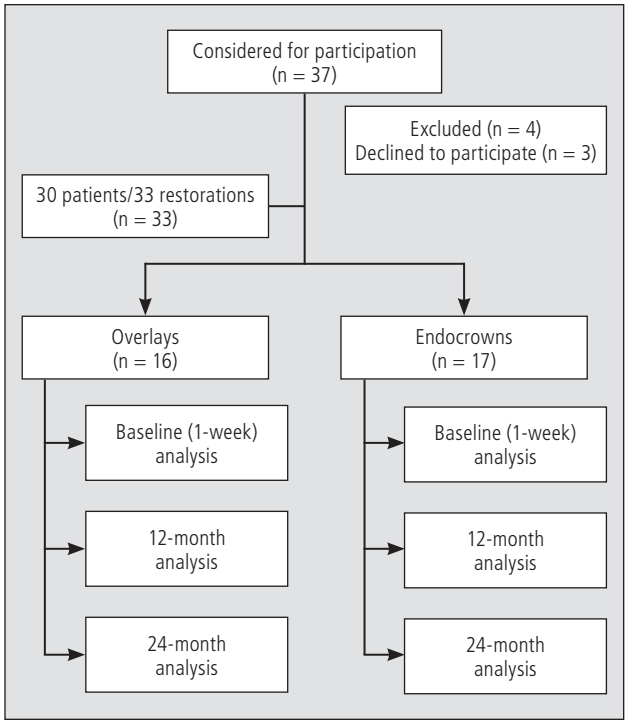

Fig 1 Flow diagram of the study.

According to the Medical Devices Regulations, which control the biocompatibility of materials for long-term use in the oral cavity, PCR has been approved as a class IIa material for permanent single tooth restorations.[8–11] PCR is produced as Varseo Smile Crownplus by BEGO and distributed as permanent crown resin by Formlabs.[7] The material's physical properties have been improved to reach the resistance required for permanent prostheses according to International Standardization Organization (ISO) standard no: 10,477.[12]

Previous in vitro studies have shown that PCR has a flexural strength of 116 mPa, water solubility 0.23 µg/mm,[3] water sorption 3.6 µg/mm,[3,13] and the shear bond strength values do not fall below 10 mPa even after thermal cycles.[14] It shows low toxicity and wettability, good biocompatibility,[7,15–17] high color stability, fracture resistance, low surface roughness, wear,[18–20] and high marginal adaptation.[8,21–24]

The manufacturer claims that PCR is clinically suitable for mid and long-term use in single-tooth restorations, which is supported by the in vitro studies mentioned. However, these were supported by very limited in vivo studies.[24] In vivo conditions are influenced by patient-related factors (oral pH, temperature, saliva expression, parafunctional habits, eating habits) that affect the survivability of the restoration which cannot be replicated in in vitro conditions. Therefore, the aim of this study was to evaluate the clinical results of indirect PCR restorations according to the modified US Public Health Service (USPHS) criteria after 12 and 24 months.

MATERIALS AND METHODS

The procedures in this study complied with the institutional and national research ethical standards and the principles of the 2008 Helsinki Declaration. The study was approved by the Clinical Research Ethics Committee of Çukurova University Faculty of Medicine (dated 05.11.2021, decision no: 55). The treatment selection steps, benefits, and risks were explained to the patients, and all study participants provided written informed consent. This study was conducted as a standards-based, observational, prospective clinical study. The study was registered at ClinicalTrials.gov with the unique identification number NCT05168852 and supported by grant No: TSA-2021-14334 from the Çukurova University Department of Scientific Research Projects.

The study included patients selected from those with carious lesions or failed restorations in the daily patient profile of the Department of Restorative Dentistry, Faculty of Dentisry, Çukurova University who met the study's inclusion criteria. Inclusion criteria were defined as patient evaluated as ASA 1, with good oral hygiene, a tooth with remaining walls of < 1.5 mm thickness, no periodontal or endodontic diagnosis in the teeth to be restored, the presence of a tooth opposite or next to the tooth to be restored, and ability to attend follow-up appointments to ensure continuity of the study. The study exclusion criteria were defined as patients who were allergic to the resin materials or adhesive components, those who were in the high-risk group for decay, the presence of malocclusion or bruxism, an inappropriate crown-to-root ratio, and those who did not provide informed consent for participation in the study.

Taking a previous study as a reference,[25] when the difference between rates was taken as w = 0.44 units, the sample size required was calculated as a minimum of 32 restorations (n1 = n2 = 16, n = 32) to provide 80% power at a significance level of 0.05 in a 95% CI.

The study included a total of 30 patients (21 women, 9 men) in the age range of 17 to 58 years, and 33 indirect restorations (16 overlays, 17 one-piece endodontic crowns) were applied by a specialist dentist (E.S.). Overlay restorations were performed on the following: maxilla—two right premolars, three right first molars, four left first molars; mandible— one left premolar, three left first molars, and two right first molars were treated. One-piece endodontic crown restorations were performed on the following: maxilla—three right first molars, one right second molar, three left first molars, one left second molar; mandible—one left premolar, five left first molars, and three right first molars were treated. To reduce possible patient-related side effects, a maximum of two restorations from the same restorative material were applied to each patient (Fig 1).

Table 1 Materials Used

Material	Category	Composition	Manufacturer	Lot no.
Formlabs Form 3+ Permanent Crown Resin (A2)	3D-printed definitive restoration material	Esterification products of 4,4'-isopropylidiphenol, ethoxylated and 2-methylprop-2enoic acid; ethoxylated bisphenol A dimethacrylate (Bis-EMA, methacrylate polymer), 30–50 wt.% inorganic fillers (particle size 0.7 µm) silanized dental glass, methyl benzoylformate, TPO	Formlabs	601068
G-ænial Universal Flo	Flowable composite	Urethanedimethacrylate Bis-MEPP, TEGDMA (31 % wt), silicon dioxide (16nm), strontium glass (200 nm), pigment (69 % wt-50 % vol), photoinitiator	GC Dental	2207101
G-Premio Bond	Universal adhesive	10-MDP, 4-MET, MDTP, BHT, Acetone dimethacrylate resins, initiators, water	GC Dental	1610250
G-Multi Primer	Silane coupling agent	MDP, MDTP, and γ-MPTS, vinyl silane, phosphoric methacrylate monomer, thiophosphoric ester monomer, methacrylic acid ester, ethyl alcohol	GC Dental	1611025
G-CEM LinkForce	Resin luting cement	Paste A: Bis-GMA, UDMA, DMA, initiator, pigment / Paste B: Bis-MEPP, UDMA, DMA , initiator, Bis-EMA, dibenzoyl peroxide, BHT	GC Dental	1611075
Porcelain Etch	Acid etching for restoration	9% buffered hydrofluoric acid	Ultradent	
K-Etchant Syringe	Acid etching for tooth	35% orthophosphoric acid	Kuraray	AH0281
Dentalon Plus	Self-curing interim crown	Ethyl-methacrylate based resin	Heraeus Kulzer	Liquid: 010356; Powder: 010589
Cavex Temporary Cement	Temporary cement	Magnesium oxides, zinc oxides, fatty acid dimer, acetic acid	Cavex BV	150532
OptraGloss	Polishing instruments	2-step diamond-embedded cup and spiral wheel system for both composite and ceramic polishing	Ivoclar Vivadent	

Detailed oral and radiographic examinations were conducted for each patient. Local anesthetic was injected before tooth preparation. The teeth prepared for overlay and one-piece endodontic crown were prepared according to the preparation techniques in the literature.[26] In the overlay preparations, a 2 to 3 mm occlusal cusp reduction was made with 1- to 2-mm-wide, 90 degrees, circumferential butt joint edges and supragingival cuts so all cervical margins were in the enamel as far as possible. A one-piece endodontic crown and some overlays were designed to be supported in the pulp chamber.[27] In cases where necessary, a retraction cord (Ultrapak, Ultradent) impregnated with a hemostatic agent (Alustat, Cerkamed) was used for bleeding control. Flowable composite (G-ænial Universal Flo, GC Dental) was used for the blocking of undercuts according to the need of the tooth. Interim restorations (Dentalon Plus, Heraeus Kulzer) were applied to the prepared teeth using provisional cementation (Temporary Cement, Cavex). The materials used are shown in Table 1.[4,18]

Scans were taken from each patient using CEREC Omnicam (Dentsply Sirona) formed by an experienced dentist (E.S.). Restorations were designed in the inLab program (Dentsply Sirona). STL (standard tessellation language) files were imported into Preform software and adjusted to the appropriate position for printing. They were uploaded to a 3D printer (Form3B, Formlabs Dental), and permanent crown resin (Formlabs Dental) was printed at 50 µm resolution using the stereolithography technic.[13,28] The printed restorations were washed with 99% pure isopropyl alcohol in a Form Wash device (Formlabs Dental) and were then made ready for use with polymerization at 60°C for 20 minutes in a Form Cure device (Formlabs Dental) twice. After curing, the surface was polished using a pumice stone and polishing compound according to the manufacturer's instructions for finishing.[28] Before being placed in the patient, the inner surface of the restoration was sandblasted with 50-µm aluminum oxide applied from a 1-cm distance, for 10 seconds at 1.5 bar pressure.

Under rubber dam isolation following the manufacturer's instructions, acid etching with orthophosphoric acid was applied for 15 seconds with the selective etching of enamel, which was then washed (15 seconds), and light air pressure was applied (5 seconds). G-Premio universal bond was spread on all prepared tooth surfaces with a microbrush (10 seconds), allowed to spread without touching (10 seconds), and then light air pressure was applied (5 seconds). Light source was applied for 10 seconds in standard power mode

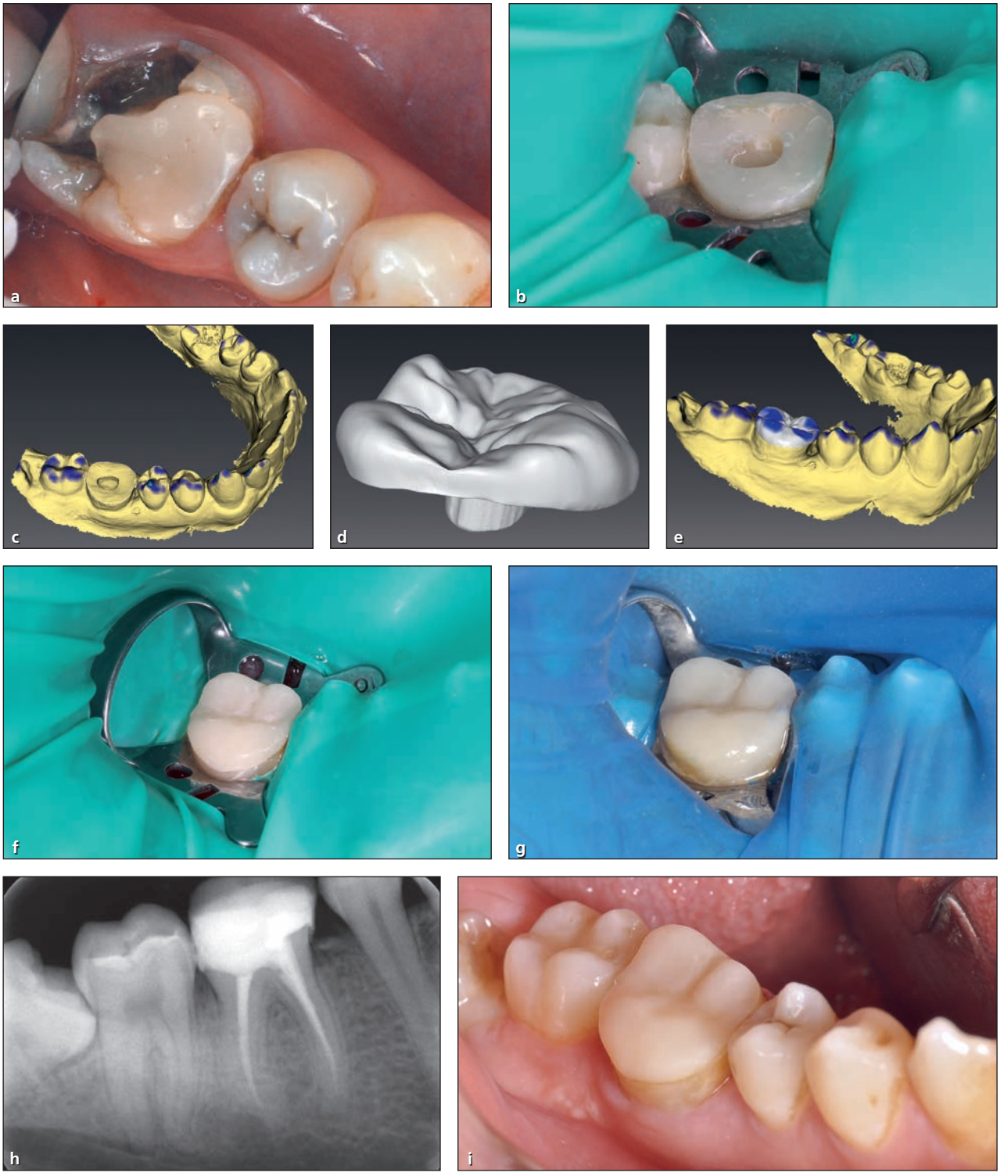

Fig 2 Fabricated 3D-printed endocrown: old filling *(a)*, preparation design *(b)*, designed restoration in inLAB *(c to e)*, finished 3D-printed permanent crown at baseline *(f)*, 12-month follow-up *(g)*, 24-month follow-up radiograph *(h)*, and 24-month follow-up *(i)*.

(1,000 mW/cm^2; VALO, Ultradent). Hydrofluoric acid was then applied (30 seconds) to the inner surface of the restoration, washed (60 seconds), and dried (5 seconds). It was then wet with multiprimer (10 seconds) and dried (5 seconds). Resin-luting cement was spread on the inner surface of the restoration while holding it with a stick (OptraStick, Ivoclar). The buccal and lingual surfaces were wet for 3 seconds, and the residual luting

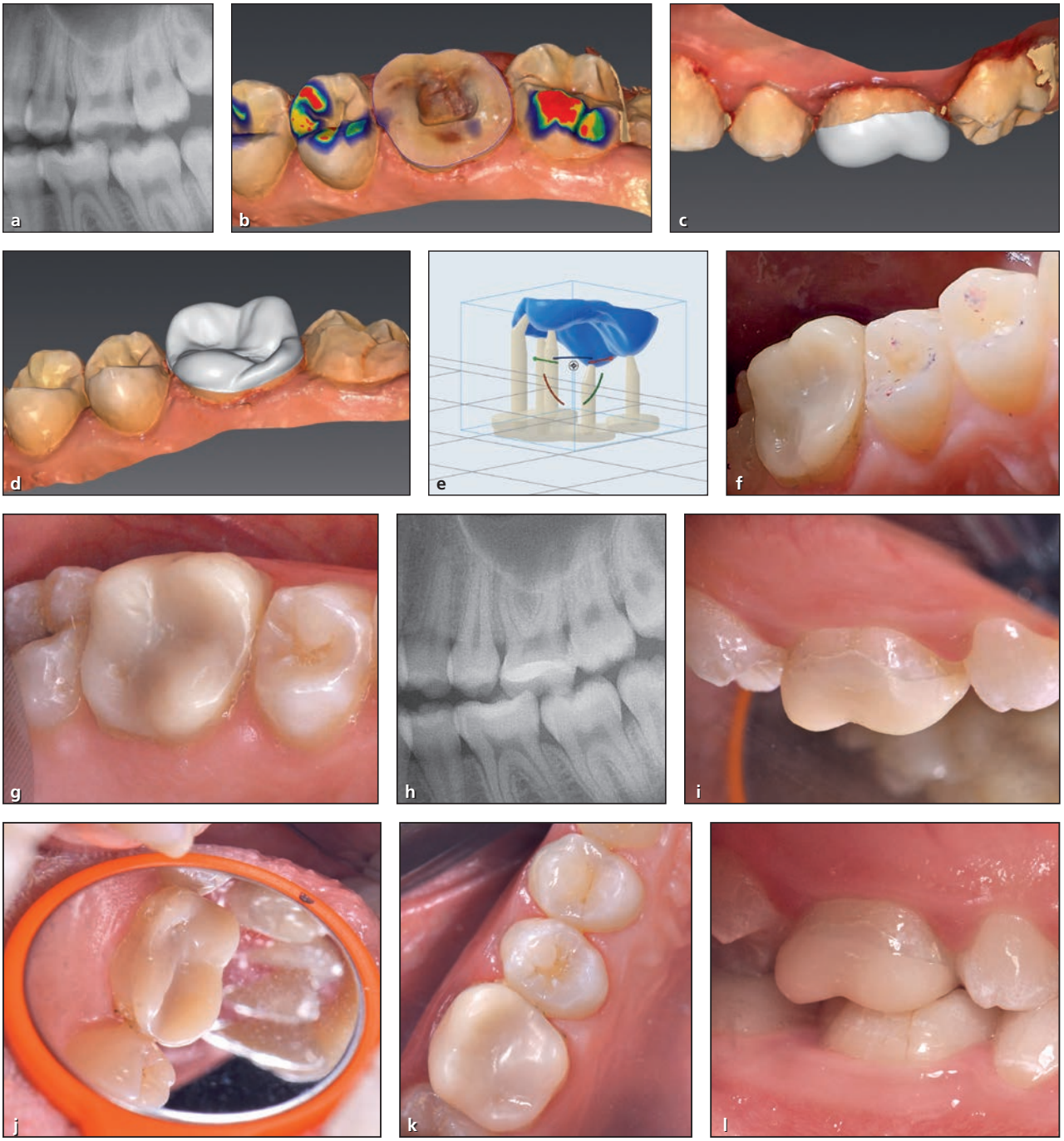

Fig 3 Fabricated 3D-printed overlay: initial radiograph *(a)*, designed restoration in inLAB *(b to d)*, STL file with support structures in Preform build platform *(e)*, finished 3D-printed permanent crown at baseline *(f)*, 12-month follow-up *(g)*, 12-month follow-up radiograph *(h)*, and 24-month follow-up *(i to l)*.

cement was cleaned with dental floss and a sable brush (GC Dental). After removing the excess, an oxygen layer inhibitor material (Airblock, Dentsply Sirona) was applied to the cementation interface. Light source was applied for 20 seconds in standard power mode (1,000 mW/cm^2) to the occlusal, mesial, distal, buccal, and lingual aspects for light-activated polymerization. The edges of the restoration were checked again with dental floss. Occlusal contacts were separated using continuous water cooling and a yellow-banded diamond bur (55 µm grit; Super Fine 862-014SF, Henry Schein). Fine finishing and high-gloss polishing were performed with composite polishers (OptraGloss, Ivoclar).[28] All the steps were performed for each restoration (Figs 2 and 3).

The restorations were evaluated by two evaluators (E.S., G.B.K.). To achieve consensus on the criteria for

Table 2 Modified USHPS Criteria

	Scores			
Parameter	Alpha (A)	Bravo (B)	Charlie (C)	Delta (D)
Marginal adaptation	No cracks are visible along the margins	The explorer slightly catches along the margins	Cracks are visible along the margins	The restoration is either fractured, missing, or movable
Marginal discoloration	No discoloration is visible along the margins	Slightly discoloration along the margins	Obvious color change along the margins	The restoration must be replaced because it looks esthetically unsightly
Retention	No loss in restorative material	Partial loss in restorative material	Complete loss in restorative material	NA
Interproximal contact	Interproximal contacts are present	Interproximal contacts are absent	NA	NA
Color match	Restoration is harmonious with the adjacent tooth in terms of tone and translucency	Restoration differs from the adjacent tooth in tone and translucency but within the normal shade range	Obvious color change from adjacent tooth	The restoration must be replaced because it looks esthetically unsightly
Surface texture	Completely smooth surface	Slightly rough surface or with small notches	Surface with significant visual and tactile roughness with visible cracks and notches	Visibly damaged surface, signs of a failed restoration
Anatomic form	Restorative material follows existing anatomical form continuously	Slight clinically acceptable deviation from an ideal form	Restoration does not follow the existing anatomical form	NA
Secondary caries	No caries detected	Caries detected	NA	NA
Postoperative sensitivity	Normal reaction to cold spray	Cold sensibility has increased	Spontaneous pain referred by the patient	The tooth does not show signs of vitality
Gingival inflammation	No gingival inflammation observed	Gingival inflammation observed	NA	NA
Tooth vitality	The tooth shows signs of vitality	The tooth does not show signs of vitality	NA	NA
Patient satisfaction	Satisfied	Complained about the esthetic outcome	Requested an improvement	Completely dissatisfied

NA = not applicable.

evaluation, a total of 10 sample photographs representing each criterion were used. Before starting the evaluations, the consensus points of the evaluators were defined as ≥ 85%. The restorations were examined using a sterile mirror and explorer under a dental chair light. Interproximal contacts were evaluated using dental floss.

Evaluations of the restorations were recorded according to the modified USPHS criteria at baseline, 12 months, and 24 months after bonding. The scores for each criterion were expressed as alpha (A): excellent—the highest degree of clinical acceptability; bravo (B): sufficient—acceptable; charlie (C): insufficient; and delta (D): reduced clinical acceptability (Table 2).[24,25,29]

At each patient's recall visit, periapical radiographs and digital photographic records were taken of the patient's restorations, and the tooth vitality of overlay was tested with a cooling spray (Roeko Endo frost cold spray, Coltene). Upon every visit, the patients were questioned about oral hygiene habits, and their verbal statements were recorded of how many times a day they brushed their teeth and whether or not they used dental floss and mouthwash.

Statistical Analysis

Data obtained in the study were analyzed statistically using SPSS version 27.0 software (IBM). In the dependent comparisons of the criteria scores at baseline, 12 months, and 24 months, related samples Cochran Q test was applied. Post-hoc paired comparisons were evaluated according to Bonferroni corrected *P* values. Fisher-Freeman-Halton test was used in the comparisons of categoric variables according to restoration type. Descriptive statistics were stated as numbers and percentages. Analyses were made in a 95% CI. $P < .05$ was accepted as the level of statistical significance.

RESULTS

The study included 33 patients, comprising 23 (69.7%) women and 10 (30.3%) men, with a mean age of

Table 3 Scores for Overlay and One-Piece Endodontic Crown at Baseline, 12 Months, and 24 Months

Modified USPHS Score	Baseline (1 week)				12 months				24 months			
	A	B	C	D	A	B	C	D	A	B	C	D
Marginal adaptation	32 (97%)	1 (3%)			32 (97%)	1 (3%)			29 (87.9%)	4 (12.1%)		
Marginal discoloration	33 (100%)				29 (87.9%)	4 (12.1%)			23 (69.7%)	10 (30.3%)		
Retention	33 (100%)				33 (100%)				33 (100%)			
Interproximal contact	33 (100%)				32 (97%)	1 (3%)			32 (97%)	1 (3%)		
Color match	31 (93.9%)	2 (6.1%)			31 (93.9%)	2 (6.1%)			31 (93.9%)	2 (6.1%)		
Surface texture	33 (100%)				33 (100%)				33 (100%)			
Anatomic form	33 (100%)				33 (100%)				33 (100%)			
Secondary caries	33 (100%)				33 (100%)				33 (100%)			
Postoperative sensitivity	32 (97%)	1 (3%)			32 (97%)	1 (3%)			30 (90.9%)	1 (3%)	2 (6.1%)	
Gingival inflammation	33 (100%)				30 (90.9%)	3 (9.1%)			30 (90.9%)	3 (9.1%)		
Tooth vitality	16 (48.5%)	17 (51.5%)			15 (45.5%)	18 (54.5%)			13 (39.4%)	20 (60.6%)		
Patient satisfaction	33 (100%)	-			32 (97%)	1 (3%)			32 (97%)	1 (3%)		

Data are explained as frequency (percentage). Related samples Cochran Q test was applied for statistical comparisons. Post-hoc comparisons were made with Bonferroni test.

28 ± 11 years (range: 17 to 58 years). The groups were formed according to restoration type with 16 (48.5%) overlay and 17 (51.5%) endocrown. In the follow-up examinations, 18 maxillary teeth and 15 mandibular teeth (29 molars and 4 premolars) were evaluated. All 30 (100%) patients attended the 12-month and 24-month follow-up examinations. The 12- and 24-month survival rate of the restorations was 100%. A diagnosis was made of irreversible pulpitis in a patient at the end of 5 months and in a second patient at the end of 2 years, and an indication for canal treatment occurred because of a periapical lesion in a third patient at the end of 2 years. Because the overlay restorations were intact in all these patients, a class 1 cavity was opened over the restoration, and canal treatment was performed without the removal of the overlay.

A statistically significant difference was determined in marginal discoloration between baseline and 24 months, with an A score obtained in 33 (100%) cases at baseline and in 23 (69.7%) cases at 24 months, with a change determined in 10 (30.3%) cases (P = .001). There was no statistically significant difference between baseline to 12 months and 12 to 24 months (P = .364, P = .060, respectively). No statistically significant difference over time was determined for marginal adaptation (P = .050), retention (P = 1), interproximal contact (P = .368), color match (P = 1), surface texture (P = 1), anatomic form (P = 1), secondary caries (P = 1), postoperative sensitivity (P = 1), gingival inflammation (P = .050), and patient satisfaction criteria (P = .368; Table 3).

In the comparison of the one-piece endodontic crown and overlay restorations according to criteria and time, it was determined that there was a statistically significant difference between the baseline, 12-month, and 24-month scores in terms of marginal discoloration (P = .044) and tooth vitality (P < .001).

There is no statistically significant difference in comparison of oral hygiene habits with modified USPHS criteria at baseline and 12 months (P > .05).

There was determined to be a statistically significant correlation between gingival inflammation and the oral-hygiene 24-month score (P = .015). Most of the patients with a gingival score of A brushed their teeth twice a day and used dental floss, and all of those with a score of B brushed their teeth once a day. No statistically significant difference was determined between oral hygiene and the other criteria (P > .05; Table 4).

DISCUSSION

There are previous laboratory studies in the literature that have evaluated the mechanical properties of 3D-printed

Table 4 Comparison of Modified USPHS Criteria and Oral Hygiene Scores at 24 Months

Modified USPHS score	Brushing teeth once a day	Brushing teeth twice a day	Brushing and flossing twice a day	*P*
Marginal adaptation				
A	7 (77.8%)	11 (91.7%)	11 (91.7%)	.652
B	2 (22.2%)	1 (8.3%)	1 (8.3%)	
Marginal discoloration				
A	4 (44.4%)	8 (66.7%)	11 (91.7%)	.073
B	5 (55.6%)	4 (33.3%)	1 (8.3%)	
Retention				
A	9 (100%)	12 (100%)	12 (100%)	NA
B	-	-	-	
Interproximal contact				
A	8 (88.9%)	12 (100%)	12 (100%)	.273
B	1 (11.1%)	0 (0%)	0 (0%)	
Color match				
A	7 (77.8%)	12 (100%)	12 (100%)	.068
B	2 (22.2%)	0 (0%)	0 (0%)	
Surface texture				
A	9 (100%)	12 (100%)	12 (100%)	NA
B	-	-	-	
Anatomic form				
A	9 (100%)	12 (100%)	12 (100%)	NA
B	-	-	-	
Secondary caries				
A	9 (100%)	12 (100%)	12 (100%)	NA
B	-	-	-	
Postoperative sensitivity				
A	7 (77.8%)	11 (91.7%)	12 (100%)	.424
B	1 (11.1%)	0 (0%)	0 (0%)	
C	1 (11.1%)	1 (8.3%)	0 (0%)	
Gingival inflammation				
A	6 (66.7%)	12 (100%)	12 (100%)	.015
B	3 (33.3%)	0 (0%)	0 (0%)	
Tooth vitality				
A	6 (66.7%)	3 (25%)	4 (33.3%)	.190
B	3 (33.3%)	9 (75%)	8 (66.7%)	
Patient satisfaction				
A	8 (88.9%)	12 (100%)	12 (100%)	.273
B	1 (11.1%)	-	-	

Data are explained as frequency (percentage). NA = not applicable.

materials.[5–10] However, there are no long-term in vivo studies on the crowns produced with PCR.[24] The present study aimed to evaluate the 12-month and 24-month follow-up results of indirect restorations produced with 3D-printed PCR, which is a popular, new treatment method in the market. It can be rapidly produced at an appropriate price, which is designed to increase the resistance of the remaining dental tissue without disrupting the relationship with the tissue surrounding the tooth.

In the literature, different criteria have been used in the evaluation of restorations. The most widely used of these are the modified USPHS, CDA (California Dental Association), and FDI criteria.[30–32] Modified USPHS was used in the present study, and this allowed comparisons to previous studies in the literature.

The restoration shape and size, material content, operator experience, application and polymerization technics, and occlusal factors in addition to patient-related factors,

affect the retention and survival in the mouth.[14] Kang et al[14] applied different surface procedures to PCRs with different content and compared the bonding of resin and cement. It was reported that universal bond containing 10-MDP or airborne-particle abrasion surface procedures increased bonding in Bis-EMA-filled dental glass PCR. At the 24-month follow-up evaluation in the present study, the success rate in the retentions of crowns was 100%. The use of PCR in the production of the restorations, and luting with universal bond containing 10-MDP and dual-cure resin luting cement made a significant contribution to clinical stability.

Marginal adaptation is very important for the long-term clinical success of fixed restorations. CAD provides ideal occlusal and proximal contact points and better marginal adaptation in the gingival wall.[33] In the in vitro study by Abdulkareem et al,[23] it was reported that PCR outperformed CAD/CAM milled crowns in terms of marginal adaptation, together with comparable fracture resistance values. Suksuphan et al[21] showed clinically acceptable marginal adaptation in milled, hybrid, nanoceramic, polymer-infiltrated, ceramic block, and PCR materials at different occlusal thicknesses, and they found that 3D-printed restorations in particular provided better results than milling. Daher et al[9] compared the adhesive bonding of the margins of 3D PCR restorations with CAD/CAM materials after thermal and mechanical cycles. Because 3D PCR provides high marginal adaptation with advantages of time and cost, it has been found to be advantageous, especially for single-tooth permanent restorations and long-lasting interim prosthesis. In the present study, the marginal adaptation success was extremely good.

Despite good marginal adaptation, the development of marginal discoloration could be caused by inadequate bonding to the enamel or degradation of the adhesive cement.[3,4,34,35] Because no marginal fracture or deterioration was seen in the anatomic form within the 2-year follow-up period of this study, inadequate bonding to the enamel was eliminated as the reason of marginal discoloration. The study by Archibald et al[34] has shown that crown material and luting cement have different elasticity modulus that can cause degradation of the resin-based luting cement under occlusal fatigue. Thus, it was thought that the dissolution of resin-based luting cement caused marginal discoloration.

In a study by Kessler et al[20] that compared the wear of 3D-printed resins to that of traditional composites, it was seen that the filler content of the material affected the wear behavior. CAD/CAM milled and two different PCRs were compared in an in vitro study by Bozoğullari et al,[18] and the lowest surface roughness value, even after thermal cycles, was observed in PCR. In the present study, no deterioration was seen in surface roughness, anatomic form, or marginal adaptation, and no evident chipping or migration was seen. This result was thought to be due to the high flexural strength of the Bis-EMA–filled dental glass PCR, in addition to dental glass ceramic inorganic particles at the rate of 30% to 50% in the content.

In a systematic review by Alghauli and Alqutaibi[22] and an in vitro study by Shin et al,[2] the need to reduce discoloration sensitivity, especially in 3D-printed resins was emphasized. Vichi et al[1] observed similar translucency in 3D printed and CAD/CAM materials. Bozoğullari et al[18] examined the discoloration of CAD/CAM blocks and two different PCRs and found no statistically significant difference between the materials in respect of discoloration. Even considering the follow-up period of 24 months in the present study, there was not seen to be any discoloration in the crowns that would make a significant difference. This outcome was thought to be due to the discoloration of the materials having been diluted in the mouth.

Shin et al[11] found that a 70-µm margin gap was a clinically acceptable margin. In the study by Suksuphan et al,[21] the marginal gap of 3D-printed crowns was reported to be < 50 µm. In a systematic review, Alghauli and Alqutaibi[22] stated that because the production of restorations with layers was highly accurate, it was possible to even produce restorations varying between 0.1 and 0.2 mm in thickness. The development of secondary decay was said to be prevented by the strong adhesion provided by the high accuracy of these restorations. Prause et al[8] evaluated the incidence of caries forming in restorations produced from 3D-printed veneers and milling blocks, and AM restorations showed less decay progression irrespective of thickness. In the present study, other than secondary decay and discoloration in the restoration margins, no pathology was determined in any patient on the radiographs taken at the end of 24 months.

Factors such as the type of bonding agent and cement used, the method of removing the smear layer, preparation depth, and the presence of occlusal incompatibility may cause postoperative sensitivity.[4,25] Canatan et al[4] used selective etching universal bond and dual-cure resin and reported that in the follow-up, postoperative sensitivity completely disappeared after 1 year. However, for two teeth in the group where self-adhesive resin-luting cement was used, endodontic treatment was applied because of oversensitivity after 18 months.[4] In another clinical experiment, sensitivity after the cementation of partial ceramic crowns with a universal bond in selective-etch mode was at a low rate and was reported to have disappeared in 6 months.[36] Stress due to the polymerization shrinkage of resin-luting cement and the use of sharp instruments to remove excess cement have been demonstrated as reasons for postoperative sensitivity.[37] In parallel with other studies in literature, in the present

study, which used resin-luting cement and universal adhesive with the selective-etching technic, sensitivity was found to disappear within a short evaluation period.

An indication for canal treatment was seen at 5 months in an 18-year-old patient in the present study. In young teeth, there is less sclerotic and tertiary dentin. Therefore, the frequency of dentin sensitivity increases due to dentin fluid flow.[38] In addition, the toxicity of luting cement and bonding can be indirectly affected by the remaining dentin thickness.[39] At the end of the second year of the present study, an indication for canal treatment was determined in two more patients. These indications were thought to be due to deep dentin cavities in these patients.

Wuersching et al[16] evaluated the biocompatibility of interim and PCR and stated that the biocompatibility of the resins was dependent on the monomer component, the presence and type of photo-initiators, and the polymerization mode. Nam et al[15] reported that surface polishing of PCR restorations increased cell biocompatibility. The present study results were compatible with the literature. It can be considered that the layer-by-layer procedures of PCR production formed a self-heating tray, thereby obtaining smooth surface tissue with the use of the UV polymerization technique and the application of good polishing, resulting in the formation of less plaque accumulation.

In a clinical study by Al-Halabi et al,[6] after a 12-month follow-up of CAD/CAM and interim 3D printing (3DP) crowns, a better response was obtained in the 3DP group. Another clinical study was conducted by Del Hougne et al,[24] who used PCR to print full crowns in Form 3B and applied them to patients as temporary crowns. In a retrospective cohort study, 98 temporary crowns were applied to 63 patients over 19 months. Of these, 42 temporary crowns were evaluated using modified USPHS criteria in 24 patients. The study found that the restorations achieved a 98% survival rate. Patient satisfaction was high regarding both the oral health–related quality of life and esthetic appeal of the crowns. Analysis of clinical parameters was promising for 3D-printed temporary crowns. The results of Del Hougne et al[24] support the results of this study investigating indirect partial crowns.

Limitations of this prospective clinical study are the lack of a comparison group, the relatively short follow-up period of 2 years, the limited sample size, and the use of a single type of resin and printer. Another limitation is that, despite best efforts, the amount of remaining coronal tooth tissue and tooth preparation cannot be standardized. Future in vivo studies can be planned as controlled and randomized with large sample sizes.

CONCLUSIONS

Within the limitations of the present study, indirect single-tooth crowns applied with 3D-printed permanent crown resin showed clinically acceptable performance in a 2-year follow-up period (≥ 99.5% A+B score at 2 years). Thus, the application of PCR for indirect restoration may be a successful approach for clinical practice. However, further long-term studies with a larger sample size are needed to confirm these findings.

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E.S. and G.B.K. performed conceptualization, methodology, software, validation, formal analysis, investigation, resources, review and editing, project administration, and funding acquisition. E.S. was also responsible for data curation and writing the original draft. G.B.K. was responsible for visualization and supervision. Both authors have read and agreed to the published version of the manuscript.

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Highlighted Literature

Aerosol Dispersion and Efficacy of Protective Strategies During Dental Procedures

Purpose: Aerosol generation during dental procedures poses significant risks due to the potential for transmitting aerosol-bound microorganisms, including those in dental unit waterlines. This study aimed to quantify aerosol dispersion at various distances from dental procedures using a high-speed electric handpiece, with a focus on the effectiveness of various aerosol mitigation strategies. ***Materials and Methods:*** Employing a mannequin head with an artificial tooth (typodont), we simulated clinical settings without the use of saliva to solely assess the contribution of dental unit waterlines and mechanical factors to aerosol production. Measurements were taken using a spectrometer at distances of 0, 0.9, and 1.8 meters from the handpiece. ***Results:*** The results showed no significant difference in aerosol dispersion between 0.9 and 1.8 meters without evacuation. In contrast, the use of high-volume evacuators, particularly the Isolite system, significantly decreased aerosol dispersion across all distances. ***Conclusions:*** We found that any type of high-volume evacuator can decrease aerosol dispersion, but the use of Isolite (Zyris) was the most effective.

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