

# Effects of Antioxidants on the Shear Bond Strength of Orthodontic Brackets Bonded to Bleached Human Teeth: An *In Vitro* Study

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## ABSTRACT

**Aim:** The aim of this study was to evaluate the effects of different concentrations of sodium ascorbate (SA), green tea (GT), and chamomile (CM) on the shear bond strength (SBS) of metal orthodontic brackets bonded to teeth bleached with 40% hydrogen peroxide (HP).

**Materials and methods:** Ninety-four sound premolars were divided into eight groups: group I (control + no bleaching), group II (bleaching + immediate bonding), group III (bleaching + 10% SA), group IV (bleaching + 35% SA), group V (bleaching + 0.5% GT), group VI (bleaching + 1% GT), group VII (bleaching + 0.5% CM), and group VIII (bleaching + 1% CM). In groups III–VIII, teeth were treated with the antioxidants for 10 minutes after bleaching with 40% HP, but before bonding. All the specimens were bonded with the resilience adhesive, and the SBS was tested with a universal testing machine (Instron 5965). The cross-head speed to break the bond was 1 mm/minute. The adhesive remnant index (ARI) was tested under 50× magnification. One-way analysis of variance, Tukey's *post hoc*, and Chi-squared tests were used for analysis ( $p \leq 0.05$ ).

**Results:** The differences in SBS among the eight tested groups were highly significant ( $p < 0.001$ ). Comparison of the eight groups using Tukey's *post hoc* test revealed significantly lower SBS ( $p < 0.001$ ) in test groups II, III, IV, and VIII than in group I. Adhesive remnant index scores showed significant intergroup differences ( $p = 0.005$ ). Most groups had a failure score of 1 (<50% of the bonding material adhering to the tooth), whereas groups II and VIII showed a failure score of 0 (no material adhering to the tooth).

**Conclusion:** Bond strength can be enhanced by using 0.5% or 1% GT or 0.5% CM to allow bracket bonding immediately after bleaching.

**Clinical significance:** The use of antioxidants would allow clinicians to bleach teeth before orthodontic treatment without delaying bonding.

**Keywords:** Bleaching, Chamomile extract, Green tea, Metal orthodontic bracket, Shear bond strength, Sodium ascorbate.

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## INTRODUCTION

Tooth discoloration is considered to be a significant esthetic issue in orthodontic treatment, and orthodontists occasionally encounter patients who report issues with the placement and color of their teeth.<sup>1</sup> Vital tooth bleaching using peroxide compounds of various concentrations is a well-accepted and safe method for treating tooth discoloration.<sup>2</sup> However, the changes in the enamel composition and structure caused by these bleaching materials can reduce the shear bond strength (SBS) of orthodontic brackets.<sup>3</sup> This adverse effect of bleaching on adhesive bonding is temporary and reversible and depends on the interval between the two procedures. However, changes caused by bleaching are undesirable, necessitating delaying of bonding by 7–14 days.<sup>4</sup> The reduced bond strength could be attributed to residual oxygen molecules trapped in the enamel structure, which prevent resin tags from fully penetrating and interlocking the tubules,<sup>4,5</sup> or the residual peroxides from the bleaching reaction that inhibit complete polymerization of the composite.<sup>6,7</sup> Compromised bond strength between the adhesive and bleached teeth has been documented in many studies.<sup>1,3,8–15</sup>

Delaying treatment after bleaching is not always practical, as many patients who have traveled from distant areas or have other commitments may require rapid treatment. To avoid these delays, application of various antioxidants either in gel or solution form has been proposed and investigated in many studies.<sup>8–15</sup> The efficiency of sodium ascorbate (SA) in reversing the reduced bond strength in bleached enamel has been proven in many studies,<sup>11–15</sup> although few studies have indicated that SA was ineffective when applied

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for 10 minutes.<sup>9,10</sup> Other antioxidants, such as 10%  $\alpha$ -tocopherol,<sup>9</sup> *Aloe vera*,<sup>12</sup> pine bark extract,<sup>13</sup> and grape seed extract,<sup>14</sup> have also shown effectiveness in reversing the bond strength reduction in bleached enamel. A few recent studies reported that 10% green tea (GT) had a satisfactory effect in reversing the SBS reduction

in bleached enamel after an application time of 60 minutes to 2 hours.<sup>14-16</sup> In the literature, several studies have assessed the effect of natural antioxidants on bleached enamel. However, there has been no report on the impact of chamomile (CM) on bleached enamel in the orthodontic literature.

The exact duration of antioxidant application to achieve complete recovery of the bond strength to baseline levels has shown multiple inconsistencies in the literature. The application time required for a full recovery to the baseline SBS level has been reported to range from 2 minutes to 2 hours.<sup>17-21</sup> Some studies have claimed that the increase in SBS following antioxidant application after bleaching was directly related to the application time,<sup>17,19,21</sup> whereas other studies have reported that the optimal application time of antioxidants is 10 minutes, with no significant increase in SBS seen subsequently.<sup>20,21</sup> Furthermore, studies have reported inconsistent findings with regard to complete reversal of bond strength to baseline levels after 10 minutes of application. The clinical objective of using antioxidants immediately for a shorter period after bleaching is to neutralize the negative effect of bleaching. This can improve the efficiency of clinical chair time and facilitate the treatment process for orthodontic patients who require bonding immediately after in-office bleaching.

We aimed to measure the changes in SBS of metal brackets immediately bonded to teeth after bleaching with 40% hydrogen peroxide (HP). Additionally, the study aimed to assess the efficacy of various antioxidant agents with different concentrations on the SBS of the orthodontic bracket bonded to the bleached enamel surface. Therefore, the null hypothesis tested was that there is no difference in the reversal of SBS after application of 10% and 35% SA solutions, 0.5% and 1% GT extracts, as well as 0.5% and 1% CM extracts.

## MATERIALS AND METHODS

Approval for this study was obtained from the Institutional Review Board of the research center (research project no. E-18-3216, CDRC no. IR 0282). A total of 94 premolars extracted for orthodontic treatment were obtained from private clinics and the oral surgery clinic of the College of Dentistry at King Saud University. The teeth were examined and excluded if they showed any of the following findings: caries, fracture, restoration, cracks, gross irregularities, hypoplasia, or hypocalcification. We included intact teeth with sufficient root length to allow mounting of the tooth in acrylic resin. Blood and tissue debris were cleaned from the teeth, and the teeth were stored in 0.025% thymol solution until all samples were collected. The sample size was determined by using data from previous studies.<sup>1,8,13</sup> A nonprobability purposive sampling technique was used. Sample power analysis designated that 12 teeth per group would result in an 89% chance of obtaining significance at the 0.05 level.

### Specimens

Ninety-four teeth were mounted vertically in self-cured acrylic jigs keeping the crowns exposed. Subsequently, they were randomly divided, 10 teeth in the control group and 12 teeth in seven study groups, as presented in Table 1 and Figure 1.

### Bleaching

The teeth were bleached using 40% HP (Opalescence Boost, Ultradent Products Inc., South Jordan, UT, USA) according to the manufacturer's instructions. First, the collected teeth were washed

**Table 1:** Treatment regimen groups

Groups	Treatment regimen
Group I	Control, no bleaching was performed; the bracket was bonded to enamel
Group II	Bleaching with 40% HP, after which the bracket was bonded to enamel
Group III	Bleaching with 40% HP + 10% SA, after which the bracket was bonded to enamel
Group IV	Bleaching with 40% HP + 35% SA, after which the bracket was bonded to enamel
Group V	Bleaching with 40% HP + 0.5% GT extract, after which the bracket was bonded to enamel
Group VI	Bleaching with 40% HP + 1% GT extract, after which the bracket was bonded to enamel
Group VII	Bleaching with 40% HP + 0.5% CM extract, after which the bracket was bonded to enamel
Group VIII	Bleaching with 40% HP + 1% CM extract, after which the bracket was bonded to enamel

HP, hydrogen peroxide; SA, sodium ascorbate; GT, green tea; CM, chamomile



**Fig. 1:** Teeth mounted in self-cure acrylic jigs

with water and then polished with pumice and water for 10 seconds using a low-speed rubber cup. Next, they were sprayed with water for 30 seconds, followed by air drying for 15 seconds. Bleaching gel was applied with the graduated syringe from the bleaching kit to the buccal surface for 20 minutes. The gel was periodically checked and reapplied every 5 minutes in areas that had only a thin layer or needed replenishing. Subsequently, the gel was suctioned using a surgical suction tip and rinsed thoroughly with air/water spray with high-volume suction. In group II (bleached), the bracket was immediately etched and bonded as in group I (control). However, in groups III–VIII, the bracket was first treated with the respective antioxidant solution (Fig. 2).

### Postbleaching Antioxidant Treatment

The antioxidants used to reverse the reduction in SBS were SA, GT, and CM (Fig. 3).

### Preparation of SA

- Two different concentrations of SA were prepared (35% and 10% w/v) in distilled water containing 0.5% low molecular weight chitosan to improve the contact time between the solution and the tested tooth.
- Sodium ascorbate was prepared by mixing solutions containing equimolar concentrations of ascorbic acid and sodium bicarbonate in a 100 mL flask containing 50 mL of distilled water. The reaction was allowed to take place by stirring with a magnetic stirrer until the cessation of effervescence.

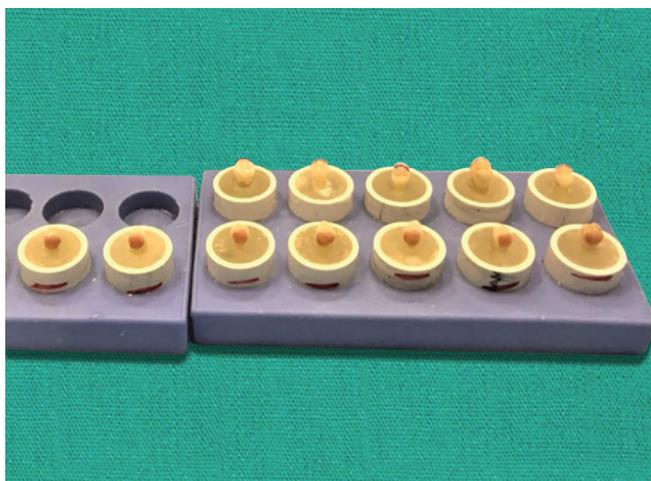


Fig. 2: Bleaching of teeth with 40% hydrogen peroxide

- The solution was then filtered, and the volume was completed by addition of distilled water containing 1% low molecular weight chitosan to bring the chitosan concentration to 0.5%.
- The prepared solutions were collected in tightly closed amber glass containers and stored at 5 C pending their use.

### Preparation of Herbal (German CM and GT) Extract Solutions

- German CM (*Matricaria chamomilla* flowers) and GT (*Camellia sinensis* leaves) powder extracts were each prepared in two different concentrations (0.5% and 1.0% w/v) in distilled water containing 0.5% low molecular weight chitosan to improve the contact between the solution and the tested tooth.
- An accurately weighed amount of the herbal powdered extract was dissolved in distilled water (50 mL).
- The volume of the solution was adjusted by addition of 1% low molecular weight chitosan to bring the chitosan concentration to 0.5%.
- The prepared solutions were collected in tightly closed amber glass containers and stored at 5 C pending their use.

Following the bleaching procedures, 1 mL of the antioxidant solution was spread on the buccal surface for 10 minutes, with two applications during this time. Then, the surface was cleaned with water for 30 seconds and dried for 15 seconds. In groups III and IV, the buccal surface was treated with 10% and 35% SA solutions, respectively. In groups V and VI, the buccal surface was treated with 0.5% and 1% GA extract solutions, respectively. In groups VII and VIII, the buccal surface was treated with 0.5% and 1% CM extract solutions, respectively.

### Bracket Bonding

Ninety-four stainless steel preadjusted edgewise bicuspid brackets with 0.022-inch slots (Lancer Orthodontics, Vista, California, USA) were used in the present study. The bracket base was microetched and had a surface area of 12.65 mm<sup>2</sup>. The orthodontic brackets were stored in the manufacturer's packaging to avoid any contamination, and they were always held with bonding tweezers. The composite resin used to bond the brackets was light-curable (Resilience LC Orthodontic Adhesive, Ortho Technology, Florida, USA).



Fig. 3: Antioxidants used in the study

We followed the recommended manufacturers' procedures for bonding; the buccal surfaces of the teeth were cleaned with pumice for 5 seconds, washed for 10 seconds, and finally dried for 10 seconds using an air-water syringe. Etching of the buccal surface of the teeth was performed with 37% phosphoric acid for 30 seconds, after which the teeth were washed for 10 seconds and air-dried for 10 seconds. Then, a layer of primer was spread on the buccal surface and light cured for 10 seconds, and the resilience adhesive was applied at the bracket base. Next, the brackets were placed on the tooth surface and pressed firmly until they adhered to the tooth. Subsequently, the extra resin pressed out was removed from around the bracket. The specimens were then light cured for 40 seconds (20 seconds on any opposing surfaces). The specimens were kept in distilled water in a sealed container at room temperature for 1 day before debonding (Fig. 4).

### Testing of SBS

A universal testing machine (Instron 5965 series, North America) with a 1 KN load cell and a cross-head speed of 1 mm/minute was used for SBS testing. After bonding, all the teeth were stored in distilled water for 24 hours at room temperature. After 24 hours, each specimen was positioned in the universal testing machine, and the bracket base was aligned parallel to the direction of the shear force. The upper section of the machine was loaded with a chisel-shaped blade that was positioned in an occlusogingival direction in contact with the bonded area of the specimen. Shear bond strength was determined in the shear mode at a cross-head speed of 1 mm/minute until debonding occurred. The values of SBS were recorded and converted into megapascal (MPa) by dividing the failure loads (Newton) by the surface area of the bracket base (mm<sup>2</sup>; Fig. 5).

### Adhesive Remnant Index

A digital microscope with ×50 magnification (KH-7700; Hirox, NJ, USA) was used to determine where the failure occurred and the extent of remaining adhesive on the enamel. Adhesive remnant index (ARI) scores at the failure area were recorded in accordance with the study by Artun and Bergland<sup>22</sup> (Table 2).

Finally, the clinical waste management system at the Dental University Hospital was used to discard all teeth samples. Extracted teeth remaining after completion of the research were discarded according to the Occupational Safety and Health Administration



Fig. 4: Bonding of bracket (unbleached and bleached groups)

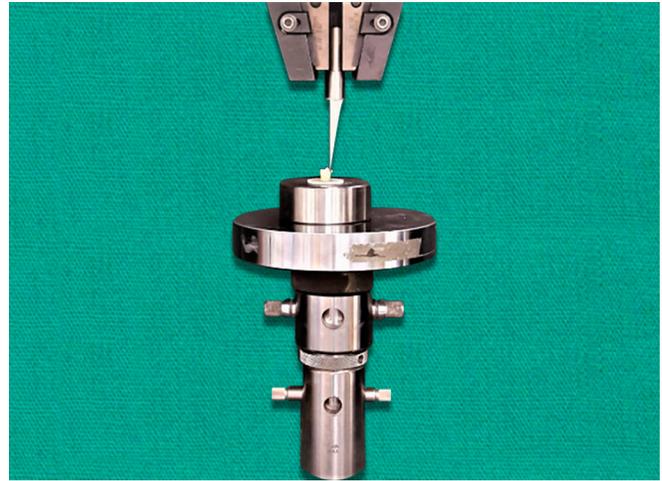
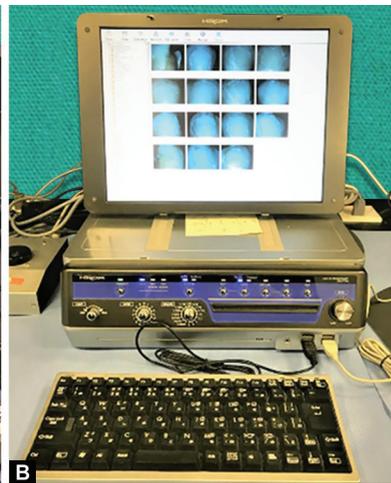


Fig. 5: Occlusogingival load applied to the bracket using Instron machine



Figs 6A and B: (A) Digital electronic microscope connected with (B) digital camera to examine the adhesive remnant index

Table 2: The adhesive remnant index\*

Index score	Enamel adhesive remnant
0	No adhesive left on the enamel
1	Less than 50% of adhesive left on the enamel
2	More than 50% of adhesive left on the enamel
3	All adhesives left on the enamel

\*Artun and Bergland<sup>22</sup>

Bloodborne Pathogens Standard. Occupational Safety and Health Administration considers extracted teeth to be potentially infectious material that should be disposed of in medical waste containers (Fig. 6).

### Statistical Analysis

Statistical analysis of the obtained data for the eight experimental groups was performed using statistical package for social science software (SPSS), version 24.0 (SPSS Inc., Chicago, IL, USA) was used, and statistical significance set at  $p < 0.05$ . Significant differences among the mean SBS values of the eight groups were determined

using one-way analysis of variance. If significant differences were present, Tukey's *post hoc* comparison test was used to determine which of the mean values were significantly different from each other. The Chi-squared test was used to compare ARI scores among the groups.

### RESULTS

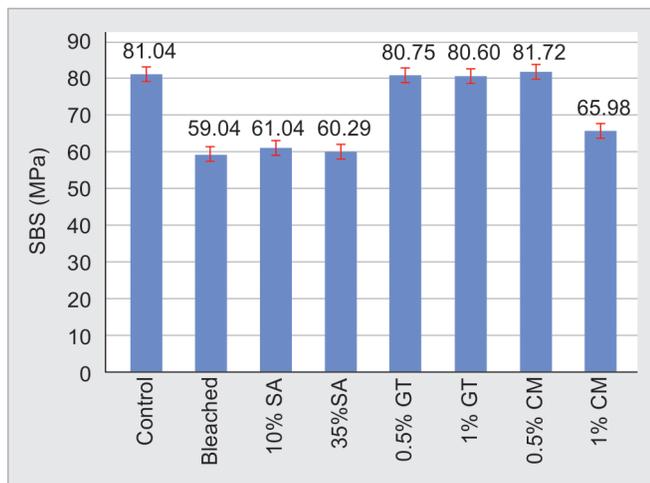
All data were tested with Shapiro–Wilk analysis and demonstrated a normal distribution ( $p = 0.518$ ). The SBS values for each group are detailed in Table 3. These descriptive statistics indicate the variations in SBS among the eight groups, with the maximum values observed in group I (control) and group VII (0.5% CM) and the minimum value observed in group II (bleached). Groups III (10% SA), IV (35% SA), and VIII (1% CM) showed some improvement in SBS. However, groups VII (0.5% CM), VI (1% GT), and V (0.5% GT) showed notable improvement in SBS. The SBS values were significantly different among the eight groups ( $p = 0.000$ ; Fig. 7).

The data for the eight groups were further analyzed using Tukey's *post hoc* test (Table 4). The results indicated that the SBS of brackets bonded immediately after bleaching with 40% HP was significantly lower than that of the control group ( $p = 0.000$ ). Comparison of the control group with the groups treated with

**Table 3:** Mean, standard deviation, and confidence interval of the shear bond strength (SBS) in MPa, and one-way analysis of variance for intergroup comparisons

Groups	No.	SBS (MPa)		p value	95% confidence interval	
		Mean	SD		Lower value	Higher value
I	10	81.04	6.54	0.000*	76.36	85.72
II	12	59.04	5.83		55.34	62.75
III	12	61.04	8.36		55.76	66.35
IV	12	60.29	7.02		55.83	64.75
V	12	80.75	8.66		75.25	86.25
VI	12	80.60	6.20		76.65	84.54
VII	12	81.72	5.22		78.41	85.04
VIII	12	65.98	6.27		62.00	69.97

Group I indicates control; group II, hydrogen peroxide bleached; group III, 10% sodium ascorbate; group IV, 35% sodium ascorbate; group V, 0.5% green tea; group VI, 1% green tea; group VII, 0.5% chamomile; and group VIII, 1% chamomile. \* $p \leq 0.05$



**Fig. 7:** Shear bond strength values of the treatment groups. SA, sodium ascorbate; GT, green tea; CM, chamomile

antioxidants revealed significant differences between the SBS values in the control group and the groups treated with 10% SA, 35% SA, and 1% CM ( $p = 0.000$ ,  $p = 0.000$ , and  $p = 0.001$ , respectively). However, the SBS values of the groups treated with 0.5% and 1% GT and 0.5% CM were not significantly different from the control group. This indicated that antioxidant treatment with 0.5% or 1% GT or 0.5% CM was significantly effective in increasing the SBS of brackets bonded to bleached enamel.

The frequency distribution of ARI scores is presented in Table 5. Significant intergroup differences ( $p = 0.005$ ) were noted in the Chi-squared comparisons. The control, 10% SA, 35% SA, 0.5% GT, 1% GT, and 0.5% CM groups showed a higher frequency of failure sites with an ARI index score of 1, which indicated that the failure showed cohesive characteristics (some adhesive was left on the tooth and bracket base). In contrast, the bleached group and the 1% CM group showed a higher frequency of failure sites with an ARI index score of 0.

## DISCUSSION

The present study aimed to assess the effects of treatment with different concentrations of SA, GT, and CM on the SBS of metal orthodontic brackets bonded to teeth bleached with 40% HP. The results showed that 1% GT, 0.5% GT, and 0.5% CM were capable of

restoring the SBS of bleached enamel bonded to metallic brackets immediately after bleaching with 40% HP. However, 10% SA, 35% SA, or 1% CM could not restore the SBS. Therefore, the study (or null) hypothesis was rejected.

Several studies have examined the interaction between HP and the SBS of a metal bracket bonded to bleached enamel. A decrease in the SBS of brackets bonded to enamel immediately after bleaching with 35–38% HP has been documented.<sup>3,9,14,17–24</sup> In this study, a pronounced reduction in SBS was noted in specimens that were treated with 40% HP and immediately subjected to bracket bonding. However, the reported adverse impact of bleaching materials on the SBS of brackets has been contradicted in the results obtained by Bishara et al.<sup>25</sup> and Uysal and Sisman.<sup>26</sup> These investigators showed that bleaching with 35% HP or 10% hydrogen carbamide did not affect or reduce the SBS of an orthodontic bracket to the enamel. The decrease in SBS caused by HP after bleaching could be related to changes in the extent of roughness of the enamel surface and structural changes caused by the loss of prismatic formation prismatic formation<sup>4</sup> or alterations in the organic material,<sup>27</sup> loss of calcium, and a decrease in microhardness.<sup>28</sup> Furthermore, the residual oxygen that is leached from the bleaching agent inhibits resin infiltration into the bleached enamel or impedes resin polymerization.<sup>22,28</sup> The use of antioxidants eliminates the remaining oxygen in the enamel structures immediately after bleaching, thereby enabling immediate bonding of the brackets.<sup>8–15</sup>

Sodium ascorbate is a sodium salt of ascorbic acid that shows effective antioxidant ability and is capable of neutralizing and reversing the oxidant effect of bleaching agents in dental structures.<sup>3,5,8–17</sup> Several studies have proven that 10% SA treatment of bleached teeth for 10 minutes before bonding of brackets reduces the degree of SBS reduction,<sup>5,23,24</sup> and another study found that application of 35% SA for 2 minutes was effective and proved beneficial.<sup>18</sup> However, the effects of different concentrations and application protocols of SA have remained a matter of debate. Therefore, the effects of two concentrations of SA (10% and 35%) were assessed. We proposed that 10% SA might not be effective as 35%, because a higher concentration of the material may increase its efficacy; therefore, we performed experiments with 35% SA. The time of application of SA for complete recovery of bond strength to bleached enamel has been reported to range from 1 minute to 120 minutes. However, longer application times were found to have no impact on the effectiveness of the SA-mediated reaction, and an application time of 5–10 minutes is sufficient.<sup>29</sup>

**Table 4:** Comparison of shear bond strength values among the eight treatment groups

Groups	Multiple comparison test (Tukey's post hoc test)							
	I	II	III	IV	V	VI	VII	VIII
I	1							
II	0.000*	1						
III	0.000*	0.999	1					
IV	0.000*	0.999	1.000	1				
V	0.999	0.000*	0.000*	0.000*	1			
VI	0.999	0.000*	0.000*	0.000*	0.881	1		
VII	0.999	0.000*	0.000*	0.000*	0.878	0.999	1	
VIII	0.001*	0.528	0.871	0.762	0.001*	0.001*	0.000*	1

Group I, control; group II, hydrogen peroxide bleached; group III, 10% sodium ascorbate; group IV, 35% sodium ascorbate; group V, 0.5% green tea; group VI, 1% green tea; group VII, 0.5% chamomile; group VIII, 1% chamomile. \* $p \leq 0.05$

**Table 5:** Frequency distribution (%) of adhesive remnant index (ARI) scores in the treatment groups

Groups	n	ARI score numbers (%)				Chi-square (df)	p value
		0	1	2	3		
I	10	0 (0)	6 (60)	2 (20)	2 (20)	41.26 (21)	0.005*
II	12	7 (58.3)	5 (41.7)	0 (0)	0 (0)		
III	12	5 (41.7)	7 (58.3)	0 (0)	0 (0)		
VI	12	3 (25)	8 (66.7)	1 (8.3)	0 (0)		
V	12	2 (16.7)	10 (83.3)	0 (0)	0 (0)		
VI	12	3 (25)	9 (75)	0 (0)	0 (0)		
VII	12	3 (25)	8 (66.7)	0 (0)	1 (8.4)		
VIII	12	7 (58.3)	4 (33.3)	0 (0)	1 (8.4)		
Total	94	30 (32)	57 (60.6)	3 (3.2)	4 (4.2)		

ARI scores: 0 indicates no adhesive on enamel; (1) <50% of adhesive left on enamel; (2) >50% of adhesive left on enamel; (3) 100% of adhesive left on enamel. Group I indicates control; group II, hydrogen peroxide bleached; group III, 10% sodium ascorbate; group IV, 35% sodium ascorbate; group V, 0.5% green tea; group VI, 1% green tea; group VII, 0.5% chamomile; group VIII, 1% chamomile. \* $p \leq 0.05$

Therefore, an application time of 10 minutes was fixed for all antioxidant treatment study groups.

The results showed that the SBS values of bonded brackets applied after SA treatment following bleaching were not different from the corresponding values for brackets bonded after bleaching without antioxidant treatment. Therefore, we concluded that 10% SA or 35% SA might not reverse the effects of the bleaching agent. This contradiction in comparison with the findings of previous studies may be attributable to methodological differences among studies, such as the type and concentration of bleaching agent, type and preparation of the antioxidant, or the antioxidant application technique. The application of a high concentration of peroxide or extended exposure to the bleaching agent could reduce the effectiveness of SA.<sup>19,30</sup> Previous studies reporting the effectiveness of SA in reversing bond strength reductions used carbamide peroxide at low concentrations.<sup>5,8,9,19,20,26,31</sup> Thus, it is possible that SA was more effective in teeth bleached with carbamide peroxide because HP releases high levels of oxygen radicals.<sup>30</sup> In contrast, 10% carbamide peroxide releases 3% HP and 7% urea,<sup>32</sup> which is 10 times lower than the radicals released by 35% HP. These differences in the kinetic degradation of different types of bleaching agents may affect the antioxidant ability of SA.

Green tea powder extracts were prepared from the leaves of *C. sinensis*, which is rich in flavonoids and catechins. Green tea has been shown to have strong antioxidant ability that is many times higher than that of ascorbic acid and  $\alpha$ -tocopherol.<sup>33</sup> This highly potent antioxidant ability of GT has been linked to catechins, which

could provide hydrogen molecules with free radical scavenging ability from the hydroxyl groups in their structure.<sup>34</sup> Studies assessing the antioxidant effects of GT solution have reported that a 60-minute application of 10% GT gel immediately after bleaching restored composite bonding strength to bleached enamel.<sup>14,15</sup> However, shorter application periods are necessary for clinical use.

Green tea was prepared at two different concentrations (0.5% and 1.0%) and applied for 10 minutes. The bond strength values in the GT-treated groups were statistically similar to those in the control group. However, they were significantly higher than those in the bleached group and the groups treated with 10% SA, 35% SA, or 1% CA. Previous studies on the bond strength to bleached enamel found that GT has a significantly greater effect on enamel bond strength than SA.<sup>14,15,34</sup> These findings could be explained by the hypothesis that GT, through its free radicals, eradicates the residual oxygen within the enamel after bleaching, which interferes with resin bonding and polymerization, thereby enabling the adhesive process to be completed immediately after bleaching.

The main components of German CM (*M. chamomilla*) include several phenolic compounds and the flavonoids apigenin and quercetin. The antioxidant properties of apigenin and quercetin have been extensively verified.<sup>31,35</sup> In the literature, several studies have proven the clinical efficiency of CM as a mouth wash in reducing gingival inflammation,<sup>36</sup> as an intracanal smear layer irrigant,<sup>37</sup> and as a topical application in burning mouth syndrome.<sup>38</sup> However, there are no studies appraising the effect of CM on the SBS of orthodontic brackets. In the current study,

CM was evaluated as an alternative to SA and GT. It was prepared from *M. chamomilla* flowers at two different concentrations (0.5% and 1.0%) and applied for 10 minutes. The bond strength values in the 0.5% CM group were statistically similar to those in the control group, but 1% CM could not reverse the bond strength of the bracket. An optimal concentration of CM is desirable to achieve the required SBS for orthodontic brackets. The CM essential oil contains other components such as bisabolol oxide, chamazulene, farnesene, spathulenol, and spiroether. The hydrophobic nature of these components may have reduced the SBS of the orthodontic brackets above the optimal concentration (0.5%).<sup>39</sup>

The ARI index is a well-known and widely used index for research purposes. It is used to identify the remaining amount of adhesive on the teeth<sup>22</sup> and to describe the site of bond failure (enamel, adhesive, or bracket base).<sup>40</sup> In this study, the results showed that the 10% SA, 35% SA, 0.5% GT, 1% GT, and 0.5% CM groups had a failure pattern similar to the control group. Most bond failures had an ARI score of 1, which can be interpreted as a greater amount of adhesive adhering to the bracket base and a smaller amount of adhesive remaining on the tooth structure. Bond failures in the adhesive or at the bracket–adhesive interface are preferable because they reduce the stress of the shear force at the enamel surface and protect the enamel surface from any damage.<sup>40</sup> The findings in the present study are in accordance with the results of earlier studies.<sup>1,14,26</sup> In contrast, the bleached group and the 1% CM group showed a greater frequency of ARI scores of 0, referring to failures at the enamel–resin interface. These failures indicate a weak interaction of the tooth structure with the bonding material, which can result in a low SBS.<sup>26</sup>

This study had several limitations. The findings of an *in vitro* study cannot ultimately represent clinical conditions and cannot be generalized to other brands of the materials used. To increase the power of the study, the sample size could have been increased. However, we tried to improve the reliability of the results by employing different concentrations of each type of antioxidant and fixing the time of application of the antioxidants to 10 minutes. Moreover, we used the ceiling of the controversial range of suggested values for acceptable bond strengths (70–100 MPa) to improve the confidence in the positive results.<sup>5,9,17</sup>

## CONCLUSION

- Bleaching of human teeth with 40% HP adversely affected the SBS of orthodontic brackets bonded to enamel.
- Treatment with 0.5% CM, 0.5% GT, and 1% GT immediately following bleaching with 40% HP reversed the SBS to the baseline level. This could be beneficial in ensuring successful bonding immediately after bleaching.
- Treatment of bleached enamel before bonding with 10% SA, 35% SA, and 1% CM did not significantly affect the reversal of the reduction in the SBS between metal orthodontic brackets and bleached enamel.
- The use of antioxidants would allow clinicians to bleach teeth before orthodontic treatment without delaying bonding.

## CLINICAL SIGNIFICANCE

Considering the increasing number of adults seeking orthodontic treatment with bleaching, this study indicates that antioxidants may be used to reverse the reduction in the SBS of orthodontic

brackets after bleaching. This treatment would allow orthodontists to avoid postponing the bonding procedure after bleaching without affecting the mechanical and physical integrity of the bond formation.

## ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study was approved by the Institutional Review Board of the research center (research project no. E-18-3216) and the Ethics Committee of the College of Dentistry Research Center at King Saud University (CDRC No. IR 0282).

## AVAILABILITY OF DATA AND MATERIALS

The data sets used and/or analyzed during the present study are available from the corresponding author on request.

## AUTHOR CONTRIBUTIONS

All the authors have read and approved the final manuscript. Laila Baidas contributed to the conception and design of the study, analysis/interpretation of the data, agreed to be accountable for all aspects of the work, and ensure questions related to the accuracy or integrity of any part of the work were appropriately investigated and resolved, involved in writing the manuscript, and approved the final version to be published. Noura Al-Rasheed and Rufaidah Murad contributed to data collection, agreed to be accountable for all aspects of the work, was involved in drafting the manuscript, and approved the final version to be published. Mohammad Abbas Ibrahim contributed to the preparation of the required solutions, was involved in conception and design of the study and interpretation of the data, and approved the final version to be published.

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