TURKISH JOURNAL OF
ORTHODONTICS

DOI: 10.4274/TurkJOrthod.2024.2024.21

Original Article

Evaluation of Microleakage in Flash-Free and Conventional Ceramic Brackets: A Microcomputed Tomography Study

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Cite this article as: Üstdal G, Küçük EB. Evaluation of Microleakage in Flash-Free and Conventional Ceramic Brackets: A Microcomputed Tomography Study. *Turk J Orthod.* 2024; 37(4): 242-248

Main Points

- Flash-free ceramic brackets and conventional ceramic brackets were similar in terms of microleakage.
- Ceramic brackets bonded with Blugloo™ adhesive were shown less microleakage than the other groups.
- Microleakage volume, percentage, and surface area did not differ between the occlusal and gingival areas of the bracket base.

ABSTRACT

Objective: The aim of this study was to evaluate and compare microleakage under the conventional and flash-free ceramic brackets bonded with different agents.

Methods: Forty extracted human maxillary premolar teeth were randomly divided into five groups. According to the groups, adhesive coated and conventional bracket systems were bonded to the tooth surfaces with the specified adhesive agents. To simulate a six-month oral environment, all teeth were subjected to a thermal cycle procedure. Micro-computed tomography (micro-CT) was used to view and measure the microleakage. Kruskal-Wallis test was used to compare the parameters and Mann-Whitney U test was used for the determination of the group that caused the difference. For intragroup comparisons Wilcoxon signed-rank test was used.

Results: Microleakage volume (mm^3) and microleakage percentage (%) measured in Blugloo™ group was found significantly lower ($p<0.05$) then other groups. There was no significant difference in microleakage volume (mm^3) and percentage (%) in comparison of gingival and occlusal regions ($p>0.05$).

Conclusion: Adhesive precoated flash-free brackets were not shown a significant difference compared to their conventional equivalent for microleakage volume. The brackets bonded with Blugloo™ adhesive were showed significant less microleakage than the other groups.

Keywords: Microleakage, microcomputed tomography, flash-free brackets, adhesive precoated brackets

INTRODUCTION

Orthodontic bonding without the right techniques and agents can lead to recurrent bracket failures, insufficient leveling, and white spot lesions.[1,2] To prevent these negative outcomes, companies are trying to produce more advanced bonding agents, and orthodontists are developing new bonding technique.

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Received: January 28, 2024 **Accepted:** September 21, 2024 **Publication Date:** 31 December, 2024

A commonly used procedure to create a reliable bond between the orthodontic bracket and tooth surface is the use of light-curing adhesives. Light-curing adhesive-associated polymerization shrinkage can lead to gaps between the bonding material and enamel.[3] These microgaps may allow oral fluids, molecules, ions, and bacteria to pass through the enamel surface. Such microleakage can cause enamel demineralization.[1] The microleakage of bacteria and oral fluids under the orthodontic bracket can lead to the progression of white spot lesions and reduce the bonding strength of the brackets to the tooth surface.[1,2]

Microleakage under orthodontic brackets has been investigated using various bracket systems,[1] polymerization devices,[3] bonding methods[4-7] and adhesives.[1,2,8,9] Despite all the scientific studies, it is still unclear which method or agent will be more useful in preventing microleakage.[9]

Adhesive precoated brackets (APC™, 3M™ Unitek Corporation, CA) were first introduced in 1991. The aim is to save the clinician's time during direct bonding procedure.[10,11] The benefits of APC™ systems compared to conventional light-cured adhesives include faster bonding and easier cleaning.[12] It has also been reported that APC™ systems improve bond strength and reduce clinical failure rates.[13,14] The composite used in the precoating is a modified form of Transbond™ XT (3M™ Unitek Corporation, CA).

APC™ Flash-Free brackets are a popular product that 3M™ Unitek (Monrovia, CA). This brackets come as single packaged brackets and are precoated on a non-woven polypropylene mesh using a low-viscosity resin. This unique structure eliminates the need for cleaning the excessive adhesive and forms a seal to decrease microleakage.[9] It is stated that this bracket system provides sufficient bond strength,[5,15] reduces bonding time and minimizes microleakage compared to conventional bonding systems.[14,15] However, the disadvantage of these systems is their high cost.

To measure microleakage; various *in vitro* methods such as compressed air, radioactive adsorption, radioisotopes, neutron activation, bacterial activity, electrochemical method, dye penetration, scanning electron microscopy, and micro-computed tomography (micro-CT) have been used.[16-18] Among these, micro-CT technology offers significant advantages over two-dimensional (2D) methods. Researchers have indicated that micro-CT is an effective and feasible technique for evaluating polymerization shrinkage and microleakage.[19]

The objective of this research was to compare microleakage under flash-free ceramic brackets and conventional ceramic brackets using micro-CT after thermal cycling.

METHODS

Ethical approval was received from Hatay Mustafa Kemal University Tayfur Ata Sökmen Medical Faculty Clinical Research Ethics Committee with the number 2017/108 (decision no.: 14, date: 24.05.2017), and written informed consent was secured from all patients who agreed to participate in the study. According to the power analysis; with an effect size of 0.6358, a standard deviation of 0.008, an alpha level of 0.05, and a power of 0.8, it was assigned that a minimum of 7 teeth per group was required (version 3.1.9.3, G*Power; HHU Düsseldorf, Germany).[6] To increase reliability and prevent poteintial losses, 8 teeth were used for each group. Forty extracted maxillary premolars were randomly divided into 5 groups, each containing 8 teeth. The teeth included in this study met the following criteria: intact buccal enamel, no caries, no cracks, no restorations, and no prior orthodontic bonding. Until the test time (maximum 8 weeks), the teeth were stored in 0.1% (weight/volume) thymol solution to inhibit bacterial growth at room temperature.[9]

At the experimental stage, all teeth were polished with a flour-free paste for 10 seconds, then rinsed and air-dried. A 37% phosphoric acid gel (3M™ Dental Products, USA) was applied for 30 seconds to the buccal surface of the enamel. The enamel surface was then rinsed with water and dried with air for 20 s. A dull white area was observed on the etched surfaces of all teeth. The same bonding process was applied to all groups using different agents as detailed in Table 1. For all groups, a thin layer of light-cured primer was applied to the buccal surface for 5 seconds on all teeth. Dry air was used to thin the primer, which was then cured with light-emitting diode device (LED) for 10 seconds with a power of 1,000 mW/cm^2. Adhesive was applied on the bracket base for non-coated groups. The brackets were then positioned on the buccal enamel surface, and 300 grams of compression force was applied for 10 seconds using a force gage (P1025-00, Leone™, Italy).[6] Excessive adhesive resin around the brackets was removed with a probe, and the LED light was applied for 10 seconds each from the distal and mesial sides of each bracket for polymerization. Ceramic Clarity™ Advanced maxillary premolar brackets were used in all groups, and all bonding procedures were performed by the same practitioner.

Table 1. Experimental groups and bonding materials used according to groups

Group	Bracket	Primer	Adhesive
APC Flash-Free	**Clarity™ Advanced**	Transbond™ XT Primer	APC™ Flash-Free
APC PLUS	**Clarity™ Advanced**	Transbond™ XT Primer	APC™ PLUS
Transbond XT	**Clarity™ Advanced**	Transbond™ XT Primer	Transbond™ XT Light Cure Adhesive
Opal Bond MV	**Clarity™ Advanced**	Opal® Seal™	Opal® Bond™ MV
Blugloo	**Clarity™ Advanced**	Ortho Solo™ Primer	Blugloo™

After the bonding procedure, to simulate 6 months of intraoral thermal environment, all teeth underwent thermocycling (Julabo GmbH, FT 400, Seelbach, Germany) for 5000 cycles between 5 °C and 55 °C, with a dwell time of 30 seconds.[9,20] The samples were then kept in a 50% silver nitrate solution, used as a radiopaque staining solution for microleakage evaluation.

A Skyscan model 1272 (Kontich, Belgium) micro-CT system was used to receive the 3D X-ray images. Each tooth was placed in a central and vertical position in the sample holder. The X-ray source was set at 90 kV and 111 Ma. Each sample was rotated 360° with a rotation step of 0.50°. A 1-mm aluminum filter was used for all scanning procedures.

For the X-ray images, NRecon (Skyscan, Version 1.7.4.2) software was used. Image pollution and radiological artifacts were eliminated at this stage with 3 units smoothing, 8 units ring artifact correction, and 46% of beam hardening correction. The DICOM (Digital Imaging and Communications in Medicine) compatible images were converted to Bit Map Picture (BMP) format. The resolution of each image was 2452x2452 pixels, with pixel size ofv 9,000 microns. The BMP files were imported to CT-Analyzer software (CTAn, Version 1.18.4.0+, SkyScan, Belgium). The adhesive under the bracket was separated from the enamel, bracket, and air in all three dimensions using the region of interest (ROI) function for all samples (Figures 1, 2). All 3D images were then thresholded and linearized (Figures 3, 4). Volumetric and percentage (microleakage/ROI×100) measurements of microleakage were obtained using the same task list. Each model was sectioned occlusally and gingivally for evaluation. All analyses were performed by the same researcher.

Statistical Analysis

SPSS (version 22; IBM, Armonk, NY) software was used for statistical analysis. The normality of data distribution was determined using the Shapiro-Wilks test. The Kruskal-Wallis and Mann-Whitney U tests were used. For intragroup comparisons, the Wilcoxon signed-rank test was used. Significant differences were evaluated at $p<0.05$ level.

RESULTS

The mean and standard deviation values of the occlusal, gingival, and total microleakage in each group are presented in Table 2. The total microleakage volume of the Blugloo group was significantly lower than that of the APC Flash-

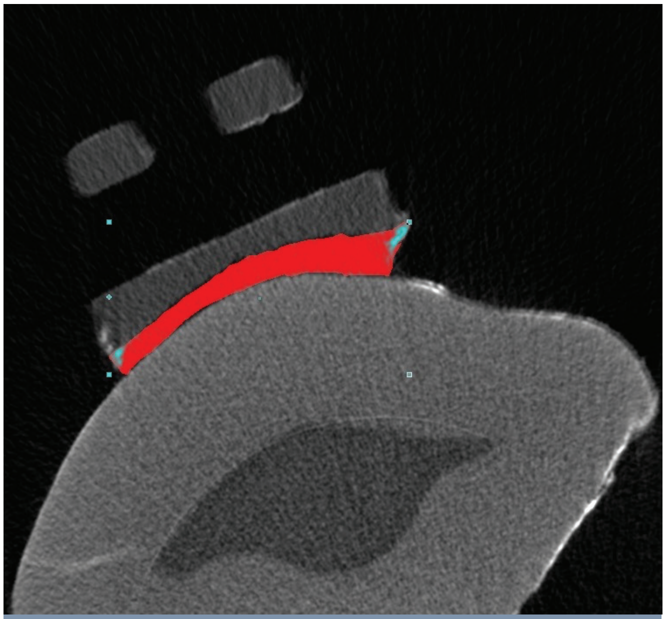

Figure 2. The working area, which was observed in red, was delineated using the ROI function
ROI, region of interest

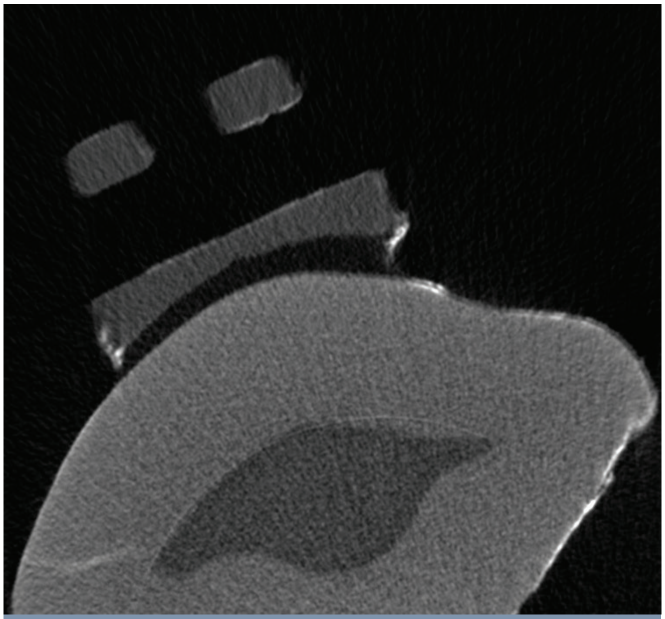

Figure 1. The unprocessed image of a slice shows the bracket, tooth, and adhesive

Figure 3. The threshold process prepares the processed 3D image for mathematical analysis using the generated ideal task list values

Free, APC PLUS, Transbond XT, and Opal Bond MV groups (p1=0.001; p2=0.011; p3=0.027; p4=0.004). On the other hand, no significant differences in total microleakage volume were observed between the other groups (p>0.05).

When the occlusal microleakage volume values were evaluated, the Blugloo group showed significantly lower values than compared to the APC Flash-Free, APC PLUS, Transbond XT, and Opal Bond MV groups (p1=0.006; p2=0.012; p3=0.027; p4=0.009). The occlusal microleakage volume of the Transbond XT group was significantly lower than that of the Opal Bond MV group (p=0.046). There were no significant differences between the other groups (p>0.05).

A significant difference was found in the gingival microleakage volume (p=0.017). The gingival microleakage volume of the Blugloo group was significantly lower than that of the APC Flash-Free, APC PLUS, Transbond XT, and Opal Bond MV groups (p1=0.003; p2=0.012; p3=0.012; p4=0.009). There were no significant differences between the other groups in terms of gingival microleakage volume values (p>0.05). A significant difference in the percentage of total microleakage was also observed between the groups (p=0.007). The microleakage percentage of the Blugloo group was lower than that of the APC Flash-Free, APC PLUS, Transbond XT, and Opal Bond MV groups (p1=0.001; p2=0.003; p3=0.016; p4=0.010). No significant differences were observed among the other groups(p>0.05).

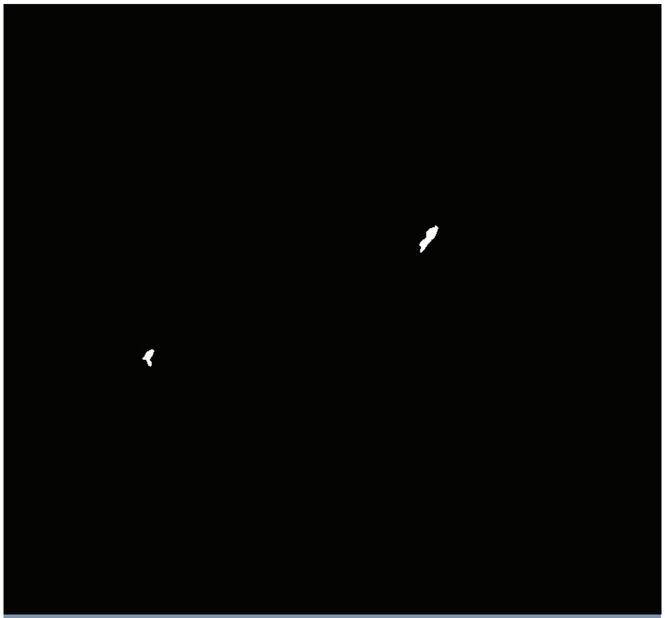

Figure 4. Binarization is the final step in separating black and white colors before 3D computation (white area demonstrates the microleakage)

When comparing the total microleakage surface areas of the the five experimental groups, the Blugloo group had a significantly lower total microleakage surface area than the other groups. These surface area results strongly support the 3D volume findings of microleakage.

The statistical comparison of microleakage volume, surface area, and percentage among the five groups in the occlusal and gingival regions is presented in Table 3. Intragroup comparisons indicated no significant differences between the occlusal and gingival regions (p>0.05).

DISCUSSION

Microleakage of bacteria and oral fluids between the enamel-adhesive surface is an undesired side effect of treatment with brackets. It may cause the development of white spot lesions and reduce the bonding strength of brackets.[1,2] These reasons make microleakage a curious topic. Therefore, various studies have been conducted to evaluate microleakage beneath brackets.[21,22]

In recent years, precoated bracket systems have been widely used in orthodontics. These brackets shorten the bonding time and reduce microleakage by providing good edge coverage. In the present study, the amount of microleakage under the brackets bonded with two different adhesive precoated

Table 2. Volumetric (mm^3), percentage (%), and surface area (mm^2) microleakage values and comparisons of the groups

3D Analysis		APC Flash-Free	APC PLUS	Transbond XT	Opal Bond MV	Blugloo	p-value
		Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	
Microleakage volume (mm^3)	Occlusal	0.006±0.005	0.012±0.019	0.004±0.003	0.019±0.019	0.001±0.001	**0.010***
	Gingival	0.010±0.009	0.015±0.019	0.014±0.022	0.015±0.016	0.001±0.001	**0.017***
	Total	0.015±0.008	0.025±0.038	0.015±0.021	0.035±0.034	0.001±0.001	**0.012***
Microleakage percentage (%)	Occlusal	0.3±0.19	0.63±1.05	0.26±0.18	1.21±1.13	0.09±0.1	**0.012***
	Gingival	0.6±0.56	0.88±1.19	1.13±1.88	1.13±1.21	0.06±0.04	**0.015***
	Total	0.91±0.5	1.52±2.19	1.39±1.89	2.35±2.1	0.15±0.12	**0.007***
Microleakage surface area (mm^2)	Occlusal	0.81±0.55	1.36±1.63	0.49±0.3	1.54±1.15	0.15±0.12	**0.004***
	Gingival	0.87±0.65	1.6±1.78	1.39±1.92	1.34±1.52	0.13±0.08	**0.011***
	Total	1.68±0.74	2.96±3.3	1.88±1.99	2.88±2.34	0.28±0.17	**0.003***

Kruskal-Wallis test, *p<0.05

Table 3. Microleakage comparisons of the occlusal and gingival regions

Group	3D Parameters	Occlusal	Gingival	p-value
		Mean±SD	Mean±SD	
APC Flash- Free	Microleakage volume (mm^3)	0.006±0.005	0.010±0.009	**0.484**
	Microleakage percentage (%)	0.3±0.19	0.6±0.56	**0.401**
	Microleakage surface area (mm^2)	0.81±0.55	0.87±0.65	**0.779**
APC PLUS	Microleakage volume (mm^3)	0.012±0.019	0.015±0.019	**0.674**
	Microleakage percentage (%)	0.63±1.05	0.88±1.19	**0.327**
	Microleakage surface area (mm^2)	1.36±1.63	1.6±1.78	**0.674**
Transbond XT	Microleakage volume (mm^3)	0.004±0.003	0.014±0.022	**0.401**
	Microleakage percentage (%)	0.26±0.18	1.13±1.88	**0.327**
	Microleakage surface area (mm^2)	0.49±0.3	1.39±1.92	**0.484**
Opal Bond MV	Microleakage volume (mm^3)	0.019±0.019	0.015±0.016	**0.484**
	Microleakage percentage (%)	1.21±1.13	1.13±1.21	**0.779**
	Microleakage surface area (mm^2)	1.54±1.15	1.34±1.52	**0.575**
Blugloo	Microleakage volume (mm^3)	0.001±0.001	0.001±0.001	**0.398**
	Microleakage percentage (%)	0.09±0.1	0.06±0.04	**0.398**
	Microleakage surface area (mm^2)	0.15±0.12	0.13±0.08	**0.735**

Wilcoxon signed-rank test, *$p<0.05$

systems and three different traditional adhesive systems were compared.

Various methods have been used to investigate microleakage under orthodontic brackets. The most commonly used *in vitro* method is the dye penetration method.[7,8,23,24] This method involves staining microleakage areas using dye solutions and evaluating them usually with a stereomicroscope. However, in this technique, the depth of dye penetration is measured in two dimensions on limited slices, which may not represent the entire 3D image of the microleakage volume.[6] Therefore, the reliability is low compared to 3D methods.[16,25] Micro-CT is a 3D method that generates reliable and comprehensive data in microleakage studies.[26] This novel method was preferred due to its reliability in this study. An *in vitro* experimental design was developed to ensure standardization and eliminate patient-derived differences.

The advantages of the micro-CT technique include its noninvasive nature, which does not damage the samples, capability to perform repetitive scanning of the same sample, potential for 3D analysis, method reliability, and ability to apply different tests to the sample. However, micro-CT studies require significant time and effort to scan, image reconstruction, and analysis each sample. In addition, it is an expensive method, and the small sample size in micro-CT studies can be considered as a limitation.[27,28]

Radiopaque staining solutions such as barium nitrate, lead nitrate, and silver nitrate have been frequently used in previous micro-CT studies to evaluate microleakage.[29] Nguyen[29] reported that a 50% silver nitrate solution is highly successful and convenient for assessing leakage in the micro-CT method. Zhao et al.[30] and Eden et al.[18] used 50% silver nitrate solution for determining the microleakage of composite restorations using micro-CT. Also, Öztürk et al.[6] used a 50% silver nitrate solution in their micro-CT study to evaluate microleakage areas under the brackets. Considering previous studies, a 50% silver nitrate solution was used in the present study. In different microleakage studies, the immersion time of the samples in the silver nitrate solution ranged from 1 hour to 24 hours.[18,29,31] In the present study, a pilot study was conducted to determine the immersion time of the samples in the silver nitrate solution, and the optimal time for monitoring leakage. Based on these findings, the immersion time was set at 12 hours for this study.

The APC™ Flash-Free system uses brackets with low-viscosity resin applied on a polypropylene nonwoven mesh. This system eliminates the need for resin cleaning after application, creates a seal to reduce microleakage, and decreases the total bonding time.[9] However, according to the results of the present study microleakage volume of APC™ Flash-Free, APC Plus, and noncoated Transbond XT groups were similar. Kim et al.[9] compared microleakage under the APC™ Flash-Free and APC™ PLUS brackets using the dye penetration method and found no significant difference. Grünheid et al.[5] evaluated the microleakage of APC™ Flash-Free and APC™ II products and found no significant difference. The findings from these studies align with the results of the present study.

In a recent study examining microleakage under stainless steel brackets, it was reported that conventional brackets exhibited more microleakage than the APC Flash-free and APC plus groups.[32] However, this study used stereomicroscopy and was limited to selected sections. Because the present study was not conducted on selected sections, it included the entire 3D microleakage volume. It is thought that the micro-CT method strengthens the results of the present study.

The results of the present study showed that the microleakage volume in the Blugloo group was significantly lower than in the other experimental groups. The reason for this result is thought to be the special structure of the adhesive, as Blugloo™ is specficially formulated for use with ceramic brackets.

In their microleakage study using the dye penetration method, Uysal et al.[33] reported that gingival microleakage scores were higher than the occlusal scores of the brackets for all groups. In contrast, in a micro-CT study, Öztürk et al.[6] reported higher values of occlusal microleakage than gingival microleakage for two experimental groups and no significant differences between the other groups. In the present study, no significant differences were observed between the occlusal and gingival microleakage volumes across the groups. The reasons for this difference between studies were thought to be the anatomical differences in the teeth used and the differences in brackets, adhesives, and methods. However, microleakages are volumetric data; therefore, 3D methods are considered to provide more accurate evaluations.

In modern orthodontic practice, the use of metal brackets is common. Despite this, ceramic brackets were selected for the present study to ensure higher quality measurements by preventing metal artifacts in micro-CT images. This can be seen as a limitation of the present study. However, Ramoglu et al.[8] reported no significant differences in microleakage between metal and ceramic brackets. Considering the results of this study, the use of ceramic brackets may not be an important limitation.

CONCLUSION

Flash-free ceramic brackets and conventional ceramic brackets demonstrated similar levels of microleakage. However, ceramic brackets bonded with Blugloo™ adhesive exhibited significantly reduced microleakage. The microleakage observed in the occlusal and gingival regions of the brackets was comparable.

Ethics

Ethics Committee Approval: Ethical approval was received from Hatay Mustafa Kemal University Tayfur Ata Sökmen Medical Faculty Clinical Research Ethics Committee with the number 2017/108 (decision no.: 14, date: 24.05.2017).

Informed Consent: Written informed consent was secured from all patients who agreed to participate in the study.

Footnotes

Author Contributions: Concept - G.Ü., E.B.K.; Design - G.Ü., E.B.K.; Data Collection and/or Processing - G.Ü.; Analysis and/or Interpretation - G.Ü., E.B.K.; Literature Search - G.Ü.; Writing - G.Ü.

Conflict of Interest: The authors have no conflicts of interest to declare.

Financial Disclosure: This study was supported by Hatay Mustafa Kemal University Scientific Research Projects Unit.

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