EVALUATION OF BOND STRENGTH AND DETACHMENT INTERFACE DISTRIBUTION OF DIFFERENT BRACKET BASE DESIGNS

Giuseppe Lo Giudice[1], Antonino Lo Giudice[1], Gaetano Isola[1], Francesca Fabiano[1,2*], Alessandro Artemisia[1], Valerio Fabiano[1,3], Riccardo Nucera[1], Giovanni Matarese[1]
[1]Department of Specialist Medical-Surgical Experimental Sciences and Odontostomatology, University of Messina - [2]Department of Electronic Engineering, Chemistry and Industrial Engineering, University of Messina, - [3]Department of Civil Engineering, Computing, Construction, Environmental and Applied Mathematics, University of Messina, Messina, Italy

ABSTRACT

Introduction*: The bond failure in metal brackets bonded on enamel was found to occur either at the bonding agent-bracket base interface, within the bonding agent itself or between the bonding agent and enamel. The aim of this study was to evaluate the influence of several bracket base designs and dimensions on bond strength and detachment interface distribution of 5 types of metal brackets each one characterized by a specific base design and dimension.*

Materials and methods*: The following base designs were tested: single mesh, (Alexander LTS, American Orthodontics, Sheboygan, WI; Damon Q, Ormco, Orange, CA; Empower, American Orthodontics, Sheboygan, WI), double mesh (Omniarch, Dentsply GAC, Bohemia, NY) and large grooves on an integral microetched base (Time 3 American Orthodontics, Sheboygan, WI). Brackets were bonded to human teeth and then debonded on custom-made testing machine, based on the Universal testing machine. A scanning electron microscope was used to examine the base design and the detachment interfaces of each bracket selected for this study. The detachment interfaces were mapped with energy-dispersive x-ray spectrometry.*

Results*: The Omniarch bracket showed the higher bond strength corresponding to 84,1 kg/base or 6,78 MPa; no significant differences ($p > 0.05$) were found among the other brackets tested for the bond strength of individual bases (kg/base). Time 3 bracket showed the lower percentage of failure between the bracket and resin and the higher percentage of cohesive failure (respectively 25% and 62 %).*

Conclusions*: The results of this study showed that brackets with a greater mesh spacing demonstrated the best bond strength results and a double layer mesh pattern (80/150 gauge double mesh) guaranteed, in this study, the best bonding performance.*

Key words*: Appliance design, adhesive, bracket, orthodontic treatment, orthodontics.*

Received *Agust 31, 2014;* ***Accepted*** *April 02, 2015*

Introduction

Aesthetics become an important concern in modern society. Functional demand is the main consideration in the dental treatment while today the focus has shifted towards dental aesthetics. Social and cultural expectations and pressures produce a culturally valid need for orthodontic treatment.

To date, specific features of the fixed appliances, specifically ligation method[1], type of ligation[2], bracket design[3] are claimed to potentially enhance the efficiency of the orthodontic treatment. However, the accidental debonding of brackets still remains a frequently encountered problem when these kind of appliances are used. An high bonding performance which withstands the orthodontic forces and masticatory loads and causes a no-traumatic removal during the debonding procedure, enhance the efficacy and efficiency of the orthodontic treatment[4,5]. Most of the efforts made to enhance the retention of the metal base-composite interface has been focused on various chemical and mechanical retentive designs: undercuts in the cast bracket bases, welded meshes of various wire diameters, different mesh patterns (one or bi-layered) and designs, added structures resulting in a bracket base with integral grooves etcetera. Metal plasma-coated bracket bases[5] metallic or ceramic particles to the bases[6], laser-structured bases[7] has been suggested as newfangled approach to enhance retention.

The bond failure in metal brackets bonded on enamel was found to occur either at the bonding agent-bracket base interface, within the bonding agent itself or between the bonding agent and enamel[8-13]. This study aimed to analyze the bond strength and detachment interface distributions of 5 types of brackets, each one characterized by a specific base design and dimension.

Materials and methods

Five types of direct-bond maxillary premolar metal brackets were selected to be tested in this study. The following characteristics of design of the bracket base were analyzed: base size, base type (retention undercuts, mesh designs etc.), mesh size and shaping method. The brackets tested were as follows: Empower (AO, Sheboygan, WI), Alexander LTS (AO, Sheboygan, WI), Time 3 (AO, Sheboygan, WI), Omniarch (Dentsply GAC, Bohemia, NY), Damon Q (Ormco, Orange, CA). Table 1 shows the characteristics of the base of the 5 brackets tested.

Brackets	Base design	Mesh spacing (mm2)	Nominal area of base (mm2)	Manufacturer
Alexander LTS	80 gauge mesh pad over an etched foil base.	Single mesh, $3,6 \times 10^{-2}$	12.6	American Orthodontics, Sheboygan, WI
Damon Q	80 gauge mesh pad over a untreated surface	Single mesh, $3,2 \times 10^{-2}$	11.61	Ormco, Orange, CA
Empower	80 gauge mesh pad over an etched foil base.	Single mesh, $3,6 \times 10^{-2}$	13.51	American Orthodontics, Sheboygan, WI
Omniarch	80/150 gauge double mesh	Double mesh, $5,2 \times 10^{-2}$ and $1,2 \times 10^{-2}$	12.39	Dentsply GAC, Bohemia, NY
Time 3	one piece design with microetched grip		13.01	American Orthodontics, Sheboygan, WI

Table 1: Characteristics of 5 maxillary right first premolar brackets.

A total of 30 maxillary premolars were collected from patients (9-16 years of age) whose plan of orthodontic treatment had required extractions. Two closed plastic boxes full-filled in physiologic saline solution were used respectively to wash and store the extracted teeth. The storage period could not exceed 90 days; otherwise the teeth would have not been considered liable to be tested.

The inclusion criteria of tooth selection were:

• smoothness of crown's surface;

• absence of previous treatment with a chemical agent, such as hydrogen peroxide or formalin;

• conformation of the contour of the labial surface of the crown to the base of the bracket before the bonding procedure.

The teeth were randomly divided into 5 groups of 5 teeth each. The buccal surface of each crown was treated as follows:

1) polishing with pumice powder (Cleanic Prophy Paste, Kerrhawe S.A., Switzerland) water paste containing no fluoride or oil for 10 seconds;

2) 10 seconds rinsing with abundant water spray;

3) 5 seconds spraying with water/air spray;

4) 10 seconds drying with air spray.

The buccal surface of the enamel was etched for 15 seconds with 30%[9,10] phosphoric acid solution. A bonding agent (Heliosit, Ivoclar Vivadent srl, Italy) was applied both to the central white surface of the pretreated crown and bracket base according to the manufacturer's recommendations. The bonding procedure was standardized as described by Wang et al[14]. A dental probe was used to remove the excess of composite on tooth's surface. All specimens were completed within 24 hours.

Every tooth/bracket couples was incubated in a 37° artificial saliva (Saliva Substitute ®; Roxane Labs, Columbus, OH) liquid bath for 24 hours; once removed, they were tested on an a custom-made testing machine, based on the Universal testing machine, with a tensile force set at 2 mm/min crosshead speed. A Compact Force Gauge (CFG+, Mecmesin, United Kingdom) was soldered to the testing machine in order to record the bond strength at which the detachment occurred. The Phenom G2 pro desktop scanning electron microscope (Phenom-World BV, Eindhoven, The Netherlands) was used to examine the base designs and the detachment interfaces of each bracket selected for this study. The detachment interfaces were mapped with energy-dispersive x-ray spectrometry (EDX 3600B Skyray Instrument inc., Braintree, MA, USA).

The measurements relative to the bracket base's surface were performed on planimetric photography.

Statistical analyses

The bond strength and detachment interface distribution were recorded.

We carried out the statistical power analysis based on data of bond strength (Mpa) of

Ultratrimm (Dentaurum, Ispringen, Germany) and Tip-edge Rx-I (TP Orthodontics, LaPorte, Ind, USA) brackets obtained from a previous study[10] as they were found to be the brackets showing the higher and lower bond strength levels respectively. The following parameters were set: Variance 1 -8,24-, Variance 2 -5,69-, Alpha 0,05, Power 0,8. A sample size of 5 measurements was found to be sufficient to accomplish a power of study of 0.8.

Analysis of data was performed using MedCalc (MedCalc Software, Mariakerke, Belgium) software. The means and standard errors were determined and analyzed by 1- or 2-way analysis of variance (ANOVA). Levene's Test was first performed to verify the equality of Variances. Student-Newman-Keuls and Bonferroni's multiple comparison tests were selected to obtain the pair-wise comparisons respectively for the 1-way and 2-way analysis of variance (ANOVA). The level of statistical significance was set at $p < 0.001$.

Results

The differences of bond strength (kg/base) were found to be statistically significant among the brackets tested as revealed by the 1-way analysis of variance ($p < 0.001$) (Table 2). Except for the Omni-arch bracket, the Student-Newman-Keuls test revealed no statistically significant differences ($p > 0.05$) among the Empower, Alexander, Damon Q and Time 3 brackets respectively (Table 2).

Brackets	n. of test	Kg/base (Mean)	Standard error	Pairwise comparison of tensile bonding strengths
1AlexanderTLS	5	62.22	1,1	4
2 Damon Q	5	52.56	2,63	4
3 Empower	5	64.26	1,78	4
4 Omniarch	5	84.1	1,37	1 2 3 5
5 Time 3	5	48.06	2,28	4

Table 2: One-way ANOVA ($p<0.001$) and Student-Newman-Keuls test ($p<0.05$) for all pairwise comparison of tensile bonding strengths (kg/base).

The differences of bond strength per area squared (MPa) were found to be statistically significant among the brackets tested as revealed by the 1-way analysis of variance ($p < 0.001$) (Table 3). The Student-Newman-Keuls test revealed no statistically significant differences among the Empower, Alexander and Damon Q brackets, while high statistically significant difference was found between the Omni-arch and all the other brackets tested ($p < 0.001$) (Table 3). The Omniarch and Time 3 brackets showed respectively the stronger and the weaker bond strength values.

Brackets	n° of tests	MPA (Mean)	Standard error	Pairwise comparison of tensile bonding strengths
1 Alexander TLS	5	4,6	0,08	4
2 Damon Q	5	4,52	0,22	4
3 Empower	5	5,09	0,14	4 5
4 Omniarch	5	6,78	0,11	1 2 3 5
5 Time 3	5	3,69	0,17	3 4

Table 3: . One-way ANOVA ($p<0.001$) and Student-Newman-Keuls test ($p<0.05$) for all pairwise comparison of tensile bonding strengths (MPa).

In this study, three types of detachment interfaces occurred: A) between the bracket base and bonding agent, B) cohesive failure within the bonding agent itself, and C) between the bonding agent and enamel. Table 4 shows the distributive percentages of the various debonded interfaces. The statistical relationships among the 5 types of brackets and the 3 types of debonded interface distributions were analyzed with 2-way ANOVA. The F value among the 5 types of brackets and 3 types of debonded interface distributions was 4.356, which indicates a statistically significant difference ($p < 0.001$). The F value among the 5 types of brackets was 0, indicating no statistically significant difference. The F value of the 3 types of debonded interface distributions was 9.318, which indicates a statistically significant difference ($p < 0.001$). The ranking of the type of debonded interfaces from high to low was A, B and C (Table 4). No statistically significant difference was found between type A and B. Table 4 shows the ranking of debonded interfaces within each group of brackets.

	A		*B*		*C*			
Brackets	**Mean**	**Std. Er.**	**Mean**	**Std. Er.**	**Mean**	**Std. Er.**	**P**	**S**
Alexander TLS	42,0	11,98	45,0	11,98	13	11,98	0.001	A, B > C
Damon Q	25,0	11,98	60,0	11,98	15	11,98	0.001	B, A > C
Empower	48,0	11,98	9,0	11,98	43	11,98	0.001	A, C > B
Omniarch	36,0	11,98	51,0	11,98	13	11,98	0.001	B, A > C
Time 3	25,0	11,98	62,0	11,98	13	11,98	0.001	B, A > C

Table 4: A, interface between bracket and resin; B, interface within resin itself; C, interface between resin and enamel; P, significance of simple main effect; S, Levene's multiple comparison tests and Bonferroni's correction ($p<0.001$); Std. Er.standard error.

Discussion

In the present study, all brackets were bonded with the same bonding agent to ensure that any significant variations in bonding strength were clearly attributable to variations in bracket base design (Figure 1).

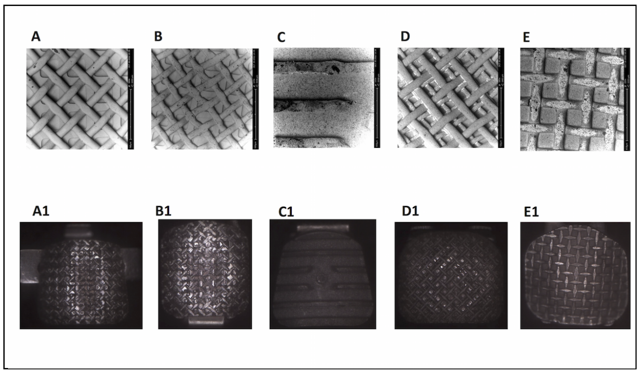

Figure 1: A – A1, Alexander LTS (American Orthodontics) bracket with 80 gauge mesh over an etched foil base; B – B1, Empower (American Orthodontics) bracket with 80 gauge mesh over an etched foil base; C - C1, Time 3 (American Orthodontics) bracket with one piece design with microetched grip; D – D1, Omniarch (Dentsply, GAC) with 80/150 gauge double mesh; E – E1, Damon Q (Ormco) bracket.

All the brackets tested in this study overcame the minimum tensile bond strength required to resist debonding forces, that is reported to be 2.86 MPa[15-16]. Except for Omniarch, no differences were found among the bond strength values of individual base (kg/base) of Empower, Alexander, Damon Q and Time 3 brackets (Table 2) suggesting that, from a clinical point of view, they may similarly tolerate the orthodontic forces and masticatory loads and require a similar amount of forces to be debonded. The bond strength values per area squared were also analyzed (Table 3). These data offer the opportunity to evaluate the bond strength for surface unit eliminating the variability related to the bracket base surface dimension. The significant differences emerged comparing MPa values demonstrate that the surface bracket base design significantly affects bond strength (Table 3 and 4).

The Omniarch bracket showed the higher bond strength corresponding to 84,1 kg/base or 6,78 MPa. Among the brackets having a mesh in this study, the Omni-arch features a bi-layered mesh pattern, incorporating horizontal and vertical metal wires of underneath a similarly aligned second layer of metal wires, that can be responsible for this behavior. This is in agreement with Willems[17].

The type of bonded interface was also analyzed in this study as qualitative parameter of bonding failure. Several studies[16, 18-23] have demonstrated that the bracket base-cement interface is the weakest point in orthodontic bonding. Time 3 showed the lower percentage of failure between the bracket and resin and the higher percentage of cohesive failure within the resin itself (respectively 25% and 62%) compared with other base designs. It is likely that the large grooves that distinguish the integral microetched base of Time 3 bracket hold the bonding agent back just as the bracket is subjected to a debonding forces increasing the probability of a detachment within the bonding agent itself; this could explain the higher percentage of cohesive failure pattern found with Time 3 bracket, even though it showed the lower bond strength values.

Empower and Alexander LTS brackets feature an identical base design but different dimension of the base (Table 1) with the former showing, in this study, an higher bond strength values (Table 2 and 3). Thus, on equal base design, our results suggest that the dimensional size of the base positively affects the bond strength. This agrees with Wang et al(10).

The mesh spacing was also measured in this study for each bracket's base featuring a mesh pattern (Table 1). The free volume between the mesh and the base was found to affect the penetration of resin, the escape of air, and the effectiveness of bonding[11]. While the Empower and Alexander brackets shared the same dimension of mesh spacing (3,6 x 10 -2 mm2), the Omniarch and Demon brackets featured respectively the greater and smaller mesh spacing (5,2 x 10-2 mm2 and 3,2 x 10-2 mm2). The results showed that greater the mesh spacing, the greater was the bond strength. This is in agreement with Wang et al[10].

In a study using finite element analysis[24], the type of stress distribution of both single- and double-mesh designs was found to change with relation to the depth reached by the adhesive layer. Bishara et al[25] reported similar bond strength values between single and double mesh designs, while the results of this study turned out opposite because the Omniarch bracket, which features a double layer mesh pattern, (80/150 gauge double mesh) showed the higher bond strength values compared with all brackets featuring a single mesh design. The reason of this contrasting findings could be attributed to the bonding agent used in this study (Heliosit, Ivoclar Vivadent srl, Italy) that is characterized by a low consistency pattern that could take advantage of a bracket base with the larger number of potential mechanical hooks as that of the Omniarch which have an additional deeper mesh layer with its relative mesh spacing (1,2 x 10-2 mm2). According to us, in order to enhance the masticatory performance[26-29] in various kind of patients[30], the intrinsic characteristics of different bonding agents, such as range of viscosities, wetting characteristics and filler level, may enhance or worsen the bonding performance of the same base's design.

The various theories espoused for maintaining teeth in their treated positions allow for reorganization of the gingival[31] and periodontal tissues[32-34], minimize changes due to growth[35], permit neuromuscular adaptation to the corrected tooth position(36-38), or maintain teeth in aesthetically or functionally desirable but unstable positions. Further studies should be evaluating the tensile bond strength of the brackets focusing on the relationship between several base designs and different bonding resins used.

Conclusions

The Omni-arch bracket which present a double layer mesh pattern (80/150 gauge), produced the greatest bond strength in this study. The interaction between the double mesh and the low-viscosity bonding agent used in this study (Heliosit, Ivoclar Vivadent srl, Italy) could explain this result.

The Time 3 bracket showed the higher percentage of cohesive failure pattern (62%) compared with all the brackets tested. This could be attributed to the particular base design of this bracket.

The larger the base's surface area, the higher were the bond strength values.

Among the brackets with mesh-type bases, the greater the mesh spacing, the higher were the bond strength values.

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Correspoding author
FRANCESCA FABIANO
University of Messina,
Contrada di Dio
98166 Messina
(Italy)