

## Enhancing Dentin Bonding of Fifth-Generation Adhesive Through Experimental 10-MDP Primer: A Pilot Study on Human Teeth

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### Abstract

**Background:** The study aimed to evaluate the effectiveness of an experimental primer (EP) based on the 10-MDP monomer when used with the fifth-generation adhesive system.

**Methods and Results:** Tests were performed on tooth samples from wisdom teeth and premolars extracted for orthodontic purposes. The EP consisted of 10-MDP monomer (10%), ethanol (40%), propanol-2 (30%), water (18%), and a camphorquinone-based photoinitiator system (2%). The pH of the EP was 2.4. The adhesive resin of the fifth-generation OptiBond Solo Plus (OSP) and the universal composite Herculite XRV were the materials of choice. Two adhesive techniques were tested: the traditional total-etch technique with OSP application, and the optional technique with sequential EP and OSP applications using a selective-etch approach. Adhesive bond strength was assessed in two groups using the ultra-test technique (Ultradent Products, Inc., USA). All samples in each group underwent two sequential shear bond strength (SBS) tests. The quality of the resin composite adhesion was assessed on four specimens using an FE-SEM (Thermo Fisher Scientific Apreo 2S LoVac). Microleakage assessment was made on 10 teeth. In each tooth, two artificial cavities of similar size were prepared. Fillings were placed using two techniques in each tooth. Depth of dye penetration at tooth-composite interface was assessed using nonparametric scores. The phase composition of the dentin surface was assessed on six tooth samples divided into three groups of two using thin-film X-ray diffraction (TF-XRD). Samples from the control group were used for XRD of the dentin surface. Samples of Group 1 were used to apply EP to the dentin surface; samples of Group 2 were used for sequential application of EP and OSP to the dentin surface.

A significant difference of more than three times ( $P=0.000$ ) was observed between the SBS values of the first and second tests in samples from Group 1 compared with those from Group 2. SEM of the filling-to-dentin interface in samples with sequential application of EP and OSP using a selective etch approach showed a more uniform hybrid layer than with OSP application with the total-etch technique. Microleakage analysis of the dentin-composite interface revealed a significantly higher dye penetration rate in samples with the traditional OSP application. The presence of the 10-MDP calcium salt peak at diffraction angle of  $2\theta=2.54^\circ$  after sequential application of EP and OSP corresponded to the longest d-spacing (3.48 nm) of the nanolayered structure on the surface of tooth dentin. (**International Journal of Biomedicine. 2026;16(1):101-106.**)

**Keywords:** tooth dentin • adhesive monomers • 10-MDP-Ca salts • shear bond strength • microleakage

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## Abbreviations

**DP**, dye penetration; **EP**, experimental primer; **FE-SEM**, field emission scanning electron microscopy; **OSP**, OptiBond Solo Plus; **SBS**, shear bond strength; **TF-XRD**, thin-film X-ray diffraction.

## Introduction

Strong and stable adhesion to tooth dentin is a pressing issue in modern restorative dentistry that, despite the availability of numerous adhesive systems, remains unresolved. Currently, there are two main concepts for bonding materials to tooth enamel and dentin. These have been implemented in total-etch and self-etch adhesive systems.<sup>1,2</sup>

The total-etch concept means acid etching of both enamel and dentin. Among the positive aspects of this technique are the formation of microporosities on the enamel surface, removal of debris, smear layer, and plugs from the dentin surface, opening of the dentinal tubule orifices, and the formation of niches on the surface of peritubular dentin, which can serve as retention sites for adhesive resin monomers during hybrid layer formation.<sup>2</sup>

Unlike enamel, dentin has a different three-dimensional organization and composition. Acid etching of dentin exposes the organic matrix, which, after losing its mineral component, can maintain its spatial structure only in the presence of moisture. The collapse of the collagen matrix, caused by drying of the etched dentin, is the main reason for its ineffective impregnation with adhesive resin monomers and the formation of a weak hybrid layer. The inconsistency in hybrid layer quality and the magnitude of polymer stress that occur in the bulk of the composite material during photoactivation lead to postoperative sensitivity, micro-gap formation, and many possible complications associated with an absence of a tight seal around the composite restoration.<sup>3</sup>

Considering the serious shortcomings of the total-etch technique and the urgent need for an alternative approach, adhesive systems with functional acidic monomers capable of forming chemical bonds with tooth hydroxyapatite began to be used in tooth restoration.<sup>4,5</sup> The mechanism of their bonding to enamel and dentin is based less on micromechanical retention and more on the chemical bond of functional monomers with the hydroxyapatite on the tooth surface. The resulting ionic bond ensures strong, stable adhesion of the composite material to the tooth.<sup>6,7</sup>

Among three commonly used functional monomers (10-MDP, 4-MET, and Phenyl-P), 10-MDP has been found to be the most effective at forming ionic bonds with hydroxyapatite. This chemical interaction results in the formation of MDP-Ca salts in a nanolayered structure on enamel and dentin surfaces. It is generally accepted that the pronounced hydrophobicity of this nanolayer determines the chemical stability of the composite material-tooth interface and prevents its hydrolytic degradation.<sup>7,8</sup>

One significant drawback of the 10-MDP monomer is its relatively large molecular size, which can negatively affect the mechanical stability of the adhesive bond. One solution to this

issue is to add monomethacrylates and dimethacrylates of low molecular weight, such as HEMA (2-hydroxyethyl methacrylate) and TEGDMA (triethylene glycol dimethacrylate), to form a composition. These compounds are necessary for cross-linking linear polymers and increasing their strength. However, HEMA and TEGDMA each have shortcomings. The first, despite their ability to adsorb to the surfaces of tooth enamel and dentin in a competitive manner with other compounding monomers, has hydroxyl groups that are unable to form ionic bonds with the mineralized portion of a tooth. The second, being hydrophilic, HEMA and TEGDMA promote water absorption, leading to hydrolytic degradation of the adhesive and hybrid layers, which is the main reason for a reduction in bond strength between the restoration and the tooth over time.<sup>9,10</sup>

Considering the positive and negative aspects of short-chain monomers, the prior application of 10-MDP monomer to initially form an uninterrupted, waterproof nanolayer on the surface of enamel and dentin, and subsequently adding it for the cross-linking of 10-MDP monomer, might offer significant practical value.<sup>10,11</sup>

Also, because most total-etch adhesive systems contain HEMA and TEGDMA and lack functional monomers capable of chemically reacting with tooth hydroxyapatite, this pilot study aimed to evaluate the effectiveness of an EP based on the 10-MDP monomer when used with a fifth-generation adhesive system.

## Methods

In the study we used caries-free wisdom teeth and premolars, which were extracted for orthodontic purposes. 10-MDP monomer was synthesized in the laboratory of the Joint Research Institute of Chemistry of RUDN University. The EP consisted of 10-MDP monomer (10%), ethanol (40%), propanol-2 (30%), water (18%), and a camphorquinone-based photoinitiator system (2%). The pH of the EP was 2.4. The adhesive resin of the fifth-generation Optibond Solo Plus (OSP) and the universal composite Herculite XRV (Kerr, Italy) were the materials of choice.

The adhesive bond strength was assessed on 20 samples prepared using the ultra-test technique (Ultradent Products, Inc., USA). To achieve a uniform level of roughness, the dentin surface was treated with sandpaper grits ranging from 300 to 600 units (Figure 1).



**Fig. 1.** Tooth sample for adhesion of composite buildups on dentin.

Composite cylindrical buildups on the dentin surface were made by fixing the tooth sample in a bonding clamp and polymerizing the material in a plastic mold. Photoactivation was performed using VALO X (Ultradent Products, Inc., USA) in the standard mode according to the manufacturer's instructions for the materials used.

In line with the study's aim, tooth samples for the shear bond strength (SBS) test were divided into two groups. In Group 1 (n=10), acid etching of the dentin was performed for 15 seconds, followed by rinsing the surface with distilled water for the same amount of time. OSP was applied according to the wet adhesive protocol and the manufacturer's instructions. In Group 2 (n=10), the acid etching step was replaced by rubbing EP into the dentin surface for 15 seconds. After application, the EP was air-thinned on the dentin surface to remove excess material and evaporate the solvent. Subsequently, the OSP was applied and air-thinned.

The strength of adhesion of the composite material to tooth dentin was assessed using the shear force in an UltraTester Bond Strength Testing Machine (Ultradent Products, Inc., USA). Tests were conducted at a speed of 1 mm/min to determine peak load capacity. In each sample, two areas on the dentin adhesive surface were selected for the sequential placement of cylindrical buildups and testing of bond strength (Figure 2). Thus, the total number of tests in each group was 20. The bond strength of the composite buildup to the tooth dentin was recorded in pounds (lb).

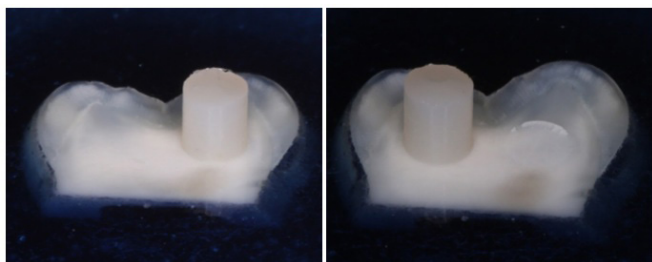


Fig. 2. Tooth sample for performing 2 consecutive SBS tests.

The quality of the resin composite adhesion was assessed on four specimens using a FE-SEM (Thermo Fisher Scientific Apreo 2S LoVac). To prepare the specimens, only the coronal portion of the teeth was used, which was sectioned into two halves using diamond discs along the central fissure under copious water cooling. The vestibular and oral enamel surfaces were also ground to expose a flat portion of midcoronal dentin. The resulting four tooth slabs were randomly divided into two groups of two specimens each.

In Group 1 samples, enamel and dentin surfaces were acid-etched (37.5% Phosphoric Acid Gel, Kerr) for 30 seconds and 15 seconds, respectively. After they were rinsed in distilled water for 30 seconds, excess moisture was removed, and OSP was applied. In Group 2 samples, only the enamel was acid-etched. After rinsing with water and air-drying, EP and OSP were sequentially applied to the enamel and dentin surfaces in accordance with the principles of sample preparation for the SBS test.

The application and polymerization of the resin composite were performed using an incremental freehand technique until the adhesive surfaces were completely laminated. The thickness of the composite laminate varied from 1.3 to 1.5 mm. The laminated tooth slabs were cut into two halves and embedded in epoxy resin. Further sample processing was performed using abrasives and polishing pastes with grit sizes ranging from 300 to 1200.

After rinsing under running water, the samples (Figure 3) were cleaned in an ultrasonic bath with distilled water for five minutes. Before scanning, the samples were coated with a 10nm gold layer using a Quorum magnetron (Q150R ES, England) sputtering system.



Fig. 3. Tooth samples for SEM.

Microleakage assessment of two adhesive regimens was performed on 10 teeth. Round artificial cavities (4 mm in diameter, 1 mm deep) were prepared on two approximal surfaces of each tooth, with half of the margin in enamel and the other half in root dentin. Mesial proximal surfaces were assigned for the traditional total-etch regimen and application of OSP, and distal proximal surfaces were assigned for the selective etching of enamel and consecutive application of EP and OSP. All cavities were filled with composite using a similar technique. After this, the fillings were polished, and the tooth samples were subjected to thermocycling (5000 cycles in separate water baths of 5°C and 55°C±2°C with a dwell time of 10 seconds in each bath and a transfer time of 1 second). Next, the apices of tooth samples were sealed with sticky wax and coated with nail varnish to exclude fillings with a 1 mm distance around them. The teeth were stained in 1% methylene blue solution for 24 hours and sectioned through the centers of restorations. Microleakage at the enamel and dentin margins was considered (Figure 4).



Fig. 4. Microleakage assessment.

Enamel and dentin dye penetration (DP) was assessed using the following scale of 0-4 scoring system: 0 - no DP; 1 - DP is up to 1/3 of the cavity wall; 2 - DP is up to 2/3 of the cavity wall; 3 - DP is spreading to the full extent of the cavity wall; 4 - DP is spreading to the bottom of the cavity.

The phase composition of the dentin surface was assessed on six tooth samples divided into three groups of two using TF-XRD (Figure 5). The analysis was performed using an Empyrean instrument (Malvern Panalytical, Netherlands) operating at an accelerating voltage of 45 kV and a current of 40 mA with a fixed incident X-ray beam angle of  $0.3^\circ$  and a scan rate of  $0.02^\circ/\text{s}$  for  $2\theta$  scanning. The specimen surfaces were ground and polished according to the principles of sample preparation for SEM analysis. However, after polishing, the dentin surface of all specimens was abraded with an erythritol-based air-abrasive mixture ( $14\ \mu\text{m}$ , Air-Flow Plus, EMS, Nyon, Switzerland) with a constant particle flow at 0.25 MPa for 10 seconds. The nozzle was held at 3-5 mm from the surface and at  $45^\circ$  angulation to it. After this, the prepared surfaces were thoroughly washed with an air-water spray for 30 seconds and dried.



Fig. 5. Tooth samples for TF-XRD.

Samples from the control group were used for XRD of the dentin surface. Group 1 samples were used to detect diffraction peaks from the dentin surface after the application of EP; Group 2 samples were used to identify changes, such as the diffraction peaks, after sequential application of EP and OSP to the dentin surface.

Statistical analysis was performed using StatSoft Statistica v6.0. The probability value of  $P < 0.05$  was considered statistically significant.

## Results

A comparative analysis of the obtained data (Table 1) revealed that applying EP to the dentin surface before OSP did not significantly affect bond strength. However, a significant difference of more than three times ( $P < 0.0001$ ) was observed between the first and second test values in samples of Group 1 than in Group 2.

Table 1.

Influence of experimental 10-MDP primer (EP) pretreatment on shear bond strength of Optibond Solo Plus (OSP) to dentin.

Group	Group 1 (n=10) (Total-etch, OSP)			Group 2 (n=10) (Selective-etch, EP-OSP)			
	1st test	2nd test	$\Delta^*_1$	1st test	2nd test	$\Delta^*_2$	
SBS test	25.0	28.9	3.9	26.4	26.5	0.1	
	29.4	25.8	3.6	27.3	28.3	1.0	
	27.3	24.1	3.2	28.1	26.9	1.2	
	28.2	24.1	4.1	29.1	28.7	0.4	
	31.1	27.4	3.7	25.4	24.3	1.1	
	25.1	27.8	2.7	20.1	20.3	0.2	
	21.2	23.5	2.3	27.2	29.6	2.4	
	26.4	29.3	2.9	25.2	25.4	0.2	
	24.3	21.1	3.2	27.5	24.9	2.6	
	28.2	32.1	3.9	29.8	30.1	0.3	
	M $\pm$ SD	26.6 $\pm$ 2.8	26.4 $\pm$ 3.3	3.4 $\pm$ 0.6	26.6 $\pm$ 2.7	26.5 $\pm$ 2.9	1.0 $\pm$ 0.9
	P-value	0.728		0.936			
$P^* < 0.0001$ (between $\Delta^*_1$ and $\Delta^*_2$ )							

SEM of resin-composite-to-dentin interfaces in Group 1 samples (Figure 6A) revealed an uneven hybrid layer width, with varying depths of adhesive resin penetration into dentinal tubules. In some areas, signs of penetration were completely absent, while in others, the adhesive tags reached  $10\text{-}12\ \mu\text{m}$ .

On the other hand, SEM of the filling-to-dentin interface surface in Group 2 samples (Figure 6B) demonstrated the presence of a uniform hybrid layer and comparatively better obturation of the dentinal tubules.

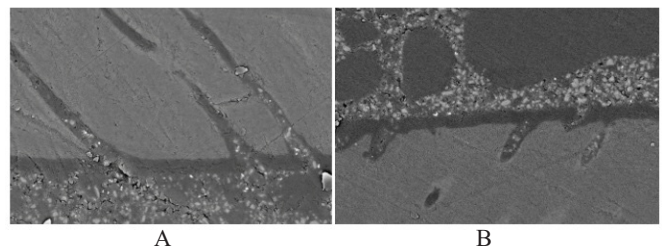


Fig. 6. A - Sector of the filling-to-dentin interface of the Group 1 sample; B - Sector of the filling-to-dentin interface of the Group 2 sample.

SEM images of the dental composite-to-enamel interface in both groups of samples (Figure 7A,B) were of similar quality, reflecting the presence of both a tight adhesion and loose marginal adaptation.

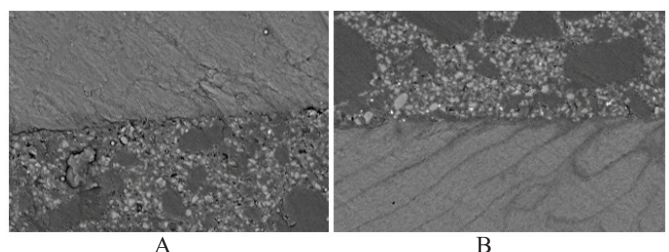


Fig. 7. A - Sector of the filling-to-enamel interface of the Group 1 sample; B - Sector of the filling-to-enamel interface of the Group 2 sample.

As for microleakage, examination of sections from tooth samples in both groups showed no significant difference in the degree of DP between the composite filling and the enamel margin. However, a microscopic examination of the interface between the composite filling and dentin (Figure 4) revealed a significantly higher leakage rate in Group 1 samples (Tables 2 and 3). Instead, Group 2 samples showed reliable adhesion of the biomaterial to dentin in 80% of cases.

Table 2.

Frequency table of the microleakage scores in groups

Site of microleakage	Enamel-filling interface	Dentin-filling interface
Nonparametric scale (score)	0 1 2 3 4	0 1 2 3 4
Total-etch mode (OSP)	7 2 1 0 0	4 1 2 2 1
Selective-etch mode (EP, OSP)	8 1 1 0 0	8 1 1 0 0

Table 3.

Descriptive statistics of the microleakage scores in groups.

Site of microleakage	Mode	Min	Max	Mean±SD	P
Enamel-filling interface	Total-etch mode (OSP)	0	2	0.4±0.7	>0.05
	Selective-etch mode (EP, OSP)	0	2	0.3±0.7	
Dentin-filling interface	Total-etch mode (OSP)	0	4	1.5±1.5	<0.05
	Selective-etch mode (EP, OSP)	0	2	0.3±0.7	

Analysis of the phase composition of the dentin surface revealed a weak peak at  $2\theta=2.40^\circ$ , likely indicating hydroxyapatite crystal destruction after mechanical processing (Figure 8). Application of EP to the dentin surface resulted in the appearance of three peaks at  $2\theta = 2.42^\circ$ ,  $4.29^\circ$ , and  $6.32^\circ$ , suggesting the formation of 10-MDP-Ca salts. Sequential application of EP and OSP onto the dentin surface also caused changes in both the number of peaks ( $2\theta = 2.54^\circ$  and  $4.31^\circ$ ) and their slight shift toward higher angles.

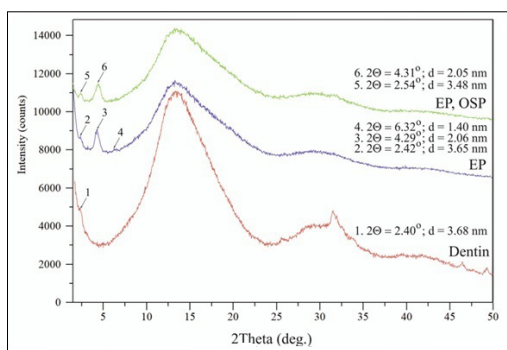


Fig. 8. TF-XRD patterns of samples under study.

## Discussion

Minimal invasiveness and maximum biocompatibility remain priority principles for developing new materials and techniques for the treatment and restoration of teeth.<sup>11</sup> Thus, Buonocore's discovery was revolutionary in adhesive dentistry, shifting the field from macroretention to microretention of dental restorations.<sup>12</sup> Later, the development and introduction of acidic monomers capable of forming acid-base-resistant ionic bonds with dental hydroxyapatite enabled the transition from micro retention to nano retention.<sup>9,13,14</sup> Despite their high chemical reactivity, these compounds have high biocompatibility and low cytotoxicity, in contrast to the monomers that make up total-etch adhesive systems.<sup>15</sup>

Fifth-generation adhesive systems are complex mixtures that combine multiple monomers and other components. Their effectiveness depends on their ability to penetrate the surfaces of tooth enamel and dentin, which requires preliminary acid etching.<sup>16</sup>

Given the absence of active monomers in their composition, the main objective of this pilot study was to improve the adhesive potential of OSP by replacing the acid etching of dentin with the application of an experimental 10-MDP primer on its surface.

It should be noted that the SBS test protocol included certain features. Specifically, two consecutive tests were performed on each tooth sample after the application of the adhesive resin, allowing assessment of the bond strength of the composite material across different areas of the dentin surface and calculation of the difference between the SBS values.

The study results showed that applying experimental 10-MDP monomer ( $\text{pH}=2.4$ ) prior to adhesive resin may be of practical value. Despite the lack of difference in the strength of adhesion to dentin between the groups, the SBS values of the experimental group samples were the most similar, which, to some extent, was indicative of the uniformity of the formed hybrid layer.

An analysis of SEM images of the filling-to-dentin interface of the tooth made it possible to establish fundamental differences in the quality of the hybrid layer of samples of Groups 1 and 2, and to explain the reason for the significant difference in the bond strength between the average values of the first and second sequential tests in Group 1 samples.

The chemical structure of 10-MDP includes a phosphate group and a long carbon chain (hydrophobic), allowing it to interact with both the hydrophilic mineral phase of tooth structure and the hydrophobic monomers of dental adhesives. Due to its amphiphilic nature, 10-MDP can act as a surfactant, reducing surface tension and promoting wetting and the penetration of the hydrophobic adhesive resin into the tooth structure. This improved wetting can promote the formation of a strong and durable bond.<sup>12,17</sup>

Results of the microleakage test may strongly support the presence of stable adhesion between the resin composite and tooth dentin when an experimental 10-MDP primer is applied prior to the test, even after simulating the aging of the adhesive bond by conducting 5000 thermocycles.

Analysis of the phase composition of the dentin surface in samples from different groups revealed the presence of several

crystalline phases, with slight shifts in peak positions toward higher angles. For example, on the surfaces of samples from the control group, a peak was detected only at  $2\theta=2.40^\circ$ , attributed to air-abrasive treatment of the dentin surface with an erythritol-based powder. However, no data in the available literature indicated the possibility of similar changes caused by air abrasion.

The appearance of additional crystalline phases (peaks #3 and #4) on the dentin surface of Group 1 samples in the range of  $2\theta=4.29^\circ$  and  $6.32^\circ$ , as well as a slight increase in the angle of the first reflex (peak #2) to  $2\theta=2.42^\circ$ , indicated the formation of 10-MDP–Ca salts. The position of these peaks corresponded to the literature data.<sup>10,14</sup>

Sequential application of EP and OSP on the dentin surface decreased the number of peaks ( $2\theta = 2.54^\circ$  and  $4.31^\circ$ ) and increased the angles (peaks #5 and #6). Considering the small interplanar distance of peak #4 ( $2\theta = 6.32^\circ$ ,  $d = 1.4$  nm), the complete disappearance of this crystalline phase in Group 2 samples was attributed either to its dissolution or to its overlap with components of the OSP adhesive resin.

Thus, based on the data obtained, it was concluded that replacing traditional acid etching of dentin with the application of a 10-MDP-containing EP may constitute a new adhesive technique in clinical practice, facilitating reliable and predictable adhesion of composite materials to dentin when using fifth-generation adhesive systems with a selective acid etching approach. Also, the presence of 10-MDP–Ca salt peak at diffraction angle of  $2\theta=2.54^\circ$  was probably the most significant for tooth dentin adhesion, as it represented the strong signal in XRD analysis, corresponding to the longest d-spacing (3.48 nm) of the nanolayered structure and underpinned the possibility of selective etch technique for adhesive system of fifth generation, but only in the case of 10-MDP primer application.

## Ethical Statement

The study was approved by the Ethics Committee of the Institute of Medicine RUDN (Protocol Number: 29, dated 06.20.2024). Written informed consent was obtained from all participants prior to the processing of their teeth.

## Competing Interests

The authors declare that they have no competing interests.

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