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Original Article

Effect of Different Liquids and Thermal Aging Procedures on the Shear Bond Strength of APC II, APC Flash-Free, and Conventional Ceramic Brackets: An *In Vitro* Study

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Main Points

- Thermo-aging procedure and fluids had a negative impact on the shear bond strength (SBS) value of each type of ceramic bracket.
- Even after exposure to gastric acid and coke, the SBS values of all three types of brackets were still higher than a clinically acceptable value.
- Despite their low-viscosity resin structure, flash-free brackets had a satisfactory SBS value.

ABSTRACT

Objective: The purpose of this study was to compare the effects of cherry juice, coffee, coke, gastric acid, and the thermo-aging procedure (TAP) on the shear bond strength (SBS) of APC II, APC flash-free, and conventional ceramic brackets.

Methods: A total of 180 human premolar teeth were randomly divided into three major groups according to the type of ceramic bracket. Then, six subgroups (n=10) were established from each major group: Group 1: control; Group 2: only TAP; Group 3: 72 hours of cherry juice exposure + TAP; Group 4: 72 hours of coffee exposure + TAP; Group 5: 72 hours of coke exposure + TAP; and Group 6: 24 hours gastric acid exposure + TAP. SBS was assessed for each specimen using a universal test device, and the adhesive remnant index (ARI) was scored under a light microscope. Kruskal-Wallis and post-hoc Tamhane tests were used to analyze the data.

Results: Among the control groups, the highest SBS value belonged to conventional ceramic brackets ($p<0.01$). SBS values for all groups decreased as a result of each liquid and TAP. Gastric acid and coke had the greatest detrimental effects on SBS, while TAP had the least negative effects. The SBS values of APC II, APC flash-free, and conventional brackets were found to be statistically insignificant after different liquid exposures and TAP.

Conclusion: TAP and various fluids had a negative impact on the SBS value of ceramic brackets. SBS values, however, were still higher than clinically acceptable (8-9 MPa) values, even after exposure to gastric acid and coke.

Keywords: Shear bond strength, APC II, APC flash-free, ceramic brackets

INTRODUCTION

Porcelain brackets are preferred for a variety of reasons, including their aesthetic appearance, biocompatibility, and magnetic resonance imaging safety.[1] Ceramic brackets, on the other hand, are inert materials that cannot create a chemical bond with the adhesive. Indentations or undercuts are typically placed at the base of the bracket to provide mechanical retention and interlocking.[2] Chemical bonding is not a viable option for porcelain

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brackets because it increases the risk of microcracks on the enamel surface during the debonding process.[3] Therefore, the value of shear bond strength (SBS) gains special importance when it comes to porcelain brackets. The SBS should not be high enough to crack the enamel during debonding. In addition, it should not be so low as to cause bracket failure during treatment.[4]

For decades, various orthodontic adhesive types developed by numerous companies have been compared in *in vivo* and *in vitro* studies.[5] The adhesive is routinely manually placed on the bracket base during the bonding procedure of orthodontic brackets. The excess resin material is then cleaned away by the orthodontist using a dental probe prior to light or chemical curing. Adhesives must provide a good marginal seal without excessive resin around the bracket to avoid white spot lesions or caries. This routine process can result in both adhesive waste and time loss.[6] To simplify and speed up the bonding process, the 3M company (3M Unitek, Monrovia, CA, USA) introduced APC brackets in 1991.[7] The product was later enhanced (less viscous, better handling properties, better blister package, and extended expiration date), and the second generation, APC II, was launched in 2000.[8]

In 2002, the third-generation adhesive precoated (APC) Plus system was created by the manufacturer. Instead of the resin composite, the APC Plus brackets include a pink-colored compomer adhesive at the base that changes color when curing. The compomer material is claimed to release fluoride during treatment and has a stronger tolerance to moisture.[9]

In 2014, APC flash-free brackets, which are the latest generation and do not require the excessive composite cleaning process, were introduced.[10] In this system, each bracket is individually packaged with the optimal amount of adhesive precoated on its base. The brackets are easily adapted to the tooth surface and cured without the need to remove excessive resin. During the fabrication process, the system, which is made of a nonwoven mat saturated with resin adhesive, can be placed at any orthodontic bracket base. The clear, low-viscosity resin forms a channeling border around the bracket's edges when it is forced up against the enamel surface.[11] Less filler resin content, according to some studies, lowers SBS and increases bracket failure.[12] However, the manufacturer asserts an acceptable bond strength of less than 2% bond failure based on internal data.[11] Other features include shorter bonding times and less discoloration around the bracket.[12]

Previous research, which mostly compared APC and regular adhesive systems, didn't look at how different fluids and thermal aging time procedures affected SBS. In the current comparative study, SBS values of APC flash-free porcelain brackets were assessed from a different point of view by exposing them to different liquids and/or thermos-aging procedures (TAP). The first null hypothesis was that the SBS values of APC flash-free, APC II, and conventional ceramic brackets (using the same manufacturer's regular adhesive system) did not differ after exposure to various liquids. The second null hypothesis was that TAP had no effect on SBS values.

METHODS

The current study's research protocol was approved by the Afyonkarahisar Health Sciences University Clinical Research Ethics Committee (approval no.: 2019/361, date: 01.11.2019). The G*Power 3.1.9.2 program (Franz Faul, Universität Kiel, Germany) was used to determine the sample size analysis (α=0.05, 1-β=0.80, and effect size: 0.38) revealed that at least 10 samples were required for each group.

In the current study, 180 human premolar teeth were used. A light microscope (Zumax, OMS2380, China) was used to inspect the enamel surfaces for cracks or fractures. Teeth with caries, fillings, or structural flaws in their crowns were excluded from the study.[13] After extraction, the debris on the teeth's surfaces was immediately removed, and the teeth were kept in the dark in a 0.1 percent thymol solution at the appropriate temperature until the investigation began.[14] The teeth were immersed in the thymol solution for a maximum of 3 months. The solution was renewed monthly.

To perform SBS tests properly, the teeth were embedded in autopolymerizing cylindrical acrylic blocks. The samples were kept in distilled water before progressing to the next stages of the research. Just before the enamel cleaning procedure, the teeth were randomly divided into three major groups, and a low-speed micromotor was used to clean the tooth surface with a rubber brush and fluoride-free paste just prior to bonding brackets. For 30 seconds, all of the crown surfaces of the teeth were etched with 37 percent phosphoric acid. The teeth were washed for 30, and dried for 30 seconds. Trasbond XT primer (3M Unitek, Monrovia, CA, USA) was then applied as a thin layer.

In the first major group, sixty conventional ceramic brackets (3M Unitek, Monrovia, CA, USA) were bonded to the teeth using a Transbond XT (3M Unitek, Monrovia, CA, USA) adhesive. First, the bracket base (mesh type) was covered with adequate adhesive, and it was properly positioned on the tooth surface. Gentle pressure was applied to the bracket with a probe to ensure full contact with the tooth surface, and excess adhesive was removed. The adhesive was polymerized for 3 seconds from the mesial and distal edges using the Valo Ortho Lighting Device (Valo, Ultradent Products Inc., USA) in extra-high power mode (3.200 Mw/cm^2).[15]

In the second major group, 60 APC II ceramic brackets (3M Unitek, Monrovia, CA, USA) were positioned on the teeth surface, and the probe was used to gently press against the brackets. The excess adhesive was removed.

In the third major group, 60 APC flash-free brackets (3M Unitek, Monrovia, CA, USA) were positioned on the teeth surfaces. Light pressure with the probe was used to achieve complete adaptation to the tooth surface. All the teeth in the three groups underwent the same light-curing procedure.

Following bonding, all samples were kept in distilled water at 37 °C for 1 day to complete polymerization.[16] The major groups were then subdivided into six subgroups: Group 1: control; Group 2: only TAP; Group 3: 72 hours of cherry juice exposure + TAP; Group 4:72 hours of coffee exposure + TAP; Group 5: 72 hours of coke exposure + TAP, Group 6: 24 hours gastric acid exposure + TAP. The definitions of the subgroups are shown in Table 1.

Except for the control group, all samples were subjected to an experimental aging protocol using a thermal cycle device (Esetron, MOD Dental, Ankara, Turkey). To simulate temperature changes inside the mouth, the cold tank was set to +5 °C and the hot tank to +55 °C. For each cycle, the samples were kept in each tank for 30 seconds. The transfer time between tanks was 5 seconds. The thermal cycle procedure was completed in 10.000 cycles.[10] This number of cycles corresponded to the 1 year contact time of the adhesive materials in the mouth.[17]

Glass containers for each subgroup were used in this step of the study. Group 3 samples were held in cherry juice for 3 days, Group 4 samples were kept in coffee for 3 days, Group 5 samples were kept in coke for 3 days, and Group 6 samples were kept in artificial gastric acid for 24 hours (Figure 1).[10] To mimic mouth temperature, the temperature of the liquids was set at 37 °C. Daily liquid changes ensured that the results would not be impacted by pH changes. A pH meter (AD12, ADWA, Szeged, Hungary) was used to measure the pH of the liquids. The content, pH value, and exposure time of the liquids used are shown in Table 2.

SBS test and adhesive remnant index (ARI) score

SBS values were measured using a universal test device (Esetron, MOD Dental, Ankara, Turkey). A chisel-edge plunger was placed in the device, and its speed was set to 0.5 mm/min. The acrylic cylinders were positioned on the device's table, and the plunger was moved. When debonding, the computer connected to the test device calculated the smallest force (Newton). By dividing the bracket base area, the force value was converted to megapascals (MPa).

The ARI was used to assess the amount of residual adhesive on the enamel surface following the SBS test. The residual composite on the teeth was scored using the Iidex as defined by Artun and Bergland:[18]

Score 0: The tooth's surface was free of any adhesive.

Table 1. Definition of the subgroups	
Subgroups	**Experimental procedure**
Group 1 (n=10)	No thermal cycle or liquid exposure
Group 2 (n=10)	Only 10.000 thermal aging procedure (TAP)
Group 3 (n=10)	TAP + cherry juice (72 hours)
Group 4 (n=10)	TAP + coffee (72 hours)
Group 5 (n=10)	TAP + coke (72 hours)
Group 6 (n=10)	TAP + gastric acid (24 hours)

Score 1: Less than 50% of the adhesive remained attached to the surface of the tooth.

Score 2: More than 50% of the adhesive remained attached to the surface of the tooth.

Score 3: The total amount of adhesive was still on the tooth.

This procedure was carried out under a light microscope (Zumax, OMS2380, China) by a single researcher to ensure the reliability and reproducibility of the scoring.

Statistical Analysis

The SPSS 22.0 package (IBM, New York, USA) was used to analyze the data. First, the Shapiro-Wilk normality test was performed. The Kruskal-Wallis test and the post-hoc Tamhane test were used for the comparison of SBS values. A chi-square test was used for the comparison of ARI scores. The significance level was set at $p<0.05$.

RESULTS

The comparison results for SBS values are shown in Table 3. In the control group, the SBS value of the conventional brackets was found to be significantly higher than the other two types of brackets ($p<0.01$). In the group (Group 2) in which only the thermal aging procedure was performed, it was found that there was no difference between the bracket types in terms of SBS values ($p=0.223$). Similarly, no significant difference in SBS values was found between the three different brackets in the cherry juice ($p=0.365$), coffee ($p=0.357$), coke ($p=0.573$), and artificial gastric acid ($p=0.387$) groups.

Cherry juice, coke, and gastric acid exposure significantly reduced SBS values in all three bracket types when compared with the control group. While coffee exposure resulted in a significant decrease in SBS values in conventional brackets, it did not cause a significant decrease in the other two groups.

In the subgroup comparison of the ARI scores for each type of bracket, there was no statistically significant difference between

Figure 1. A sample following a 24 h wait in artificial gastric acid

the subgroups (Table 4). In the comparison of the main groups, however, only the control (p<0.05) and cherry juice (p=0.037) groups showed a statistically significant difference.

DISCUSSION

Numerous *in vivo*, *in vitro*, and *ex vivo* studies have been conducted to evaluate the performance of orthodontic adhesives.[12,19] These studies all share the same objective, which is to improve bonding strength and reduce bracket failure. Many factors affect bracket bond strength, including salivary contamination, poor clinician technique, bracket base feature, prepared enamel surface, masticatory forces, and patient diet or behavior.[20] Another cause of bracket failure is the frequent exposure of adhesives to low-pH liquids as a result of soft drink consumption.[21] The reason for the reduction in bonding strength is the softening of the enamel around the bracket or degradation in the adhesive interference. As a result, microleakage occurs between the bracket and the tooth surface, which negatively affects the SBS value.[22] Extrinsic erosive agents such as soft drinks, as well as intrinsic fluids such as stomach acid, may reduce adhesive performance.[23] Because the pH of gastric acid is lower than that of soft drinks, its enamel or adhesive abrasive effect is greater. In some populations, the prevalence of gastroesophageal reflux has increased by up to 50%.[24] According to this point of view, gastric acid is an important intrinsic factor that can negatively influence SBS values. Pace et al.[25] reported that 24% of gastroesophageal reflux patients had dental erosion, and 32.5% of those with dental erosion had reflux. The adhesive's aging is another factor that affects SBS. Orthodontic adhesive ages as the mouth temperature changes during food consumption. Bracket bond strength decreases as the adhesive ages.[10]

Table 2. The content, pH value, and exposure time of the liquids

Product	Ingredients	pH values	Immersion time of the samples
Coffee (Nescafe, Switzerland)	Soluble coffee	5.0	72 hours
Coke (The Coca Cola Company, USA)	Water, sugar, carbon dioxide, colorant, cola extract, caffeine, acidity regulator (phosphoric acid)	2.53	72 hours
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 hours
Artificial gastric acid	0.06 M HCL 0.113% solution in deionized water	1.2	24 hours

Table 3. Comparison of SBS values

Groups adhesive type	Group 1 Mean±SD (MPa)	Group 2 Mean±SD (MPa)	Group 3 Mean±SD (MPa)	Group 4 Mean±SD (MPa)	Group 5 Mean±SD (MPa)	Group 6 Mean±SD (MPa)	p-value
Conventional	23.88±1.50^{Aa}	19.11±3.16^{Ba}	16.22±3.88^{Ba}	17.69 ±3.22^{Ba}	16.30±3.45^{Ba}	15.24±2.63^{Ba}	0.001*
APC II	21.40±1.27^{Ab}	18.99±3.09^{ABa}	16.11±2.99^{Ba}	17.32±3.48^{ABa}	16.24±3.57^{ABa}	15.20±3.84^{Ba}	0.008*
Flash-free	19.94±1.16^{Ab}	16.99±2.67^{ABa}	14.26±3.30^{Ba}	15.44±4.26^{ABa}	14.98±2.10^{Ba}	13.39±3.49^{Ba}	0.002*
p-value	0.001*	0.223	0.365	0.357	0.573	0.387	

*Kruskal-Wallis and post-hoc Tamhane test. In each column and each row, different superscripts (uppercase for row and lowercase for column) indicate a statistically significant differences between groups (*p<0.05).
SBS, shear bond strength; SD, standard deviation; MPa, megapascal; Group 1, Control; Group 2, only TAP (thermal aging procedure); Group 3, 72 hours of cherry juice exposure + TAP; Group 4, 72 hours of coffee exposure + TAP; Group 5, 72 hours of coke exposure + TAP; Group 6, 24-hour gastric acid

Table 4. Comparison of ARI scores

			ARI 0	ARI 1	ARI 2	ARI 3	p-value
	APC II	Count	$6_{a, b}$	$10_{a, b}$	35_{b}	9_{a}	
		% within bracket	10.0%	16.7%	58.3%	15.0%	
	Conventional	Count	0_{a}	3_{a}	23_{a}	34_{b}	
		% within bracket	0.0%	5.0%	38.3%	56.7%	
	Flash-free	Count	$8_{a, b}$	18_{b}	$23_{a, c}$	11_{c}	
		% within bracket	13.3%	30.0%	38.3%	18.3%	
Total		Count	14	31	81	54	
		% within bracket	7.8%	17.2%	45.0%	30.0%	0.01*

*Chi-square test results. Each subscript letter denotes a subset of ARI categories whose column proportions do not differ significantly from each other at the 0.05 level.
ARI, adhesive remnant index

In many studies, flash-free brackets have been compared to non-coated brackets.[10] In these studies, variables such as enamel demineralization, periodontal condition, microleakage, and debonding pain were investigated in addition to SBS. To our knowledge, the current study is the first to compare the effects of different fluids on the SBS strength of APC flash-free brackets with other brackets. According to the literature, the exposure times of resin materials to various liquids range from 1 day to 1 month.[26] Considering the average years of orthodontic treatment, the exposure time for sour cherry juice, coke, and coffee was determined to be 72 hours. However, because the pH of gastric acid is less than 2.0, the exposure time was limited to 24 hours.[12] Aldamaty et al.[27] exposed ceramic surfaces to gastric acid for 96 hours, simulating 10 years of intraoral exposure. In the current study, considering that orthodontic treatments last for an average of 2 years, the samples were kept in gastric acid for 24 hours.[28]

The adhesive used to bond conventional brackets, as well as the adhesive precoated on the base of APC II brackets, had the same content as in the current study. The adhesive on the flash-free bracket base, on the other hand, has a spongy, non-woven-mat structure. It also has a relatively low viscosity due to its lower filler content.[10] Faltermeier et al.[29] reported that low-viscosity adhesives reduce SBS value and increase bracket failure.

The first and second null hypotheses of the current study were rejected. Only in the control group were the SBS values of conventional brackets found to be statistically significantly higher than those of precoated brackets in the current study. This finding was consistent with those of Bearn et al.[30] However, this study found no significant difference in SBS values between groups after exposure to TAP and different liquids. Similar studies in the literature have reported a variety of outcomes. Marc et al.[31] found no statistically significant differences between precoated and non-coated brackets. Alakttash et al.[32] found no difference in the bond failure rate between precoated and non-coated brackets in their systematic review and meta-analysis study. In a systematic review study by Thanetchaloempong et al.,[33] it was reported that the SBS of precoated and non-coated brackets was similar. In the systematic review and meta-analysis study by Wang et al.,[6] there were also no significant differences in bond failure rates between the two bracket types. Inconsistent results found in the literature could be because of different factors that affect the bonding process, such as the type of bracket used, the enamel etching protocol, the tooth structure, and the polymerization protocol. In the current study, there was no statistically significant difference between the subgroups in the comparison of the ARI scores for each type of bracket. However, only the control and cherry juice groups showed a statistically significant difference when the main groups were compared. Foersch et al.[11] found that ARI scores did not differ significantly between the APC flash-free and APC Plus groups. According to Grünheid and Larson[15] APC flash-free adhesives had higher ARI scores than conventional adhesives. However, they claimed that APC adhesive removal times were 22.2% faster than conventional adhesive removal times. A high ARI score indicates that there has been a failure between the bracket base and the adhesive, or within the adhesive itself. The fact that the adhesive remains on the enamel surface can be viewed as a benefit, as this reduces the risk of enamel surface damage, especially with porcelain brackets. The inconsistency in ARI score findings across studies may be due to differences in the etching procedure, light-curing method, and bracket type (metal or porcelain).

Study Limitations

One of the study's limitations is that it was conducted *in vitro*, and saliva buffering not being replicated. In addition, the effect of microbial flora on adhesive performance is unknown. More *in vitro* and *in vivo* studies with more samples are needed to generalize the results.

CONCLUSION

TAP and fluids had a negative impact on the SBS value of each type of ceramic bracket. Even after exposure to gastric acid and coke, the SBS values of all three types of brackets were still higher than a clinically acceptable value. Despite their low-viscosity resin structure, flash-free brackets had a satisfactory SBS value.

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Ethics

Ethics Committee Approval: The Afyonkarahisar Health Sciences University Clinical Research Ethics Committee approved the study protocol (approval no.: 2019/361, date: 01.11.2019).

Informed Consent: Written consent for publication was obtained from each participant.

Author Contributions: Surgical and Medical Practices - H.C., Ş.C.Ç.; Concept - H.C.; Design - H.C.; Data Collection and/or Processing - H.C., Ş.C.Ç.; Analysis and/or Interpretation - H.C., Ş.C.Ç.; Literature Review - H.C., Ş.C.Ç.; Writing - H.C.

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