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Effect of different liquids on APC flash-free ceramic bracket's color stability, shear bond strength, and slot surface roughness

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Objective: The aim of this in vitro study was to evaluate the effect of thermal aging and five different discolouring solutions on the shear bond strength (SBS), discoloration, and slot surface roughness (SSR) of Flash-Free ceramic brackets.
Methods: A total of 70 human premolar teeth were randomly divided into seven groups: group 1: no procedure was performed; group 2: Only thermal cycling (TC); group 3: TC + immersion in cherry juice for 72 hr; group 4: TC + immersion in coffee for 72 hr; Group 5: TC + immersion in Coke for 72 hr; group 6: TC + immersion in artificial gastric acid for 24 hr; group 7: TC + immersion in artificial saliva for 72 hr. SBS values were determined by using a universal testing machine. The discolouration was evaluated using a Vita Easy Shade spectrophotometer which is based on the International Commission on Illumination system (CIE Lab colour system). A 3D optical profilometer was used to measure the roughness of the bracket slot bases.
Results: Coke, coffee, cherry juice, and gastric acid all significantly increased slot surface roughness. There was, however, no statistically significant difference in the roughness caused by these liquids. The lowest SBS value was observed in the gastric acid group. Gastric acid and Coke were observed to induce the largest colour change.
Conclusions: Thermal aging and different liquids cause discolouration and increased surface roughness on APC flash-free brackets. The adhesive bond strength was clinically acceptable even after immersion in gastric acid.
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Introduction

For the application of fixed appliances, an orthodontic adhesive is manually applied to the base of the bracket prior to placement. After applying a seating force, a flash usually remains around the bracket, and therefore must be removed. Plaque accumulation or a discolouration around the bracket occurs when the flash is not entirely cleared.[1–3]

Because of recent advancements in adhesive technology, it is now possible to enhance shear bond strength (SBS) and reduce chairside time by simplifying the bonding procedure. In the early 1990s, the 3M Unitek company (Monrovia, CA, USA) produced pre-coated brackets known as APC. A second generation of precoated brackets (APC II system) was introduced a decade later. In comparison to the first system, the APC II adhesive was less viscous, had a longer shelf life and better packaging to facilitate handling. Subsequently, the company upgraded the product and released APC Flash-Free brackets. The brackets in this system are applied directly onto a prepared tooth surface without the subsequent removal of adhesive excess.[4] The manufacturer claims that these brackets shorten the bonding time and have a failure rate of less than 2%.[5] In an independent study, Lee et al. reported that the APC Flash-Free system reduced bonding time and improved bonding strength.[6]

Due to their aesthetic appearance, ceramic brackets are preferred by adult patients.[7] The brackets, however, have disadvantages, related to discolouration, low fracture toughness, a high slot friction rate, and surface cracks after debonding.[8]

The factors that contribute to the colouration of ceramic brackets are classified as internal and external. Beverages such as tea, coffee, Coke, and cherry juice cause external discolouration. These liquids have varying pH levels and are therefore capable of causing roughness of the ceramic slot surface.[1] Normally, the frictional resistance of ceramic brackets is higher than metal brackets.[9] The increase in surface roughness due to the intraoral thermal cycle and acidic foods further increases friction, which may lead to an increased treatment time.[10]

The aim of the present study was to therefore evaluate the effect of a thermal cycle and exposure to different solutions on the SBS, discolouration, slot surface roughness (SSR) of APC Flash-Free ceramic brackets. The null hypothesis stated that ceramic brackets maintained their integrity and expected SBS.

Materials and method

Preparation of samples

The research protocol of the current study was approved by the Clinical Research Ethics Committee of Afyonkarahisar Health Science University (ID:2019/361). Following informed consent from all patients, the study acquired 70 human premolar teeth extracted for orthodontic reasons. Teeth affected by caries, fillings, structural defects, or surface crown damage were excluded. After extraction, the teeth were cleaned of all soft tissue residue and debris. The teeth were kept in 0.1% aqueous thymol solution at 4°C for a maximum of 3 months until required.[11]

The tooth roots were embedded in self-cured acrylic cylinders (Imicryl, Turkey) to provide stability during the SBS tests.[12,13] Before bonding, all teeth were cleaned using fluoride-free pumice, washed, and air dried. Following preparation, the enamel surface was etched with 35% phosphoric acid (Universal Etchant, 3M ESPE, Germany) for 30 sec, washed for 30 sec and dried with oil- and moisture-free air. Subsequently, using an applicator, Transbond XT primer (3M Unitek, Monrovia, California, USA) was applied to the tooth in a uniformly thin layer. A VALO cordless curing device (Ultradent Products Inc., South Jordan, Utah, USA) was used for 3 sec in an extra power mode. All brackets were bonded by the same researcher (Ş.C.Ç) using the same light curing device.

Using a moderate seating force, APC Flash-Free precoated brackets were placed on each tooth surface. No flash was observed due to the special spongy structure of the adhesive. As a result, there was no need to remove excess adhesive. Three seconds of curing light were separately applied to the mesial and distal sides of the brackets. Following bracket bonding and curing, the samples were kept in distilled water at 37°C for 24 hr to complete polymerisation. The teeth were subsequently randomly divided into 7 groups (n = 10) (Table I). The SBS established for Group 1 provided a control level as no further procedures were applied to this group.

Thermal aging

To mimic temperature changes in the mouth, all samples except for Group 1, were subjected to thermal cycling in hot and cold water tanks set at 55°C and 5°C, respectively[14]. During each cycle, the samples were held for 30 sec in the cold and hot tanks, and for 5 sec in the air between tank transfer[11]. The thermal aging procedure was completed after 10,000 cycles which corresponded to a one-year lifespan of dental materials in the mouth[15]. The data from Group 2 were used to assess the sole effect of the thermal cycle on parameters (SBS, SRS, discolouration).

Commonly exposed solutions

Group 3, Group 4, Group 5, Group 6, and Group 7 were immersed in the following solutions, respectively: Cherry juice, coffee, Coke, gastric acid, and artificial

Table I. Definition of the groups.

Groups	Experimental procedure
Group 1 (n = 10)	No thermal cycle or staining liquids
Group 2 (n = 10)	Only 10.000 thermal cycle (TC)
Group 3 (n = 10)	TC + coke (72 hr)
Group 4 (n = 10)	TC + coffee (72 hr)
Group 5 (n = 10)	TC + cherry juice (72 hr)
Group 6 (n = 10)	TC + gastric acid (24 hr)
Group 7 (n = 10)	TC + artificial saliva (72 hr)

saliva. The samples were kept in their respective solutions for 3 days[16] but in gastric acid for only 24 hr.[17] The temperature of the solutions was set at 37°C to simulate the intraoral conditions and each solution was renewed daily to prevent pH fluctuation. The ingredients and pH values of the solutions are shown in Table II.

Evaluation of discolouration

Discolouration was evaluated using a Vita Easy Shade spectrophotometer (VITA Zahnfabrik, Bad Sackingen, Germany) before and after thermal aging, as well as 24 hr and three days following immersion in the solutions. The device generated colour measurement values via the CIE Lab system which identifies colour by its location in three-dimensional color space. L^* is the coordinate aperture, a^* is the colour's position on the red-green axis, and b^* is the colour's position on the yellow–blue axis.[18] The following formula was applied in the CIE Lab colour system to determine the difference between two colours: $\Delta E^* = [(L1^* - L0\ ^*)2 + (a1^* - a0\ ^*)2 + (b1^* - b0\ ^*)2]1/2$. A white background paper was placed under the samples to standardise the measurements which were conducted in daylight by the same person (Ş.C.Ç). The upper right wing of each bracket was the consistent area analysed for all samples.

Evaluation of SSR

A 3D optical profilometer (NANOVEA, ST400) was used to measure the roughness of the bracket slots. Measuring from the mesial edge of each bracket slot provided standardisation. The surface topography of the slot was obtained in three dimensions for each sample by scanning for 2 min at a frequency of 400 Hz and at a sensitivity of 2 nm over an area of 0.1 mm × 1 mm. The 'Ra' parameter, which is defined as the average roughness value, was used to compare the surface slot roughness of each group.[19–21]

SBS analysis

The acrylic cylinders holding each tooth were fixed to the base plate of a universal testing machine (Esetron, ESEMIN5TD20116, MOD Dental, Ankara, Turkey). A chisel-edge plunger was mounted in the movable crosshead of the testing machine. The plunger speed was set at 0.5 mm/min and was applied until the bracket debonded. Force values were tracked and recorded using a computer linked to the device, and the smallest force was recorded in Newtons. For conversion to Megapascals (MPa), the force was divided by the bracket's base area.

Adhesive remnant Index

Following the debonding of the brackets from the tooth, the tooth surfaces were examined under a light microscope (Zumax, OMS2380, China). Residual composite remaining on the teeth was scored according to the index defined by Årtun and Bergland (Adhesive Remnant Index =ARI):[22]

Score 0: No adhesive remained on the tooth surface,
Score 1: Less than 50% of the adhesive remained on the tooth surface.

Table II. Liquids-related knowledges.

Product	Ingredients	pH values	Immersion time of the samples
Coffee (Nescafe, Switzerland)	Soluble coffee	5.0	72 hr
Coke (The Coca Cola Company, USA)	Water, sugar, carbon dioxide, colorant, cola extract, caffeine, acidity regulator (phosphoric acid)	2.53	72 hr
Cherry juice (The Coca Cola Company Cappy, USA)	Water, Sugar, Cherry Juice Concentrate, Acidity Regulator (Citric Acid), Fruit and Vegetable Extract (Blueberry, Carrot), Flavorings.	2.60	72 hr
Artificial gastric acid	0.06 M HCL 0.113% solution in deionized water	1.2	24 hr
Artificial saliva	1.160 g/L sodium chloride, 0.600 g/L calcium chloride, 0.600 g/L potassium phosphate, 1.491 g/L potassium chloride, 0.050 g/L sodium fluoride	6.93	72 hr

Score 2: more than 50% of the adhesive remained on the tooth surface.

Score 3: All adhesive remained on the tooth surface.

To test the reproducibility of all measurements, the same investigator microscopically re-examined and scored 20 randomly selected samples 2 weeks later. The intra-class correlation coefficient between repeated scores was calculated.

Statistical analysis

All analyses were performed using the SPSS 22.0 package software program. The Shapiro-Wilk normality test, the Kruskal-wallis test and post hoc Tamhane test were applied to compare data between groups. The level of significance was set at $P < 0.05$. Intra-examiner variability was compared using the dual measurements via the intra-class correlation coefficient test.

Results

Slot surface roughness

The roughness value caused by the thermal cycle and liquids on the slot surface is shown in Table III. Bracket slot optical profilometer images are illustrated in Figure 1. Compared to the initial values, the increase in surface roughness caused by the thermal cycle and artificial saliva was not statistically significant. Coke, coffee, cherry juice, and gastric acid were noted to cause a statistically significant increase in roughness. However, no significant difference was observed between the roughness values caused by these liquids.

Discolouration

The findings of the colour change that occurred after 24 hr are shown in Table IV. It was seen that the greatest change in ΔE was caused by gastric acid. It was also observed that Coke and coffee caused a significant colour change.

Colour changes that occurred after 3 days are shown in Table V. The greatest colour change was produced by Coke and coffee. Cherry juice and artificial saliva also caused significant but lesser colour change compared to the standard thermal cycle.

Shear bond strength

The effect of the thermal cycle and the liquids on the SBS is provided in Table III. The decrease caused

Table III. Distribution of surface roughness values, shear bond strength, and ARI scores between groups.

	Group 1 Mean ± SD	Group 2 Mean ±SD	Group 3 Mean ±SD	Group 4 Mean ±SD	Group 5 Mean ±SD	Group 6 Mean ±SD	Group 7 Mean ±SD	*P* value
Slot surface roughness (Ra)	0.132 ± 0.009^{A}	0.146 ± 0.015^{A}	$0,273 \pm 0.031^{B}$	0.267 ± 0.017^{B}	0.270 ± 0.038^{B}	0.289 ± 0.045^{B}	0.151 ± 0.022^{A}	0.03
Shear bond strength (Mpa)	19.94 ± 1.16^{A}	16.99 ± 2.67^{AB}	14.98 ± 2.10^{B}	15.44 ± 4.26^{AB}	14.26 ± 3.30^{B}	13.39 ± 3.49^{B}	16.75 ± 2.19^{AB}	0.01
ARI scores	1.40 ± 0.51^{A}	1.50 ± 0.70^{A}	1.60 ± 0.84^{A}	1.60 ± 0.69^{A}	1.70 ± 0.67^{A}	1.90 ± 0.73^{A}	1.60 ± 0.69^{A}	0.787

Note: Kruskal–Wallis and post hoc tamhane test result. Ra: average roughness value, Mpa: Mega pascal, ARI: Adhesive remnant index, SD: standard deviation. In each row, different superscripts indicate statistically significant differences between groups.

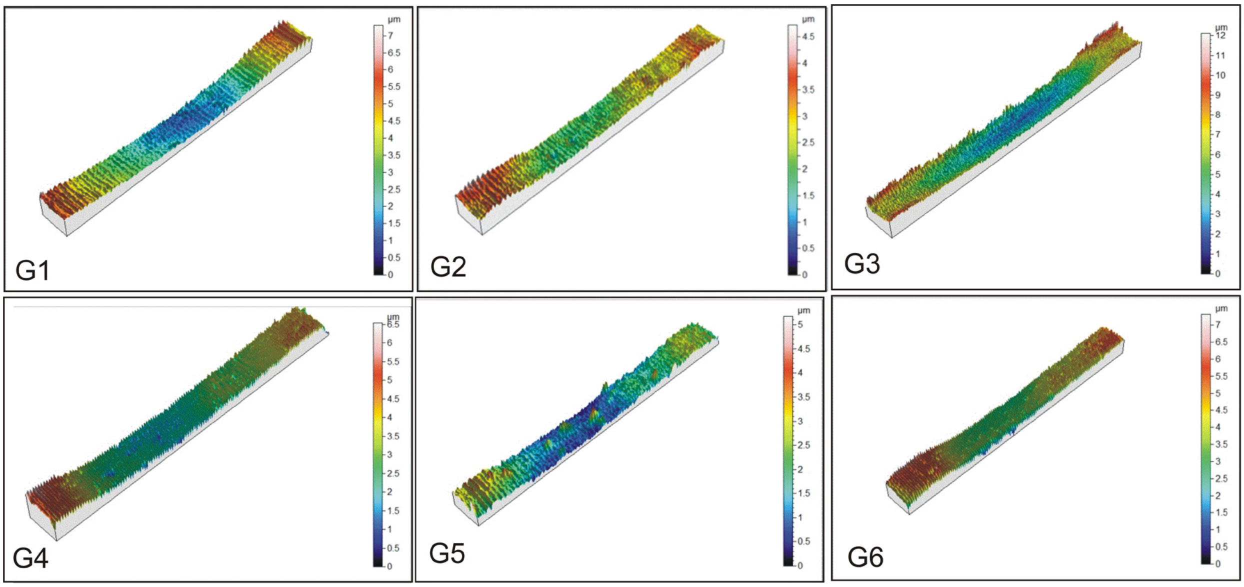

Figure 1. Optical profilometer images of slot surface. G: group.

Table IV. Color change results for 24 hr immersion.

	Group 2 Mean ± SD	Group 3 Mean ± SD	Group 4 Mean ± SD	Group 5 Mean ± SD	Group 6 Mean ± SD	Group 7 Mean ± SD	*P* value
Δ*E* values	1.28 ± 0.26^{AB}	2.79 ± 0.52^{CDEF}	2.43 ± 0.53^{CDE}	2.21 ± 0.41^{BCDE}	3.11 ± 0.28^{FC}	1.77 ± 0.29^{ABE}	0.001

Note: Kruskal–Wallis and post hoc tamhane test result. ΔE: the average amount of color change. In the row, different superscripts indicate statistically significant differences between groups.

Table V. Color change results for 72 hr immersion.

	Group 2 Mean + SD	Group 3 Mean + SD	Group 4 Mean + SD	Group 5 Mean + SD	Group 7 Mean + SD	*P*
Δ*E* values	1.28 ± 0.26^{A}	5.07 ± 0.23^{C}	4.60 ± 0.34^{C}	3.30 ± 0.27^{B}	2,90 ± 0.19^{B}	0.001

Note: Kruskal–Wallis and post hoc tamhane test result. Δ*E*: the average amount of color change. In the row, different superscripts indicate statistically significant differences between groups.

by the thermal cycle and artificial saliva was not statistically significant. It was observed that the action of Coke, cherry juice and gastric acid significantly reduced the SBS value.

Adhesive remnant index

ARI scores of all groups are presented in Table III. The mean scores of the groups were similar and the minor group differences were not statistically significant.

Discussion

The adhesive performance of Flash-Free pre-coated brackets has been investigated by previous in vivo or in vitro studies.[23,24] The hot-cold cycling of the oral environment causes thermal aging of the adhesive, resulting in a significant decrease in SBS value.[11] The thermal cycling has also been shown to affect the colour stability of ceramic brackets.[15]

Discolouration and slot friction are disadvantages of ceramic brackets. Drinks that are consumed on a daily basis, such as tea, coffee, and Coke, can cause ceramic bracket discolouration.[25] Similarly, gastric acid is an unwanted liquid associated with bracket discolouration[17] and surface roughness,[1] especially in patients with gastroesophageal reflux disease (GERD). In earlier studies, only shear bond strength (SBS) or discolouration of Flash-Free brackets was evaluated. However, according to current knowledge, the effects of frequently consumed liquids and gastric acid on shear strength and colour change have not been previously evaluated.

In the present study, the effects of different liquids and thermal cycle on the SBS and colour stability were evaluated. A 3D profilometer surface topography analysis was also performed to see if the various liquids increased the roughness of the ceramic slot surface.

In previous in vitro studies, the accumulated colouration of brackets was simulated by immersion in solutions such as coffee, tea, Coca-Cola, and wine.[25,26] The type of solution and the exposure period has been found to have a substantial impact on the level of colour change. Coffee, tea, and Coca-Cola are reported to be the most notorious staining agents.[27] In addition to dietary acid, intrinsic stomach acid can produce staining and roughening of a ceramic surface. Gastric acid reaches the oral cavity via reflux which significantly affects 18% to 28% of the population.[28]

The exposure periods of dietary staining agents varies between 1 and 30 days. Faltermeier et al., in an evaluation of aesthetic brackets, placed the adhesive samples in staining solutions for 72 hr. Gastric acid has an extremely low pH (<2.0) well below the critical pH (5.5) that enamel can tolerate, and so the potential for tooth erosive damage is high.[16] There is no well-established in vitro method for replicating stomach acid and so Marlon et al. restricted gastric acid immersion time to 1 day.[29] Considering that bulimia patients purge on average three times daily, and the anticipated contact time of stomach acid on brackets is 30 sec, the immersion time equaled approximately 2 years of gastric exposure.[30] In the current study, 0.113% hydrochloric acid and deionised water were used to create artificial gastric acid at a pH of 1.2. Samples were immersed in this solution for 24 hr. Alnasser et al. in a prosthodontic study, subjected the ceramic material to artificial gastric acid for 45 to 91 hr.[1] In the current study, however, exposure for more than 24 hr may have significantly reduced the SBS value in Group 6, and therefore negatively influenced the intergroup comparison results.

Frictional resistance is a disadvantage of ceramic brackets.[31] Kavitha et al. reported that the frictional resistance increased as the SSR increased.[32] In the present study, it was observed that dietary solutions and gastric acid caused a significant increase in the SSR. Aliping-Mckenzie et al. reported that citric acid in fruit juices has a greater corrosive effect than the phosphoric acid in Coke.[33] However, no statistically significant difference was found in the current study between the Ra values caused by Coca-Cola, cherry juice, coffee, and gastric acid. This situation can be explained by the different exposure times or the different chemical structures of the materials whose roughness was evaluated.[34] By reflecting an irregular and diffuse pattern of light, rough surface increase will also change and affect the colour and general appearance of a ceramic bracket.[35]

In the current study, discolouration was observed in brackets solely treated by thermal aging, which was similar to the findings of Lee et al.[15] The solutions that caused the greatest change in ΔE at the end of the 24-hr exposure were gastric acid, Coke, coffee, and cherry juice, respectively. Measurements taken at the end of the third day also revealed that ΔE values increased significantly in all groups. Similarly, Faltermeier et al. found that discolouration increased as exposure time increased in a study comparing 24-hr and 72-hr exposure[25]. Because ΔE measurements in the current study were taken while the brackets were on the tooth surface, it should be noted that the reflection of adhesive colour change from the base of the brackets could have an impact on the results.

The inıtal SBS for the Flash-Free ceramic bracket (group 1 = 19.94 + 1.16) was similar to the results of an in vitro study reported by Ansari et al.[36] and Marc et al.[5] The enamel etching procedure (37% phosphoric acid for 30 sec) and the brand of adhesive primer (Transbond XT) was also similar to those used in the current study. Lower mean SBS values were found in similar published studies by Lee et al. who reported an SBS of 13.7 MPa. However, self-etch primer was used in their study[12] and so the different enamel etching procedures might explain the significant differences in the SBS values. Each of the liquids in the current study resulted in a decrease in SBS value. The lowest SBS score was seen in the gastric acid group. However, even after exposure to gastric acid (13.39 + 3.49), the SBS value was above the threshold value of 10 Mpa accepted by Lee et al.[12]

The in vitro design of the current study has some limitations. The effect of microbial flora on roughness and discolouration was an unknown confounding factor and requires investigation. The pH buffering impact of saliva and the mechanical cleansing effect of oral hygiene are also unknown and require investigation.

Conclusions

1. The solutions of different pH values significantly reduced the SBS value of Flash-Free brackets. However, the SBS values remained clinically acceptable even after the samples were kept in gastric acid for 24 hr.
2. Gastric acid and the other solutions caused significant discolouration of the brackets.
3. Each of the solutions caused an increase in the SSR. It should be noted that the expected increase in friction may prolong the treatment time.

Ethics approval

This study was approved by Afyonkarahisar Health Science Clinical Research Ethics Committee.

Consent for publication

Written consent for publication was obtained from each participant.

Availability of data and materials

Data and materials are available at the Orthodontic Department in the Faculty of Dentistry, University of Afyonkarahisar Health Science.

Conflict of Interest

The authors declare that there is no conflict of interest.

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