

The effect of thermocycling and debonding time on the shear bond strength of different orthodontic brackets bonded with light-emitting diode adhesive (In vitro study)

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ABSTRACT

Background: Thermocycling simulates the temperature dynamics in the oral environment. This in vitro study done to measure and compare the effect of thermocycling on the shear bond strength of stainless steel and sapphire brackets bonded to human enamel teeth using light cured orthodontic adhesive and debonded at various time, and to measure adhesive remnant index after debonding.

Materials and Methods: one-hundred-twenty extracted upper first premolars for orthodontic reason were used in this study; depending on weather thermocycled or not, the sample was divided into two main groups, then within each group 30 teeth were used for stainless-steel brackets (Bionic®) and for sapphire brackets (Pure®). Both groups were subdivided into three groups (n = 10) according to the debond times: I: debond after 24 hour, II: debond after 7 days and III: debond after 30 days. Within 24 hr, half of the sample was thermocycled manually for 500 complete cycles between 5/55°C and the remaining sample was stored in distilled water at room temperature and water was changed daily until debond time for each group was performed. The adhesive remnant index was tested under 20X magnification lens using stereomicroscope.

Results and Conclusions: Both bracket types demonstrated high shear bond strength values before thermocycling ($P \leq 0.05$), whereas after 500 thermocycles, there were significant changes in shear bond strength resulted in marked reduction in the stainless steel brackets than in the sapphire brackets ($P \leq 0.05$). Shear bond strength values increased with time for both stainless steel and sapphire brackets with and without thermocycling ($P \leq 0.05$). The tendency of bond failure was increased at the bracket/adhesive interface rather than enamel/bracket interface in the stainless steel brackets whereas at the enamel/bracket interface rather than bracket/adhesive interface in the sapphire brackets.

Keywords: Shear bond strength, thermocycling, debond time, sapphire, stainless steel. (J Bagh Coll Dentistry 2013; 25(1):139-145).

INTRODUCTION

In orthodontic practice, it is essential to obtain reliable adhesive bonds between orthodontic brackets and tooth enamel ⁽¹⁾. Shear bond strength (SBS) should not only be high enough to resist the forces during the course of orthodontic treatment but also low enough to allow the removal of the bracket without any complications at the end of orthodontic treatment ⁽²⁾.

Because of the fact that orthodontic adhesives are routinely exposed to thermal changes in the oral cavity, it is paramount to establish whether these changes introduce stress in the adhesive that might affect bond strength. Thus, any new adhesive should be tested both at 24 hours of storage in water and after thermal cycling ⁽³⁾. Thermal cycling is the in vitro process through which the adhesive resin and the tooth are subjected to temperature extremes compatible with the oral cavity ⁽⁴⁾. Gale and Darvell ⁽⁵⁾ pointed to the absence of agreement and standardization between the various thermocycling studies. Different thermocycling regimens were used in the in vitro studies ^(1, 6- 9). The main difference among these studies was in the number of thermal cycles (500, 750, 1500, 2500, 6000 and 10000).

At the same time, the temperature extremes were different. The low-temperature points were 5°C or 10°C, and the high-temperature points were 45°C, 50°C, or 55°C. Nevertheless, in these studies the thermocycled samples were not compared with non-thermocycled samples as recommended by Bishara *et al.* ⁽³⁾ who have suggested that thermal cycling should be part of the testing protocol of any new adhesives.

Such large variations between the thermocycling protocols led the International Organization for Standardization (ISO/TR 11405: 1994) to provide specific criteria for conducting such tests to enable investigators and industry to interpret and compare results ⁽¹⁰⁾, which indicates that a thermocycling regimen comprising 500 cycles in water between 5 and 55°C is an appropriate artificial ageing test, and many studies have been carried out following the ISO standard. Many studies in orthodontics have used various number of thermocycles: approximately 1500 cycles between 10 and 50°C after 3 months of storage ⁽⁸⁾, 500 cycles between 5 and 55°C ⁽⁶⁾, 6000 cycles between 5 and 55°C ⁽¹¹⁾, and 10,000 cycles between 5 and 55°C ⁽⁹⁾, such studies conclude no greater differences in the SBS after increasing thermal cycling. Most research into dental composite bond strength is in vitro because it is difficult to expose the materials to and retrieve them from the oral environment without

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interfering with the environment itself or taxing the subjects' compliance⁽¹²⁾. Traditionally, orthodontic bonding systems are evaluated by in-vitro SBS tests with a universal testing machine which considered the standard for assessing bond strength in vitro⁽¹³⁾. Therefore; thermocycling is essential to simulate the temperature dynamics in the oral environment of in vitro studies. With direct bonding adhesives; thermocycling reduces the bond strength of orthodontic adhesives⁽¹⁴⁾.

Orthodontic brackets may be composed of several materials, such as stainless steel, polymers, porcelain, titanium or their combination. As the number of adults seeking orthodontic care has increased, orthodontists have felt the need to provide their patients with more esthetically appealing appliances. This perceived need has motivated manufacturers to design various types of esthetic brackets, including sapphire brackets. Sapphire (Pure[®]) brackets designed to be one of the esthetic bracket systems, made from high quality monocrystalline sapphire with zirconia spheres to provide superior SBS and predictable debonding⁽¹⁵⁾. However, only a few studies have investigated modifications in the bonding technique, even for metallic or sapphire brackets.

In clinical orthodontic practice, there is no consensus about the minimum time required before loading the bracket⁽¹⁶⁾. Testing at 24 hr is generally preferred because it has been widely reported, and allows comparison with other in vitro bond strength studies⁽¹⁷⁾. Furthermore, polymerization is expected to be complete at the end of 24 hr⁽¹⁸⁾. However, this time period of 24 hr does not reflect clinical orthodontic practice, in which the archwire is usually placed after bracket bonding^(19, 20). On the other hand, bracket-bonding failures sometimes occur during different stages of treatment due to heavy forces produced by an archwire, in addition, significant degradation of the adhesive and its bond to tooth enamel would have occurred over time in the relatively harsh oral environment and light-cured materials are subjected to thermal changes in the oral cavity. Also there is a lack of studies in which these orthodontic brackets (Sapphire, Pure[®]) are subjected to thermocycling. Therefore; the aim of this study was to compare the SBS of sapphire (Pure[®]) and stainless-steel brackets cured with light-emitting diode (LED) under thermocycling at different debond times (24 hr, 7days, and 30 days) as well as to evaluate the enamel conditions after the debonding, through adhesive remnant index (ARI).

MATERIALS AND METHODS

Teeth

A total of one-hundred-fifty upper first premolar teeth were collected, which have been extracted from 12-18 years old Iraqi patients seeking orthodontic treatment. After extraction, the teeth were washed by water to remove any traces of blood. Then each tooth was thoroughly scaled and rinsed to remove calculus, soft tissue remnants, and debris. The collected teeth were stored in fresh distilled water containing crystals of thymol and changed weekly to prevent dehydration and bacterial growth in closed container at room temperature until preparation and testing.

One-hundred-twenty teeth were selected after examining with no decay, restorations, or infections. Also teeth pretreated with chemical agents, such as hydrogen peroxide were excluded.

Brackets and Groups Tested

The selected one-hundred-twenty teeth were randomly assigned into two main groups 60 teeth of each on the basis of thermocycled or without thermocycling, then within each group 30 teeth were used for stainless-steel brackets (Bionic[®]) and the other for sapphire brackets (Pure[®]). Both groups were subdivided into three groups (n = 10) according to the debond times:

Group (I): debond after 24 hr.

Group (II): debond after 7 days.

Group (III): debond after 30 days.

The base surface area of the Bionic[®] and Pure[®] brackets were: 10.9 mm² and 11.9 mm² respectively, as provided by the company (Ortho Technology Company, USA).

Bonding

To exclude the possible differences in bond strength caused by the orthodontic adhesive, all brackets were bonded with the same material (Light-cured orthodontic adhesive, Resilience[®], Ortho Technology Company, USA).

All the teeth were mounted, retentive wedge shaped cuts were made along the sides of the roots of each tooth to increase the retention of the teeth inside the self-cured acrylic blocks. Each tooth was then fitted on a glass slab in a vertical position using soft sticky wax at the root apex, in a way that the middle third of the buccal surface was oriented to be parallel to the analyzing rod of the surveyor, so that the force could be applied at right angle to the enamel-bracket interface because SBS measurements were significantly influenced by the direction of the debonding force. Two other teeth were fixed following the above mentioned procedure with 1cm apart

between them on the same glass slab. The occlusal surfaces of the three teeth were oriented to same height by cutting from the root apices using a stone disc bur. Then two L-shaped metal plates, were painted with a thin layer of separating medium (Vaseline) and placed opposite to each other to form a box around the teeth. Powder and liquid of self-cured acrylic were mixed and poured around the teeth to the level of the cemento-enamel junction of each tooth. After setting of the cold-cured acrylic resin, the two L-shaped metal plates were removed, the sticky wax used for fixation of teeth in the proper orientation removed too and the resulting holes filled with cold-cured acrylic⁽²¹⁾.

The mounted teeth were stored in distilled water containing thymol crystal to prevent dehydration until bonding. The buccal surface of each tooth polished with slurry non-fluoridated pumice for 10 seconds, then washed with water spray for 10 seconds, and dried with oil-free air for 10 seconds. Phosphoric acid gel was applied for 15 seconds, washed with air water spray for 20 seconds, and then dried with oil-free air for another 20 seconds, until the buccal surface of the etched tooth appeared chalky white in color. A load of about 200g was attached to the vertical arm of the surveyor to standardize the pressure applied on the brackets during bonding^(22,23).

The bonding agents were handled according to manufacturer's instruction. Each bracket was placed at the center of the buccal surface, the load was applied for 10 seconds⁽²³⁾, and any excess material was removed with sharp explorer. The light source was of high powered light emitting diode (LED type) cordless curing light with the wavelength range for polymerization of: 440-480 nm (Radii plus, Southern Dental Industries (SDI), Australia) that was applied mesially and distally for 20 seconds (10 seconds for each) with a minimum separation distance (1-2) mm. Every tooth was left undisturbed for 30 minutes to ensure complete polymerization of adhesive material; the specimens were stored in distilled water at 37±2°C.

Thermocycling Procedure

Within 24hr, half of the sample (60 teeth) was thermocycled between 5°C and 55°C for 500 complete cycles. The thermocycling was done manually following the recommendation of the ISO/TS 11405, the exposure to each bath was 30 seconds, and the transfer time between the two baths was 5-10 seconds⁽⁹⁾. The remaining sample was stored in distilled water at room temperature and water was changed daily until debond time for each group was performed.

Debonding Procedure

Debonding was performed using an Instron universal testing machine with a crosshead speed of 0.5mm/minute⁽²¹⁾ at room temperature for each group according to the different debonded-time intervals (after 24 hr, 7 days and 30 days).

The samples were tested for bond strength; the readings were recorded in Newtons (N). The force was divided by the surface area of the bracket base to obtain the stress value in Mega Pascal Units (MPa), with the following equation:

Shear force (MPa) = debonding force (N)/ surface area of bracket base (mm²), so that 1MPa=1N/mm².

Residual Adhesive

After debonding, the enamel surface of each tooth and the bracket bases were examined with a stereomicroscope (magnification 20X) by one investigator to determine the amount of residual adhesive remaining on each tooth. The adhesive remnant index (ARI) was used to assess the amount of adhesive left on the enamel surfaces⁽²⁴⁾. This scale ranges from 0 to 3, following the scores defined as follows:

0 = no adhesive left on the tooth;

1 = less than half of the adhesive left on the tooth;

2 = more than half of the adhesive left on the tooth;

3 = adhesive totally left on the tooth with a distinct impression of the bracket mesh.

Statistical analysis

The results were expressed by measuring SBS means in each group in MPa and the data collected were analyzed using SPSS software version 15 (2006). Statistical analyses were performed including means, standard deviation and standard errors of the mean for each group. One-way analysis of variance (ANOVA) with F-test was used for multiple comparisons between the three time intervals for debonding of each bracket type (stainless steel and sapphire) and independent sample t- test was used to compare differences between the bracket types with and without thermocycling at each debond time. A value of P≤0.05 was considered significant.

RESULTS

Descriptive statistics including means, standard deviation and standard errors of the SBS at three time intervals (time I = after 24 hr, time II= after 7 days, time III = after 30 days) with and without thermocycling using stainless steel and sapphire brackets are shown in Table (1). The mean SBS is higher with sapphire brackets than

that with stainless steel brackets at three debonding time with and without thermocycling.

- Without thermocycling: ANOVA test showed a high significant difference among three debonding time with stainless steel bracket and non-significant difference with sapphire brackets. Whereas, with thermocycling this difference is highly significant with both stainless steel and sapphire brackets. LSD (Least Significant difference test) done to compare between each two debonding time of stainless steel brackets, showed that the difference in the SBS is highly significant between time I with time II and III but insignificant between time II and III.
- With thermocycling: ANOVA test showed a high significant difference in the SBS among the three debonding time with both types of bracket used. LSD test showed a high significant difference in the SBS between times I with III and between time II with III, but non-significant difference between time I and II with both stainless steel and sapphire brackets.

Table (2) and Fig (1and2) showed that the SBS with sapphire bracket is significantly higher than that with stainless steel brackets at three debonding time with and without thermocycling, except that, this increment is non-significant after 30 days in group without thermocycling. Moreover, a high significant reduction in the SBS was noticed after thermocycling at both time I and II and this reduction is non-significant at time III with both stainless steel and sapphire brackets Table (3) and Fig (3and 4).

The ARI frequency was shown in Table (4), score 0 seen with both types of brackets. With stainless steel brackets it was seen more without thermocycling, whereas with sapphire bracket it was seen more after thermocycling. Score 1 seen with both types of brackets. With stainless steel brackets it was seen more after thermocycling whereas with sapphire brackets it was seen more without thermocycling. Score 2 seen more with sapphire brackets than stainless steel brackets and score 3 seen only with stainless steel brackets only.

DISCUSSION

During function, orthodontic brackets are subjected to either shear, tensile or torsion forces, or even a combination of these factors. In the present study the mean SBS in all groups was exceeding the minimal limits suggested by Reynolds⁽²⁵⁾ which is 5.9 – 8.7 Mpa to be adequate for most clinical orthodontic needs with much higher values with sapphire brackets in

comparison with stainless steel brackets, this could be related to the translucency of sapphire brackets which allow more chance for the light to pass through resulting in a more complete polymerization in comparison to stainless steel brackets.

A marked reduction in the SBS was noticed after thermocycling and this could be attributed to the differences in the coefficient of thermal expansion between the adhesive, brackets and enamel which in turn could adversely affect the adhesion of the resin to the bracket and tooth⁽²⁶⁾. Also the cyclical stress of thermocycling at two different temperature extremes could also cause any weakened areas within the bond to grow progressively in size⁽²⁷⁾. This marked reduction in the SBS following thermocycling was noticed in the stainless steel brackets than in the sapphire brackets, which could be attributed to the base design of sapphire bracket compared to stainless steel brackets which allowed for a better retention of the adhesive to the base. The presence of zirconia particles coating the bracket base creates millions of undercuts that secure the bracket in place, due to the micro mechanical retention means. Therefore; in the clinical orthodontic practice, with metallic brackets the clinician must consider the critical question of whether the bond is strong enough to withstand forces applied during orthodontic treatment, while with sapphire brackets, the concern is whether the bond is weak enough for safe debonding⁽²⁸⁾.

With regard to relationship between debonding time and the SBS values, the present study evaluated three different debonding times, 24 hr, 1 week and 1 month. The results demonstrated the highest SBS with stainless steel brackets was noticed after 1 month, with and without thermocycling, and this agree with findings of AL-Arar,⁽²⁹⁾ who used three debonding time 24hr, 1month and 3 months revealed that the maximum SBS was achieved after 1 month and reduced after 3 months., and disagree with the findings of Hajrassie and Khier,⁽³⁰⁾ who evaluated periods of 10 min, 24 hr, 1 week and 4 weeks after bonding and concluded that SBS values using orthodontic adhesives to metallic brackets increase with the debond time, but no statistically significant difference was reported for both the *in vivo* and *in vitro* data. However, the highest SBS with sapphire brackets was observed after 1 week without thermocycling and after 1 month with thermocycling, this mean that the effect of thermocycling in the reduction of SBS was increased with time in sapphire brackets this could be attributed to increased water absorption or solubility of the composite, or both. In terms of

composite resin, the principal interaction occurs with water, which diffuses into the matrix causing hygroscopic expansion of the material as well as a chemical degradation of the material⁽³¹⁾. Moreover, SBS studies have shown a decrease in bond strength of orthodontic composites after immersion in water, the longer the composite is immersed, the lower the bond strength and the greater the degradation of the composite resin⁽³²⁾.

Concerning the site of bond failure, with stainless steel brackets less ARI score was seen with higher SBS value in both with and without thermocycling, this mean that the high SBS value comes from more retention of adhesive to bracket base rather than enamel surface. Whereas with sapphire brackets ARI score reduced with thermocycling, this mean that the effect of thermocycling occur more on the enamel bracket interface rather than bracket adhesive interface and this may be related to the retention mean on the base of sapphire brackets which is coated with zirconia powder that increase the retention mean on bracket base.

As a conclusion, thermocycling is the best process to mimic the thermal changes in the oral environment of in vitro studies, resulted in a significant reduction in the SBS. This marked reduction was noticed in the stainless steel brackets than in the sapphire brackets; eventhough, SBS of sapphire brackets is greater than that of stainless steel brackets without thermocycling. When evaluating bond strength studies, it is important to be aware of the stresses that the intraoral environment induces with time. With regard to relationship between debonding time and the SBS values, the SBS values were increased with time for both stainless steel and sapphire brackets with and without thermocycling.

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Table 1: SBS (MPa) of stainless steel and sapphire brackets bonded using orthodontic adhesive with and without thermocycling at three debonding time.

Conditions	Brackets	Debonding Time	Descriptive Statistics			Differences				
			Mean	S.D.	S.E.	ANOVA Test		LSD Test		
						F-test	P-value	I-II	I-III	II-III
Without thermocycling	Stainless steel	I	12.17	0.99	0.40	57.16 NS	0.000 **	0.000 **	0.000 **	0.08 NS
		II	25.56	2.49	1.02					
		III	28.64	4.12	1.68					
	Sapphire	I	32.74	3.65	1.49	1.89 NS	0.19 NS	-	-	-
		II	38.20	3.69	1.51					
		III	33.42	7.58	3.09					
With thermocycling	Stainless steel	I	7.80	0.96	0.39	279.71 NS	0.000 **	0.18 NS	0.000 **	0.000 **
		II	6.52	0.83	0.34					
		III	25.73	2.41	0.98					
	Sapphire	I	18.52	1.10	0.45	33.83 NS	0.000 **	0.12 NS	0.000 **	0.000 **
		II	21.42	2.10	0.86					
		III	32.06	4.62	1.89					

Table 2: Bracket difference in the SBS (MPa) with and without thermocycling at three debonding time.

Conditions	Without thermocycling						With thermocycling					
	Stainless steel		Sapphire		Differences		Stainless steel		Sapphire		Differences	
	Mean	S.D.	Mean	S.D.	t-test	P-value	Mean	S.D.	Mean	S.D.	t-test	P-value
I	12.17	0.99	32.74	3.65	-	0.000**	7.80	0.96	18.52	1.10	-	0.000**
II	25.56	2.49	38.20	3.69	-6.96	0.000**	6.52	0.83	21.42	2.10	-	0.000**
III	28.64	4.12	33.42	7.58	-1.36	0.2 NS	25.73	2.41	32.06	4.62	-2.97	0.014**

NS: Non-significant P> 0.05, *: Significant 0.05>P>0.01, **: Highly significant 0.01>P>0.001.

Table 3: Comparison of the SBS with and without thermocycling using stainless steel and sapphire brackets at three debonding time

Brackets	Stainless steel						Sapphire					
	Without thermocycling		With thermocycling		Differences		Without thermocycling		With thermocycling		Difference	
	Mean	S.D.	Mean	S.D.	t-test	P-value	Mean	S.D.	Mean	S.D.	t-test	P-value
I	12.17	0.99	7.80	0.96	7.77	0.000**	32.74	3.65	18.52	1.10	9.15	0.000**
II	25.56	2.49	6.52	0.83	17.76	0.000**	38.20	3.69	21.42	2.10	9.68	0.000**
III	28.64	4.12	25.73	2.41	1.49	0.17 NS	33.42	7.58	32.06	4.62	0.38	0.71 NS

NS: Non-significant P> 0.05, *: Significant 0.05>P>0.01, **: Highly significant 0.01>P>0.001.

Table 4: ARI scores for stainless steel and sapphire brackets with and without thermocycling at three debonding time.

Conditions Brackets Score	Without Thermocycling						With Thermocycling					
	Stainless steel			Sapphire			Stainless steel			Sapphire		
	I	II	III	I	II	III	I	II	III	I	II	III
0	0	7	6	2	3	5	2	0	4	10	7	5
1	0	3	4	8	0	5	2	4	6	0	0	5
2	5	0	0	0	7	0	0	0	0	0	3	0

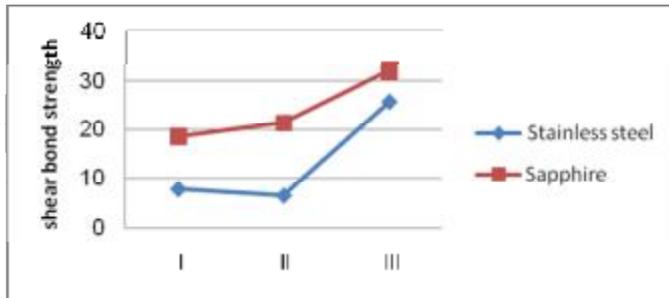


Figure 1: Adhesive SBS with thermocycling using stainless steel and sapphire brackets at three debonding time.

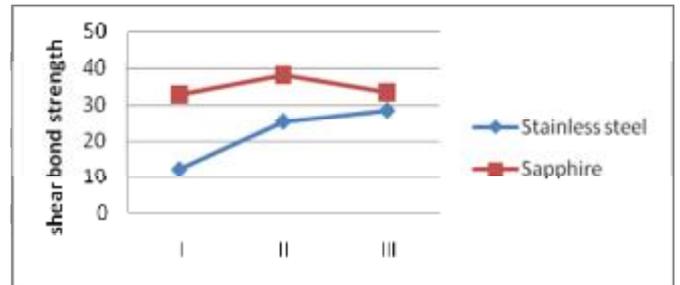


Figure 2: Adhesive SBS without thermocycling using stainless steel and sapphire brackets at three debonding time.

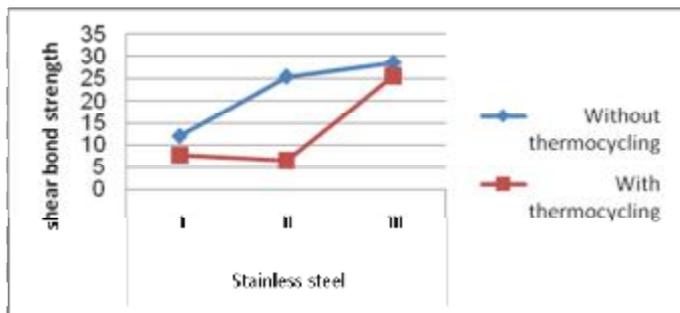


Figure 3: adhesive SBS with and without thermocycling using stainless steel brackets at three debonding time.

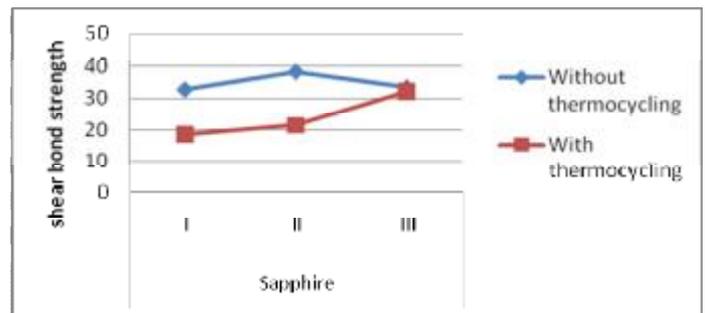


Figure 4: Adhesive SBS with and without thermocycling using sapphire brackets at three debonding time.