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Shear bond strength of self-ligating brackets

Maria Francesca Sfondrini*, Sara Gatti* and Andrea Scribante*,**
Departments of *Orthodontics and **Surgical Sciences, University of Pavia, Italy

Correspondence to: Andrea Scribante, Dipartimento di Discipline Odontostomatologiche 'S. Palazzi', Reparto di Ortognatodonzia, Policlinico San Matteo, Piazzale Golgi 2, 27100 Pavia, Italy. E-mail: andrea.scribante@unipv.it

SUMMARY The aim of this study was to compare the shear bond strength (SBS) and adhesive remnant index (ARI) scores of conventional and self-ligating brackets.

Conventional stainless steel brackets (group 1, Step®; Leone) and three different passive and interactive self-ligating brackets (group 2, Smart Clip®, 3M Unitek; group 3, Quick®, Forestadent; and group 4, Damon 3MX®, Ormco) were tested. Four groups of 20 specimens each were bonded with an adhesive system (Ortho Solo® primer, Ormco and Transbond XT resin, 3M Unitek) onto bovine enamel and subsequently tested using an Instron universal testing machine. SBS values and adhesive failure rate were recorded. Statistical analysis was performed with analysis of variance and Scheffé tests to determine bond strength values, whereas a chi-square test was used for ARI scores.

Groups 2 and 4 showed significantly higher SBS values than the other two groups. Moreover, groups 1 and 3 showed a higher frequency of ARI score 1, whereas groups 2 and 4 showed higher frequency of ARI score 2. All the brackets demonstrated a clinically adequate SBS.

Introduction

Self-ligating orthodontic brackets are gaining popularity because of their advantages in reducing friction and treatment time in orthodontic mechanotherapy (Harradine, 2003).

Recently, a number of studies have evaluated various aspects of self-ligating brackets. Friction of self-ligating brackets has been widely studied *in vitro* (Franchi *et al.*, 2008; Gandini *et al.*, 2008; Matarese *et al.*, 2008). Other studies have evaluated torque (Badawi *et al.*, 2008; Morina *et al.*, 2008) and rotation (Pandis *et al.*, 2008a) expression of conventional versus self-ligating brackets. Self-ligating brackets have been clinically tested in various studies, evaluating periodontal indices (Pandis *et al.*, 2008b), bonding with self-etching primers (Elekdag-Turk *et al.*, 2008), and also use in trifocal distraction–compression osteosynthesis (Baek *et al.*, 2008).

There are only two published studies in the literature concerning the shear bond strength (SBS) of self-ligating brackets (Chalgren *et al.*, 2007; Northrup *et al.*, 2007). The first evaluated the SBS of one self-ligating bracket in various enamel and bracket preparation procedures (Chalgren *et al.*, 2007), while the other compared the SBS of a conventional and a self-ligating bracket using two different bonding systems (Northrup *et al.*, 2007). To date, there are no studies that have compared the SBS of different self-ligating brackets.

Accordingly, the aim of the present investigation was to measure and compare the SBS and adhesive remnant index (ARI) scores of a conventional and three different self-ligating brackets. The null hypothesis of the study was that there is no significant difference in SBS values and debond locations among the various groups.

Materials and methods

Eighty freshly extracted bovine permanent mandibular incisors were collected from a local slaughterhouse and stored for 1 week in a solution of 0.1 per cent (w/v) thymol. The criteria for tooth selection included intact buccal enamel with no cracks caused by extraction, and no caries. The teeth were cleansed of soft tissue and embedded in cold-curing fast-setting acrylic (Leocryl; Leone, Sesto Fiorentino, Italy). Metal rings (15 mm diameter) were filled with the acrylic resin and allowed to cure, thus encasing each specimen while leaving the buccal surface of the enamel exposed. Each tooth was orientated so that its labial surface was parallel to the shearing force. The teeth were randomly divided into four groups of 20 specimens.

Four different orthodontic stainless steel maxillary central incisor brackets were tested: Step® (Leone), Smart Clip® (3M Unitek, Monrovia, California, USA), Quick® (Forestadent, Pforzheim, Germany), and Damon 3MX® (Ormco, Glendora, California, USA). The materials were tested following the guidelines of Fox *et al.* (1994) on bond strength testing in orthodontics.

Before bonding, the labial surface of each incisor was cleaned for 10 seconds with a mixture of water and fluoride-free pumice in a rubber-polishing cup with a slow-speed handpiece. The enamel surface was rinsed with water to remove pumice or debris and then dried with an oil-free air stream.

The teeth were etched with 37 per cent phosphoric acid gel (Phosphoric Etchant Syringes®; 3M Unitek) for 30 seconds, followed by thorough washing and drying. A thin layer of primer (Ortho Solo®; Ormco) was applied to the etched enamel, and the brackets were then bonded with a resin (Transbond XT®; 3M Unitek) near the centre of the facial surfaces of the teeth. Sufficient pressure was applied to express excess adhesive, which was removed from the margins of the bracket base with a scaler before polymerisation. The brackets were then light cured with a visible light-curing unit (Ortholux XT®; 3M Unitek) for 10 seconds on the mesial and 10 seconds on the distal side (total cure time 20 seconds). After bonding, all samples were stored in distilled water at room temperature for 24 hours and then tested in shear mode on a universal testing machine (Model 4301; Instron, Canton, Massachussetts, USA). The specimens were secured in the lower jaw of the machine so that the bonded bracket base was parallel to direction of the shear force.

The specimens were stressed in an occlusogingival direction at a crosshead speed of 1 mm/minute, as in previous studies (Jobalia *et al.*, 1997; Millett *et al.*, 1999; Cacciafesta *et al.*, 2003). The maximum load necessary to debond or initiate bracket fracture was recorded in Newtons and then converted into megapascals (MPa) as a ratio of Newtons to surface area of the bracket. After bond failure, the bracket bases and the enamel surfaces were examined under an optical microscope (Stereomicroscope SR; Zeiss, Oberkochen, Germany) at ×10 magnification.

The ARI was used to assess the amount of adhesive left on the enamel surface (Årtun and Bergland, 1984). This scale ranges from 0 to 3. A score of 0 indicates no adhesive remaining on the tooth, 1 less than half of the adhesive remaining on the tooth, 2 more than half of the adhesive remaining on the tooth, and 3 all adhesive remaining on the tooth with a distinctive mesh imprint remaining. The ARI scores were used as a more complex method of defining bond failure site between the enamel, the adhesive, and the bracket base.

Statistical analysis was performed with Stata 7.0 software (Stata, College Station, Texas, USA). Descriptive statistics, including the mean, standard deviation, median, and minimum and maximum values were calculated for all groups.

Analysis of variance (ANOVA) was applied to determine whether significant differences in debond strength values existed among the groups. Scheffé's test was used for *post hoc* comparison. The chi-square test was used to determine significant differences in the ARI scores among the different groups. Significance for all statistical tests was predetermined at $P < 0.05$.

Results

Descriptive statistics for the SBS (MPa) of the different brackets are illustrated in Table 1 and Figure 1. Normality of the data was calculated using the Kolmogorov–Smirnov test. ANOVA showed the presence of significant differences among the various groups ($P = 0.0073$). *Post hoc* testing showed that the brackets in groups 2 and 4 had significantly higher SBS values than the other groups ($P = 0.0208$) but without a significant difference between them ($P > 0.05$). No significant difference in SBS values was found between groups 1 and 3 ($P > 0.05$).

The results of ARI scores are presented in Table 2. The chi-square test showed a higher frequency of ARI score 1 for groups 1 and 3 ($P = 0.020$) but without a significant difference between them ($P > 0.05$). Groups 2 and 4 exhibited a higher frequency of ARI score 2; no significant difference was found between these two groups ($P > 0.05$).

Discussion

The null hypothesis of the study was rejected. In the present investigation, the Smart Clip and Damon 3MX brackets had significantly higher SBS values than the other groups but without a significant differences between them. Moreover, no significant difference in SBS values was found between the Step and Quick brackets. There are only two published studies in the literature relating to the SBS of self-ligating brackets. Chalgren *et al.* (2007) evaluated the SBS of one passive self-ligating bracket in various enamel and bracket preparation procedures. The results showed that self-etching primer, gel etchant, and liquid etchant produced equal and sufficient bond strengths in combination with a self-ligating bracket with a composite bracket pad.

Northrup *et al.* (2007) compared the SBS of a conventional and a passive self-ligating bracket using two different

Table 1 Descriptive statistics of the four groups tested (MPa)

Groups	Number of observations	Mean	Standard deviation	Minimum	Median	Maximum	Scheffé grouping *
Group 1 (Step)	20	13.72	3.51	7.16	14.71	18.7	A
Group 2 (Smart Clip)	20	18.01	3.79	10.89	18.92	22.99	B
Group 3 (Quick)	20	11.8	2.41	8.57	11.37	18.4	A
Group 4 (Damon 3MX)	20	19.75	4.93	7.28	20.68	26.48	B

*Means with the same letters are not significantly different.

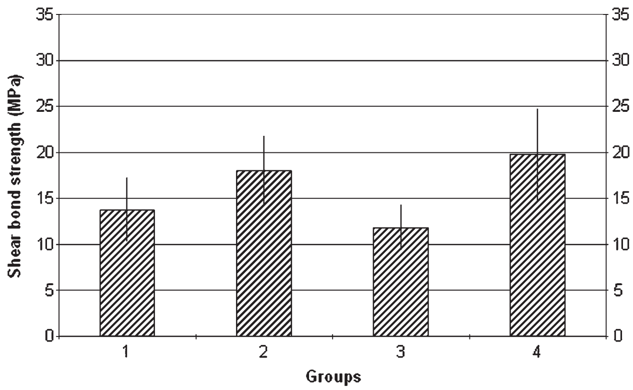

Figure 1 Mean shear bond strengths and standard deviations of the different groups. (group 1: Step, group 2: Smart Clip, group 3: Quick, group 4: Damon 3MX).

Table 2 Frequency of distribution of adhesive remnant index (ARI) scores

Groups	ARI = 0 (%)	ARI = 1 (%)	ARI = 2 (%)	ARI = 3 (%)
Group 1 (Step)	0 (0.0)	15 (75.0)	3 (15.0)	2 (10.0)
Group 2 (Smart Clip)	0 (0.0)	3 (15.0)	17 (85.0)	0 (0.0)
Group 3 (Quick)	0 (0.0)	16 (80.0)	2 (10.0)	2 (10.0)
Group 4 (Damon 3MX)	0 (0.0)	1 (5.0)	15 (75.0)	4 (20.0)

bonding systems. The conventional brackets showed lower SBS values than the self-ligating brackets, whereas no significant difference was found between the two adhesive systems used with self-ligating brackets. To date, there are no studies that have compared the SBS of different passive and interactive self-ligating brackets.

Reynolds (1975) suggested that a minimum bond strength of 6–8 MPa was adequate for most clinical orthodontic needs because these values are considered to be able to withstand masticatory and orthodontic forces. In the present research, the bond strengths of all groups were above these limits.

Previous studies have shown that bovine and human enamel are similar in their physical properties, composition, and bond strengths, and therefore, bovine enamel has been reported to be a reliable substitute for human enamel in bonding studies (Nakamichi *et al.*, 1983; Barkmeier and Erickson 1994; Oesterle *et al.*, 1998).

In the present investigation, ARI scores were recorded. The Step and Quick brackets had a significantly higher frequency of ARI score 1 and exhibited no significant differences between them. No significant difference was found between the Smart Clip and Damon 3MX brackets, both showing a higher frequency of ARI score 2. Previous investigations evaluating SBS of self-ligating brackets showed a higher frequency of ARI score 3 (Chalgren *et al.*, 2007; Northrup *et al.*, 2007). An ARI score of 0 indicates higher adhesion of the bonding system more to the bracket base than to the tooth on removal. This involves less time to remove adhesive from the tooth. In contrast, an ARI score of 3 indicates failure between the bracket and adhesive, with less risk of enamel fracture during debonding (Northrup *et al.*, 2007). The results of the present investigation demonstrated a higher frequency of ARI scores 1 and 2, showing a mixed adhesion modality.

Conclusions

The results for this study demonstrated the following:

1. Smart Clip and Damon 3MX brackets showed significantly higher SBS values than Step and Quick brackets.
2. Step and Quick brackets showed a higher frequency of ARI score 1, whereas Smart Clip and Damon 3MX brackets showed a higher frequency of ARI score 2.

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