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Original Article

The evaluation of effectiveness of adhesive systems on dental amalgam restorations

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Abstract

Aim: The purpose of this study was to evaluate the effectiveness of different adhesive systems in amalgam restorations and their effects on microleakage.

Methodology: In this study, 105 caries-free extracted human permanent molar teeth were used. Teeth were randomly assigned to five groups (n=21), and class I cavities were created on the surface of each tooth. The first was a control group to which no adhesive system was applied. Amalgam Liner (VOCO GmbH, Cuxhaven Germany) was applied to Group II, Clearfil SE-Bond (Kuraray Europe GmbH, Frankfurt Germany) was applied to Group III, Panavia F 2.0 (Kuraray Europe GmbH, Frankfurt Germany) was applied to Group IV, Amalgambond Plus (Parkell Inc.Edgewood, NY USA) was applied to Group V, and then amalgam (Tytin, Kerr, California USA) restorations were placed. After the polishing process, samples were subjected to thermocycling 1,000 times. Teeth were sectioned bucco-palatinally/lingually, and microleakage scores of the occlusal walls were evaluated under a stereomicroscope at 15X magnification by a standardized scale ranging from 0 to 4. One tooth was selected randomly from each group for SEM (Scanning Electron Microscope), and SEM LEO EVO 40 (LEO Ltd., Cambridge UK) photographs of amalgam-tooth hard tissue interfaces were also taken at different magnifications. The results of the microleakage tests were statistically analyzed by both the Kruskal-Wallis Test and the Mann Whitney U Test.

Results: In terms of microleakage among groups, the differences that were determined were significant ($p<0.05$). Microleakage within the control group was determined to be the highest, and statistically important differences were observed between the other groups. Group V (Amalgambond Plus) was determined to have the lowest microleakage scores.

Conclusion: In prepared class I cavities, amalgam adhesive systems are effective in preventing occlusal microleakage but do not completely blocked it.

Keywords: dental amalgam, adhesive, scanning electron microscope

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Introduction

Despite the growing number of protection methods, caries still occurs, and it should be treated with appropriate materials and techniques. Various restorative materials are available in dentistry for this purpose, including amalgam, composite, glass ionomer, etc. (1)

Amalgam is one of the most commonly used restorative materials because it is less sensitive and less costly than the other materials and has sufficient physical properties (2). The strength of the materials used in the restoration of the posterior group teeth—the ones that take most of the pressure of chewing—plays an important role, as the material must resist the chewing force during the use period in the mouth. Amalgam is preferred because it has many advantages: for example, it has been the most durable restoration material used in dentistry for years; it is easy to apply, and it does not dissolve in mouth fluids (3). However, there are also problems with its use in the interstices between the teeth and in restoration, which include discoloration on the sides of the cavity, mercury toxicity, dental sensitivity, and secondary caries (3,4). Adhesive systems have been used to improve the properties of restorative materials in dentistry. Although adhesive systems have been developed for composite resins, they have also been used to increase retention and reduce microleakage in amalgam restorations (5). It has also been claimed that the use of amalgam adhesive systems in amalgam restorations helps to strengthen dental tissues, reduce post-operative sensitivity, provide better edge adaptation, and prevent the formation of secondary caries (7-9).

In addition to the use of adhesive systems in combination with amalgam, "amalgam-bonding" materials specifically produced for amalgam have also been launched into the market. These materials have been designed to combine the advantages of bonding agents, such as adhesive bonding and strengthening of dental tissue, with the performance of amalgam6,7) The use of amalgam alloys in combination with adhesive systems has been shown to improve the fit of the restoration to the cavity, thus helping to prevent secondary caries and increasing the dental fracture resistance (10-13). For these reasons, excessive loss of dental material may also be prevented with adhesive systems (14-16).

The aim of this study is to evaluate the effectiveness of different adhesive systems in amalgam restorations.

Materials and Methods

This study was planned and conducted at Dicle University Faculty of Dentistry, Department of Pediatric Dentistry. Ethical clearance was taken execution of the study (2011-KAEK-2). In this study, 105 non-carious extracted molar teeth were used. The teeth had been extracted in the last three months for different reasons (surgery, orthodontic). After extraction, the soft tissues and debris on the roots were removed with a cretuar, and the teeth were cleaned with the help of pumice and a polyture brush. Then these teeth were kept in distilled water at 37° C in an incubator (Nuve Incubator EN 500, Ankara, Turkey).

Class-I cavities were created on the occlusal surfaces of all the teeth with diamond burs (No:809 Bosphorus Dental Burs / BOSPHORUS A.Ş.-Turkey) under water cooling. After every five cavities, the drill was replaced. Each cavity was prepared with approximate mesio-distal width 4 mm, buccal-lingual width 2 mm, and depth 2 mm. The base of every cavity was finished with a diamond reverse taper bur (No:805G Bosphorus Dental Burs / BOSPHORUS A.Ş.- Turkey).

Then, the teeth were randomly divided into five groups, each containing 21 teeth. The following treatments were performed on the teeth in each group:

Group 1 (control group): Amalgam (Tytin, Kerr, California, USA) restorations were performed without any adhesive system application. Then amalgam restorations were done with amalgam hand tools

Group 2: Amalgam Liner (VOCO GmbH, Cuxhaven, Germany) was applied to the prepared cavity according to the manufacturer's recommendations. Then amalgam restorations were done with amalgam hand tools

Group 3: The self-etching adhesive Clearfil SE-Bond (Kuraray Europe GmbH, Frankfurt, Germany) was applied to the prepared cavity according to the manufacturer's recommendations. Then amalgam restorations were done with amalgam hand tools

Group 4: Panavia F 2.0 (Kuraray Europe GmbH, Frankfurt, Germany) was applied to the prepared cavity according to the manufacturer's recommendations. Then amalgam restorations were done with amalgam hand tools.

Group 5: Amalgambond Plus (PARKELL Inc. Edgewood New York - USA) was applied to the prepared cavity according to the manufacturer's recommendations. Then amalgam restorations were done with amalgam hand tools.

The application methods and specifications of the adhesive systems used in our study are shown in Table 1.

After restorations, these teeth were kept for 24 hours at 37° C in an incubator (Nuve Incubator EN 500, Ankara, Turkey) at Dicle University, Faculty of Medicine, Microbiology A.D. After 24 hours, the amalgam was polished under water cooling using polishing tires. The polished samples were subjected to thermal cycling, conducted at Dicle University, Faculty of Science Analytical Chemistry Laboratory. The thermal cycling procedure was performed in a Memmert water bath (Memmert GmbH, Schwabach, Germany), cycling between 5 ±2° C and 55 ±2° C with a 15 sec waiting time, and repeated 1,000 times. The apicals of the teeth were then covered with the fluid composite resin ÆLITE FLO™ (Bisco Inc., Schaumburg, USA) using the single-stage self-etch system Clearfil S3 Bond (Kuraray Europe GmbH, Frankfurt, Germany).

Table 1. Application method, manufacturer, contents of adhesive materials used in study

Used materials	*Amalgam Liner*  Lot:0941235	*Clearfil SE Bond*  Lot:041760	*Panavia F*  Lot:041333	*Amalgambond Plus*  Lot:110501
Manufacturer	VOCO GmbH Cuxhaven Germany	KURARAY EUROPE GmbH Frankfurt Germany	KURARAY EUROPE GmbH Frankfurt Germany	PARKELL Inc. Edgewood NY USA
Contents	Ethylacetat, nitrocellulose alkohol, İsopentyl propionat, natrium fluorid	Primer: MDP, HEMA, dimethacrylate monomer, water, catalyst Bond: MDP, HEMA, dimethacrylate monomer, microfiller, catalyst	(1) A Paste • 10-Methacryloyloxydecyl dihydrogen phosphate (MDP) • Hydrophobic aromatic dimethacrylate • Hydrophobic aliphatic dimethacrylate • Hydrophilic aliphatic dimethacrylate • Silanated silica filler • Silanated colloidal silica • dl-Camphorquinone (2) B Paste • Hydrophobic aromatic dimethacrylate • Hydrophobic aliphatic dimethacrylate • Hydrophilic aliphatic dimethacrylate • Silanated barium glass filler • Surface treated sodium fluoride	HEMA, Methyl Methacrylate, MEHQ, Poly methyl methacrylate, citric acid, Ferric chloride solution, Polyvinyl alcohol, water
Application Method	Shake bottle before use 1 drop liner is applied applied to cavity with disposable brush Dry with air spray for 30 sec	Apply primer and wait 20 sec The cavity is dried with air Bond is applied and spread with air all around cavity. 10 sec light is applied.	ED PRIMER II Ave B are mixed evenly and applied to the tooth. Wait for 30 seconds and thinned with air spray. Paste A and B are mixed in equal amounts for a minimum of 20 seconds. The mixture is applied to the cavity	Activator is applied to the cavity (10 sec in dentin and 30 sec in enamel) and washed with air and water. Apply a thin layer of adhesive agent and air dry for 30 sec. 3 drops base, 1 drop of catalyst, 1 shovel HPA powder is applied to the cavity by mixing.

The samples were coated with two layers of nail polish to within 1 mm of the restoration margins. The teeth were then immersed in a 0.5% basic fuchsin dye solution for 24 hours at 37° C. Then, the specimens were rinsed under running water. For examination, each sample was sectioned longitudinally through the restoration in the buccal-lingual direction on the restoration using a cutting diamond disc mounted in handpiece. Sections were examined by the researcher (M.Ü.) with an Olympus SZ 40 SZ-X7 binocular stereomicroscope (Olympus Corporation, Tokyo, Japan) at a 15x magnification (Figure 1-5).

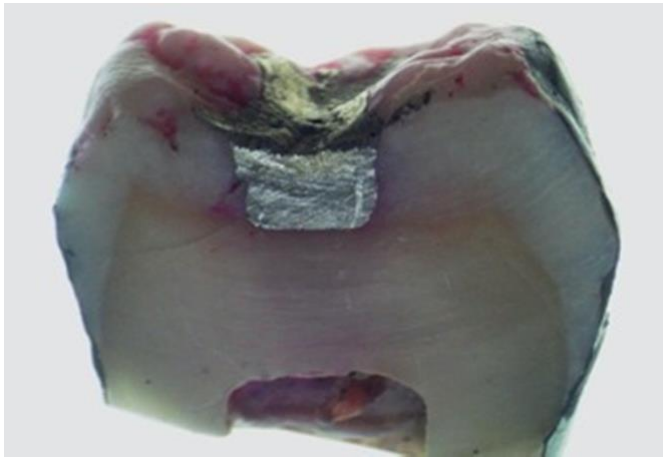

Figure 1. Microleakage in the non-adhesive control group (Score 4)

Figure 2. Microleakage in amalgam liner group (Score 1)

Figure 3. Microleakage in Clearfil SE Bond group (Score 0)

For each section, microleakage was evaluated at both occlusal and pulpal walls using the following scoring system:
0 = No marginal dye penetration;
1 = Dye penetration in less than ½ of the cavity wall;
2 = Dye penetration throughout the cavity wall;
3 = Dye penetration throughout the cavity wall and cavity floor;
4 = Dye penetration in the pulp.

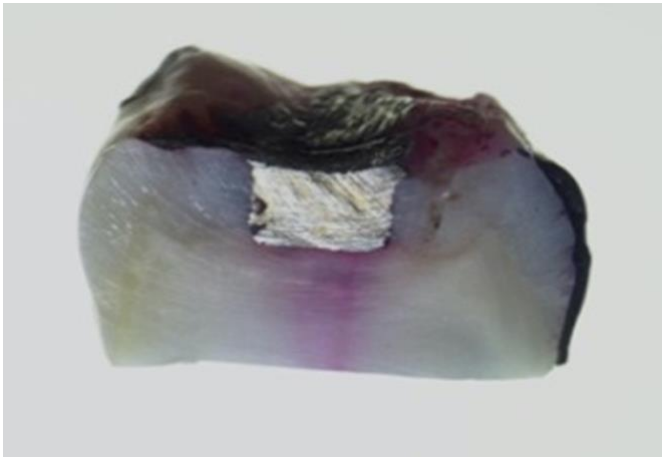

Figure 4. Microleakage in the Panavia F 2.0 group (Score 4)

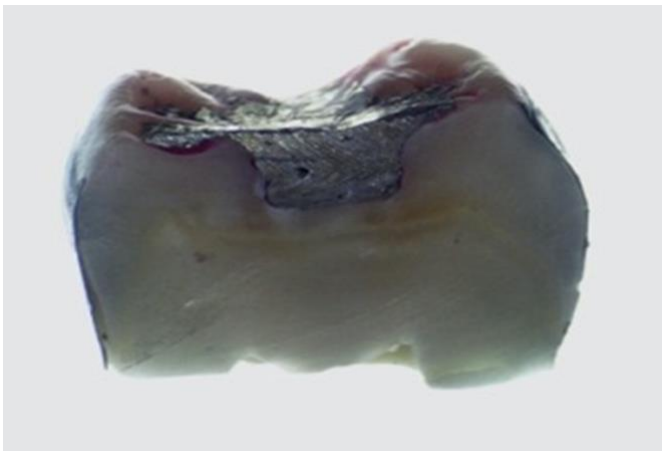

Figure 5. Microleakage in the Amalgambond Plus group (Score 2)

Statistical analysis

Data were analyzed using Kruskal-Wallis and Mann Whitney U pairwise statistical tests (p=0.05) (Graph. 1 and Table 2).
The samples were examined by SEM at the Inonu University Scientific and Technological Research Center. One sample was randomly selected from each group for SEM evaluation to determine the presence or absence of marginal gaps along the entire tooth-restoration interface. The specimens were washed with deionized water and gently dried with oil-free compressed air to remove the surface debris. Sections were coated with gold-palladium with BAL-TEC SCD 050 (Capovani Brothers Inc., Scotia, New York, USA). The analysis of the interface was carried out using a LEO EVO 40 SEM (LEO Ltd., Cambridge, UK). Micrographs were taken at 250 and 1000 operating magnifications (Fig. 6–10).

Graphic 1. Graph of the change in the microleakage values of the adhesive systems used in our study

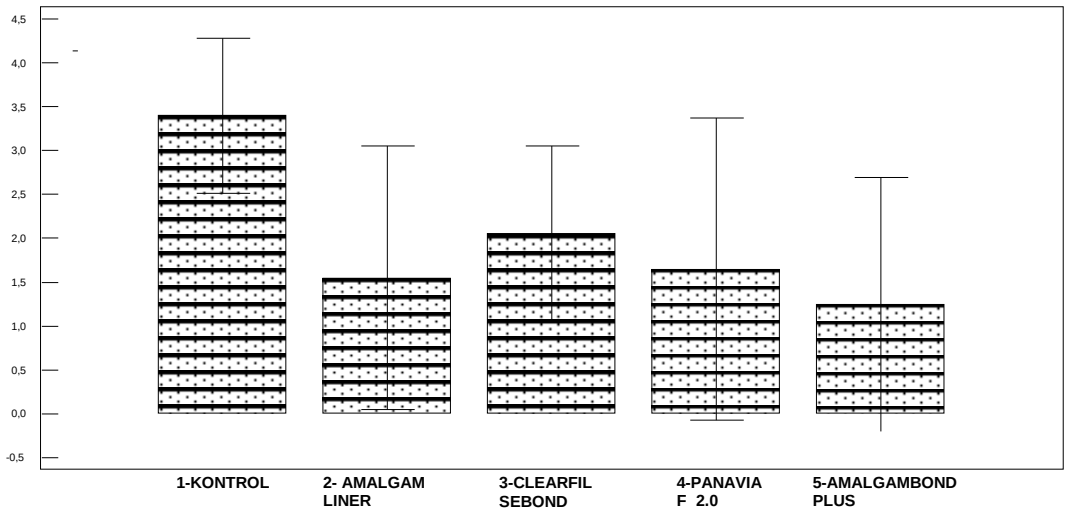

Table 2. The statistical results of the change in the microleakage values of the adhesive systems used in our research according to the Mann-Whitney U Test

Groups	Rank Average	Total	Mann-Whitney U	p
Control	26,98	539,50	70,500	0,000
Amalgam Liner	14,03	280,50		
Control	27,18	543,50	66,500	0,000
Clearfil SE Bond	13,83	276,50		
Control	26,13	522,50	87,500	0,001
Panavia F 2.0	14,88	297,50		
Control	27,98	559,50	50,500	0,000
Amalgambond Plus	13,03	260,50		
Amalgam Liner	17,68	353,50	143,500	0,115
Clearfil SE Bond	23,33	466,50		
Amalgam Liner	20,63	412,50	197,500	0,944
Panavia F 2.0	20,38	407,50		
Amalgam Liner	21,88	437,50	172,500	0,439
Amalgambond Plus	19,13	382,50		
Clearfil SE Bond	22,23	444,50	165,500	0,336
Panavia F 2.0	18,78	375,50		
Clearfil SE Bond	24,30	486,00	124,000	0,035
Amalgambond Plus	16,70	334,00		
Panavia F 2.0	21,58	431,50	178,500	0,539
Amalgambond Plus	19,43	388,50		

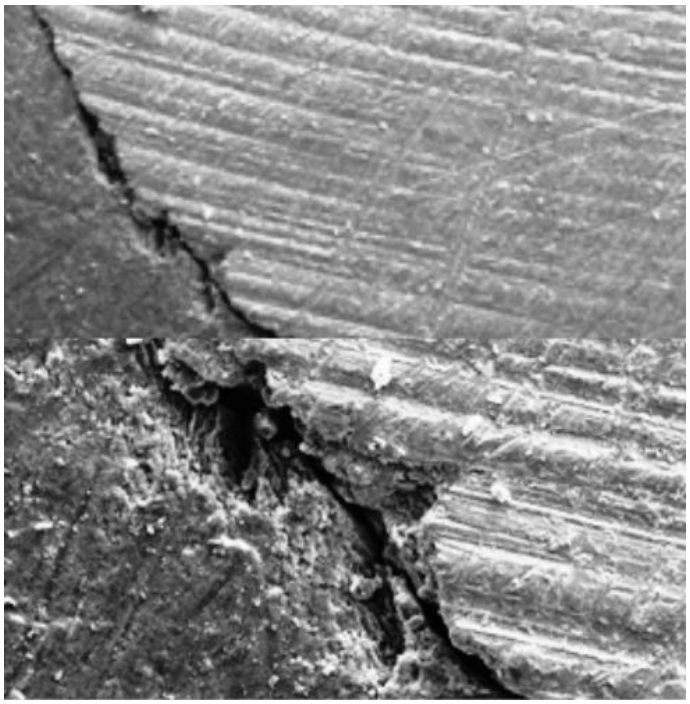

Figure 6. SEM image of the control group without adhesion (x250 and x1000)

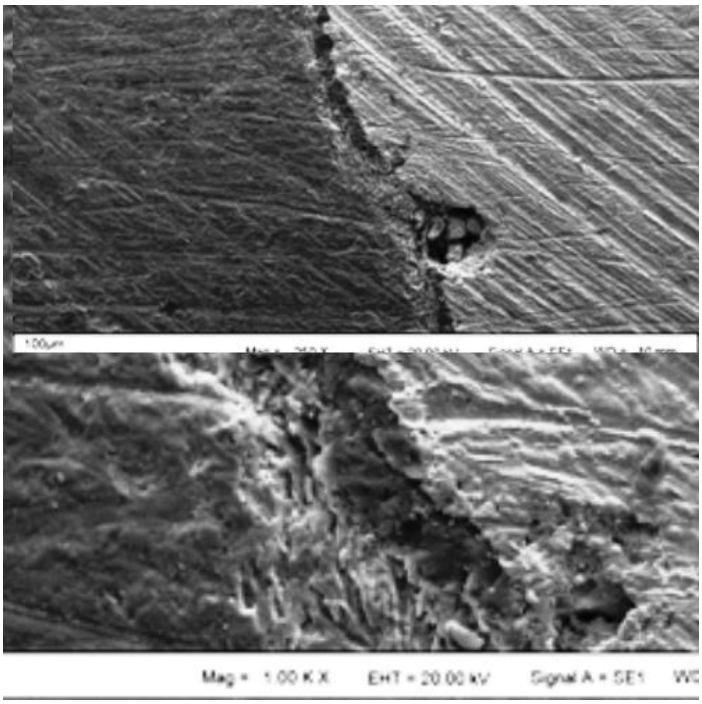

Figure 8. SEM image of the Clearfil SE Bond group (x250 and x1000)

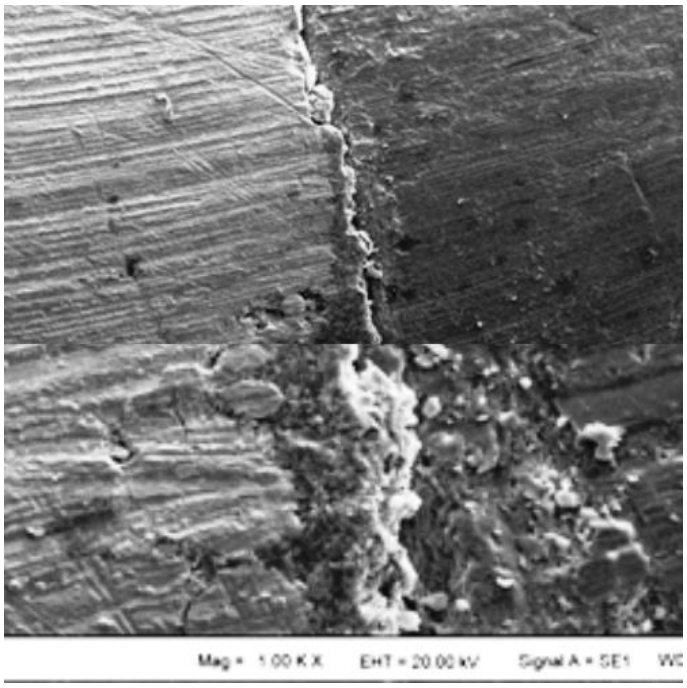

Figure 7. SEM image of the Amalgam Liner group (x250 and x1000)

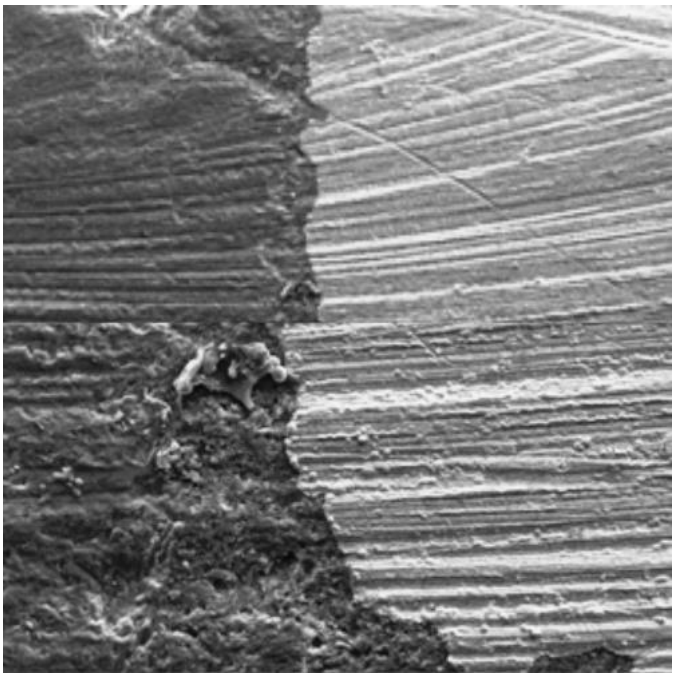

Figure 9. SEM image of the Panavia F 2.0 group (x250 and x1000)

Figure 10. SEM image of the Amalgambond Plus group (x250 and x1000)

Results

Microleakage scores can be seen in Table 3. The greatest number of microleakages was observed in the control group, where direct amalgam restoration was performed on the cavity without the application of any adhesive system. In the groups to which the cavity liner and Clearfil SE Bond were applied, microleakage values were lower than in the control group. The best results were obtained in the groups treated with Amalgambond Plus, and Panavia F. The lowest microleakage values were observed in the group using Amalgambond Plus.

Adhesive systems have been shown to reduce microleakage between the amalgam and the cavity and to be more successful in fitting the amalgam to the cavity. When the microleakage was compared between the groups, there was a statistically significant difference between the Amalgambond Plus group and the Clearfil SE Bond group. There were no statistically significant differences in microleakage between the other adhesive systems themselves (p>0.005

Table 3. Distribution of microleakage scores in groups

Microleakage results					
Score	0	1	2	3	4
Grup 1 Control	0	1	2	5	12
Grup 2 Amalgam Liner	6	6	3	1	4
Grup 3 Clearfil SE BOND	1	4	10	3	2
Grup 4 PANAVIA F 2.0	9	1	3	2	5
Grup 5 AMALGAMBOND PLUS	9	4	2	3	2

In the SEM scans of the groups, the dental hard tissue, adhesive systems, and amalgam material were examined under SEM, and their surface properties were evaluated. In the control group, the interface gaps were very clearly visible. It was observed that these gaps were filled by the adhesive systems in the other groups.

In the group using the Amalgam Liner, interstices were observed where the adhesive was bonded to the dental tissue. In the group treated with Clearfil SE Bond, the dentin adhesive bonds were found to be tighter than those in the Amalgam Liner, but gap were detected between the amalgam and Clearfil SE Bond. In the Panavia F and Amalgambond Plus groups, the best sealing was observed between adhesives and both the dentin and the amalgam.

Discussion

Adhesive systems have been developed (and continue to be developed) in order to eliminate the microleakage that has caused problems for both the traditional amalgam and other restorations (17-23). Adhesives are commonly used in dentistry today. In our study, we also use these adhesives.

Adhesive agents have been used in composite and amalgam restorations to increase retention and reduce microleakage. Moreover, it has been reported that the use of adhesive systems under amalgam restorations helps to strengthen the remaining dental tissues, reduce post-operative sensitivity, provide better edge adaptation, reduce microleakage, and prevent the formation of secondary caries (7, 8, 24).

Adhesive systems used in amalgam restoration prevent oral fluids and bacteria from diffusing into the dentin tubules because they seal the dentin tubules in a stable state (17). Adhesive systems are flexible, which allows them to compensate that occur during the crystallization phase of the amalgam. The long-term marginal integrity of amalgam restorations has increased significantly with the use of adhesive systems. It has also been shown that the formation of secondary caries is less likely in amalgam restorations done using an adhesive agent. Studies also claim that adding fillers to the adhesive agents may increase the strength of the bond between the tooth and amalgam (1, 25, 26).

Because amalgam is hydrophobic, and enamel and dentin are hydrophilic, amalgam adhesive systems need to contain both hydrophobic and hydrophilic layers. The adhesive agent must be modified with a co-monomer to make both the hydrophobic and hydrophilic surfaces wettable. Adhesive systems have frequently been modified with 4-META (4-methacryloyloxyethyl trimellitate anhydride). This co-monomer also contains 10% citric acid and 3% iron chloride. Adhesive agents containing 4-META have been reported to bind dentin, enamel, amalgam, composite, and both precious and base metals (7,8). In our study, we compared Amalgambond Plus (which contains 4-META) used under the amalgam with the Clearfil SE Bond and Amalgam Liner adhesive systems (which do not contain Panavia or 4-META).

The most important function of amalgam adhesive agents is to cover the dentin surface and bond to it. For this reason, these agents can be used as an adhesive system in cavities opened through a conservative approach. Amalgam adhesive systems form a layer (10-20 µm thick) on the surface of the cavity. This layer strengthens the bond between the amalgam and the cavity wall by locking in the microstructure of the amalgam during condensation (7). In vitro studies have also shown that the use of adhesive agents may increase the retention and fracture resistance of amalgam. Moreover, it has been shown in clinical trials that the formation of secondary decay in amalgam restorations done with an adhesive agent is lower. Adhesive systems have also been reported to prevent unnecessary tissue loss for retention in amalgam restorations (7,25,26,27).

In a study comparing various adhesives (Amalgambond, Scotchbond Multi-Purpose, All-Bond2, Probond, Optibond, Copalite) in amalgam restorations, Berry et al. reported that the least number of microleakages was observed in the group that was treated with Amalgambond (28). In the present study, which is similar to the previous research by Berry et al., the group to which Amalgambond Plus had been applied likewise had the least microleakage. We think that the reason for this is that the adhesives containing 4-META are both hydrophobic and hydrophilic and adapt well to both the amalgam and the tooth tissues at the same time (28,29).

In another study, Hürmüzlü et al. found that adhesive systems reduced microleakage in amalgam restorations but did not find a statistically significant difference between their samples (24). It has been reported that adhesives are effective in filling the micro-gaps between the amalgam and the cavity, but they cannot completely prevent microleakage. It is also known that the micro-interstices between amalgam and teeth occasionally get blocked by corrosion products found in amalgam (30,31).

Charlton et al. evaluated different adhesive systems (Copalite, Amalgambond, Panavia EX, Prisma Universal Bond 2) in terms of microleakage in amalgam restorations. They reported that microleakage in the group treated with Amalgambond was the lowest, and that the difference was statistically significant (32). The only other statistically significant difference in this study was found between the Amalgambond Plus group and the Clearfil SE Bond group.

The results of the studies indicate that the application of adhesive agents under amalgam restoration helps prevent microleakage (33, 34). The SEM images show that the adhesion between the amalgam and the adhesive is mechanical and forms as a result of the amalgam's interlacing with the adhesive material protruding into the amalgam (35). In the current study, no significant effects were observed on the surface morphology of Panavia F and Amalgambond Plus from interactions with amalgam. But the control group samples had irregularities in the area between the amalgam and the dentin surface.

Despite significant improvements in composites in recent years, marginal spacing due to poor resistance to abrasion and polymerization remains a problem in composites. Regarding the clinical effectiveness of amalgam restorations with adhesives, amalgams can successfully bond to enamel and dentin, and dental preparation for amalgam restorations can be generally performed as a composite restoration (2). Therefore, in order to assess the potential of adhesive-applied amalgam restorations, there is a need for clinical studies focusing on applications of amalgam combined with adhesives (26). Moreover, since amalgam restorations have secondary caries rates that are lower than composite restorations, their potential is higher than that of posterior composite restorations (36).

Amalgam restorations continue to be controversial, although their negative effects on general health have not been proven. Nevertheless, amalgam restorations

are still considered the standard against which other materials developed in recent years are tested (37).

Conclusions

When adhesive systems are used alongside other restoration materials, the results of the restoration are improved. As the adhesive systems evolve to suit the properties of the restoration materials, long-lasting restorations will be possible.

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Ethical Approval: Ethical Approval: Ethics committee approval was received for this study from Afyonkarahisar Health Sciences University, Faculty of Dentistry in accordance the World Medical Association Declaration of Helsinki, with the approval number: 2020/92.

Peer-review: Externally peer-reviewed.

Author Contributions: Conception – M.Ü.; Design –F.A., M.Ü.; Supervision – F.A.; Materials – M.Ü., F.A.; Data Collection and/or Processing – M.Ü., F.A.; Analysis and/or Interpretation – M.Ü.; Literature Review – F.A., M.Ü.; Writer – F.A.; M.Ü.; Critical Review – F.A

Conflict of Interest: No conflict of interest was declared by the authors.

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