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A novel bracket base design: biomechanical stability

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SUMMARY The aim of this research was to investigate the retention of a bracket equipped with a novel base, the R-system®. The design of the bracket base is characterized by concentric grooves. The behaviour of this bracket was compared with a bracket with a conventional mesh base from the same manufacturer.

Thirty lower adult bovine incisors were selected and metallic brackets were bonded using the Concise adhesive system. Each bracket–adhesive–enamel interface was investigated according to torsion debonding. One-way analysis of variance was used for statistical evaluation. Finite element analysis was also undertaken. In order to assess if the technique was detrimental to the enamel, the mode of failure was determined using the Adhesive Remnant Index (ARI). The debonded surfaces were analysed using scanning electron microscopy (SEM) and electron dispersion spectrometry (EDS).

The R-system® provided a bond strength greater than that of the mesh-base bracket. EDS showed that the amount of calcium on the novel base was higher than that on the conventional base, which allowed transfer of torsional stress more uniformly to the substrate, resulting in higher bond values for the R-system®. On the other hand, as debonding of the R-system® occurred at the enamel–composite interface, lesions to the enamel substrate are possible.

Introduction

The evolution of multibracket therapy has resulted in a series of advantages, both to the patient and to the orthodontist. However, accidental debonding of brackets still remains a frequently encountered problem. As brackets are stressed by orthodontic forces and masticatory loads, a high bonding performance is required, but the brackets have to be easily removed at the end of treatment (Wang *et al.*, 2004).

Adhesion to teeth, accidental debonding of brackets, and damage to the enamel surface have motivated investigation of these problems (Sorel *et al.*, 2002) according to different variables (e.g. adhesive material, design of the base, type of pre-treatment, method of debonding, and curing technique).

Concise, which is used as an adhesive material, shows higher retention compared with light-cured adhesives (Wendl and Droschl, 2004). Torsion tests, which are used to evaluate adhesive properties, are less damaging to the enamel and more suitable for clinical debonding (Valletta *et al.*, 2002). Surface pre-treatment is important and etching is commonly used in order to achieve a high bond strength (Abu Alhaija and Al-Wahadni, 2004).

The morphology of the base is an important variable for the retention of a bracket (Knox *et al.*, 2000). Those authors suggested that the base design may improve penetration of the adhesive material. The size of the base is also an important factor (Wang *et al.*, 2004).

The aim of this study was to investigate a novel retentive system consisting of concentric grooves on the base of the bracket. The rationale for this novel design was based on the physical principle of 'hydrodynamic analogy' (Popov, 1968; Munson *et al.*, 2005). According to this principle, this type of base should transfer torsional stresses more uniformly to the substrate than a conventional mesh base. The biomechanical behaviour and any potential clinical application of this bracket were considered.

Materials and methods

Thirty central lower bovine incisors were obtained from animals sacrificed at an average age of 2 years (±2 months). These teeth have been commonly used for *in vitro* debond testing (Saleh and Taymour, 2003); moreover, bovine enamel is easily attainable and has a similar microstructure to human enamel (Oesterle *et al.*, 1998).

Each of the extracted teeth (Figure 1a) was cleaned from the residual ligament and stored in a 10 per cent thymol solution at 37°C for 48 hours until mechanical testing. Further analysis by optical microscopy facilitated the identification and marking of an area with an optimally smooth and flat surface on the vestibular side of each tooth.

The samples were cleaned with pumice and sectioned with a Buehler Isomet Microtome (Buehler Ltd., Lake Bluff, Illinois, USA), equipped with a diamond saw rotating at a speed of 150 rpm and cooled by water. The section was then placed on adhesive tape and embedded into a steel cylinder (Figure 1b) filled with self-curing methyl methacrylate-based resin (Formatray; Kerr Corporation, West Collins Orange, California, USA) as shown in Figure 1c.

The brackets were bonded with Concise (3M Unitek, St Paul, Minnesota, USA), a chemically activated paste–paste composite.

The enamel surface was conditioned with orthophosphoric acid (37 per cent) for 30 seconds, then rinsed for 30 seconds, and dried with an oil-free air jet. The adhesive resin and the composite paste were applied to the enamel surface and to the bracket base, respectively. A 300 g weight was then placed on the bracket for 15 seconds and excess cement was carefully removed (Figure 1d).

The brackets were bonded on the enamel specimens (Figure 1d) and divided into three groups (each consisting of 10 specimens) according to the base: concentric grooves with a thickness of 150 μm (group 1), concentric grooves with a thickness of 100 μm (group 2), and conventional mesh base (group 3; Figure 2). These brackets were produced through the metal injection moulding process (SIA Orthodontic Manufacturer Rocca D'Evandro, Caserta, Italy).

To allow curing of the resin, mechanical testing was carried out 24 hours after bonding. (Regan and van Noort, 1989; Harris *et al.*, 1990; Abu Alhaija and Al-Wahadni, 2004; Wang *et al.*, 2004).

Torsion tests were undertaken using a servohydraulic dynamometer (MTS 858 Bionix, Minneapolis, Minnesota, USA) using a load cell, with a load and torque range of 2.5 kN ad 25 Nm, respectively. The tests were carried out controlling for the angular position. An angular speed of 5 degrees/minute was used. Data (load, torque, and angular position) were acquired at 10 points/second.

Finite element analysis (FEA) was used to evaluate the regions where maximum stresses occurred (Katona, 1997; Knox *et al.*, 2001).

Analysis of the fractured surfaces was performed using an optical microscope. The enamel and bracket surfaces were observed at ×50 and ×60 magnification, respectively. The magnification was set at ×290 in order to observe the bracket–adhesive interface along the grooves of the base of the bracket. This type of analysis of the enamel surfaces, the bracket bases and the enamel–adhesive interfaces, allowed detection of the regions where fractures occurred and propagated.

For each sample, the amount of composite adhering to the enamel substrate was quantified using the Adhesive remnants index (ARI; Årtun and Bergland 1984; Arici and Minors, 2000; Summers *et al.*, 2004; Hirani and Sherriff, 2006), which attributes a score of 1, when all composite remains on the enamel surface and a clear imprint of the bracket is evident; 2, when more than 90 per cent of the composite is present on the enamel surface; 3, when 10–90 per cent of the composite remains on the enamel surface; 4, when less than 10 per cent of the composite remains on the enamel surface; and 5, when there is a complete transfer of the composite to the bracket base.

Statistical significance of the results was assessed using one-way analysis of variance (Cheremisinoff, 1987) through the Origin® 6.0 package (Microcal Software, Northampton, Massachusetts, USA). Confidence levels of 99 and 95 per cent were set for the analysis of mechanical strength and ARI data, respectively.

All the samples were examined with scanning electron microscopy (SEM) in order to verify the presence and sites of the fractures. In addition, energy dispersive spectroscopy (EDS) was used in order to detect calcium (Ca++) on the adhesive material removed during debonding of the brackets. The EDS technique has been commonly used to investigate debonding of ceramic restorations (Whitlock *et al.*, 1994).

Results

The maximum values of the mechanical torsional test were 519 Nmm [standard deviation (SD) 144] for group 1, 225 Nmm (SD 20) for group 2, and 175.71 Nmm (SD 65) for group 3. The torsion data, expressed in Nmm, are consistent with the literature (Gibb and Katona, 2006; Katona and Long, 2006).

Mechanically, there was a statistically significant difference between groups 2 and 3 ($P < 0.01$) and between groups 1 and 2 ($P < 0.01$). A weaker statistical difference was found between groups 1 and 3 ($P < 0.05$).

Optical images of the fractured surfaces of representative specimens from the three groups are shown in Figure 3. Table 1 reports the ARI scores for the three groups of brackets. Higher values were measured for group 1.

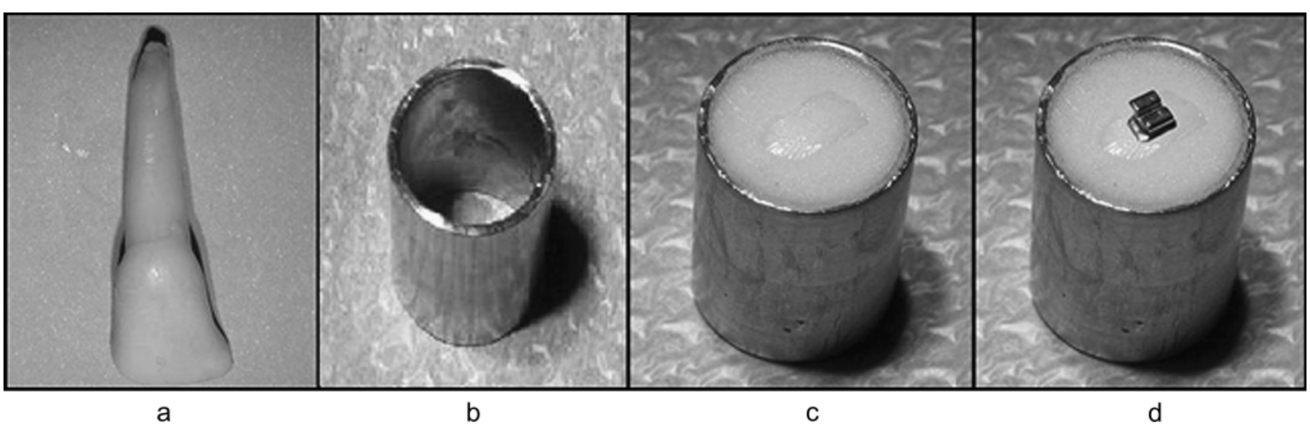

Figure 1 Specimen preparation: (a) selection of 30 sound teeth, undamaged by the extraction procedure; (b) steel cylinder; (c) cementing of the specimen with poly (methyl methacrylate) and bracket bonding; (d) sample storage.

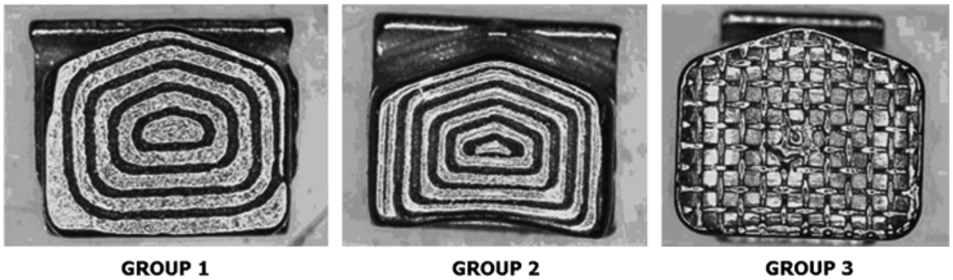

Figure 2 The three types of brackets used in the study: group 1, wide grooves; group 2, narrow grooves; and group 3, the conventional bracket.

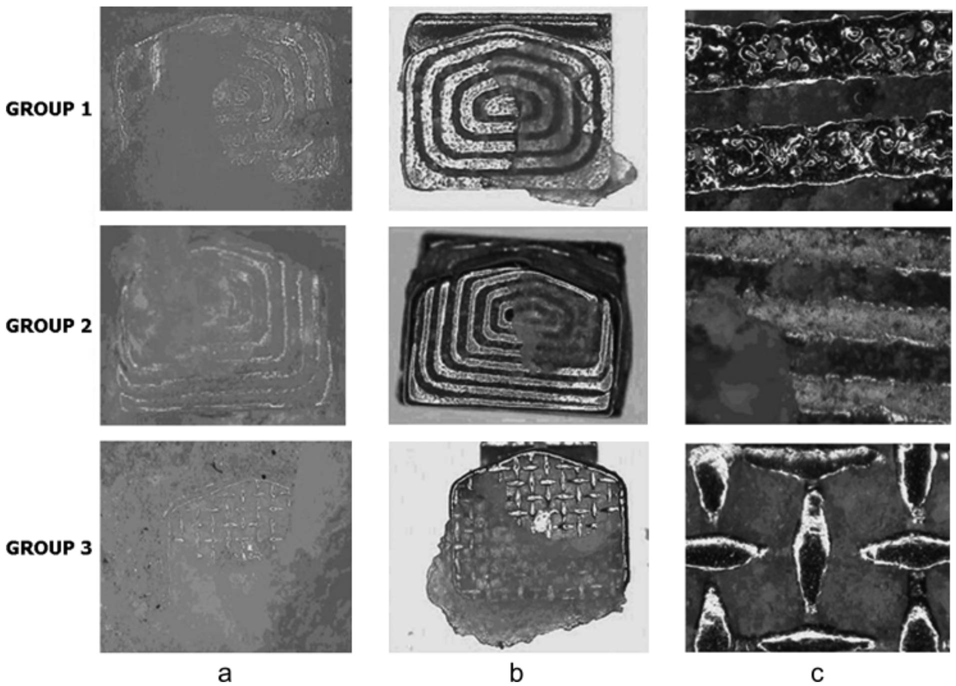

Figure 3 Analysis of the fractured surfaces with an optical microscope using ×60 magnification for the dental surface (a), ×50 magnification for the bracket base (b), and ×290 magnification for the retentive system of each group of brackets (c).

Table 1 Mean Adhesive Remnants Index (ARI) scores for each group.

Group 1											
Specimen	1	2	3	4	5	6	7	8	9	10	Mean
ARI value	4	1	5	4	4	4	5	4	3	2	3.6
Group 2											
Specimen	1	2	3	4	5	6	7	8	9	10	Mean
ARI value	3	5	2	2	3	2	2	5	3	3	3
Group 3											
Specimen	1	2	3	4	5	6	7	8	9	10	Mean
ARI value	3	3	2	5	3	5	3	2	3	3	3.2

SEM images of the base of the bracket base and enamel surface are illustrated in Figure 4.

EDS analysis showed a minimal amount of hydroxyapatite (Ca++) on the composite attached to the base of group 3, while a high amount of Ca++ was observed in group 1 (Figure 5).

FEA showed that for group 3, the base of the bracket was more stressed than that of group 1. Mechanical stresses were concentrated on the upper margins of the base and in the deepest part of the grooves for group 1 (Figure 6a) and in the bottom of the mesh for group 3 (Figure 6b).

The surface of the conventional bracket demonstrated many points of stress concentration, while the concentric bracket had an improved stress distribution. This is consistent with the principle of hydrodynamics. The FEA results confirmed the presence of many areas of stress concentration on the conventional compared with the stress distribution in the concentric base of the novel bracket (Figure 6). This result was consistent with the ARI findings; in fact the bracket–adhesive interface of the concentric bracket was also more stable than that of the conventional bracket.

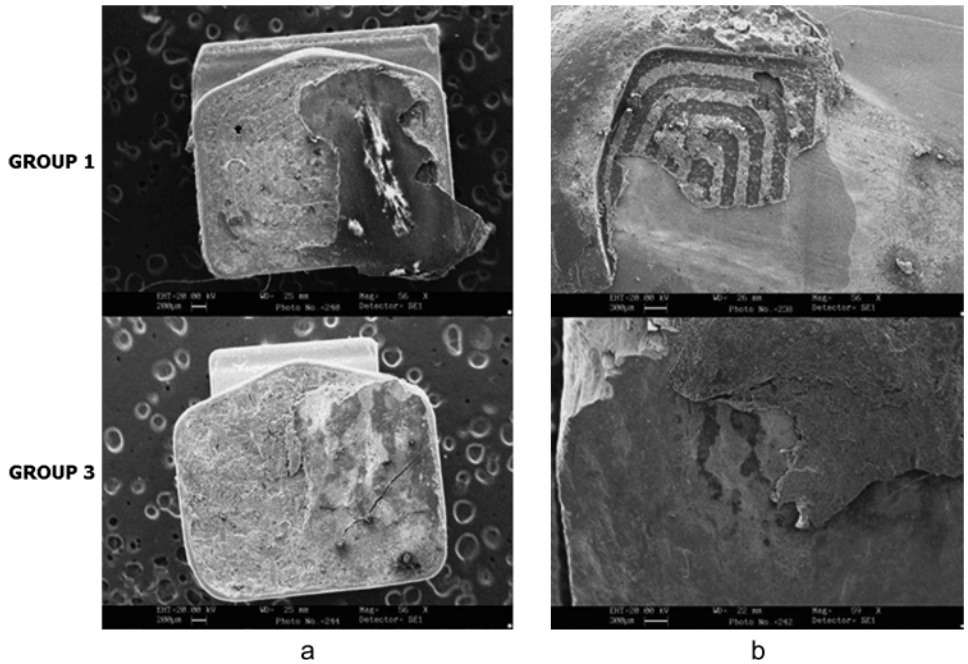

Figure 4 Scanning electron microscopy of mesh (a) and concentric (b) base.

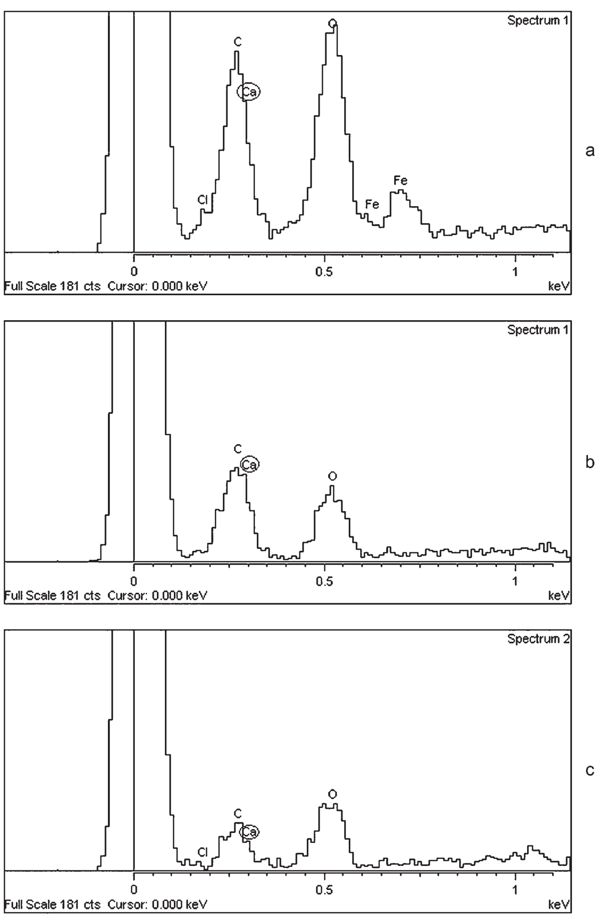

Figure 5 Energy dispersive spectroscopy for evaluation of the presence of Ca++ on the brackets bases of groups 1 (a), 2 (b) and 3 (c). The value is highest in group 1 and lowest in group 3.

Discussion

Consistent with previous research (Abu Alhaija and Al-Wahadni, 2004), the results of this investigation suggest a strong relationship between the base of orthodontic brackets and the retention capability. The wide grooves of the bracket in group 1 allowed improvement of composite resin penetration compared with the narrow grooves in group 2.

The R-system provided high bonding values. The bases of the brackets with the wide grooves (group 1) transferred the torsional stresses more uniformly to the substrate than the conventional brackets (group 3). The high torsional debonding value for the R-system can be attributed to the principle of hydrodynamics (Popov, 1968; Munson *et al.*, 2005). In fact, when a bracket, as a solid member, is stressed in torsion, the stress distribution can be obtained by the lines of constant velocity of a laminar viscous flow (Hassenpflug, 2003). Therefore, as the design of the base of the R-system bracket is based on these flow lines, concentric grooves result in lower stress concentration compared with the base of the conventional bracket.

The bases of the brackets with narrow grooves resulted in the lowest adhesion values because of the lower adhesive material penetration. Knox *et al.* (2000) showed how a particular base design allows improved cement penetration. These results were confirmed by the ARI findings.

EDS showed that the conventional brackets demonstrated less damage to the enamel surface. Group 3 showed cohesive fractures in the composite resin that left some of the resin on the enamel surface, which reduces the risk of hydroxyapatite removed after debonding. The same result was found by Sorel *et al.* (2002), who observed that with a conventional mesh

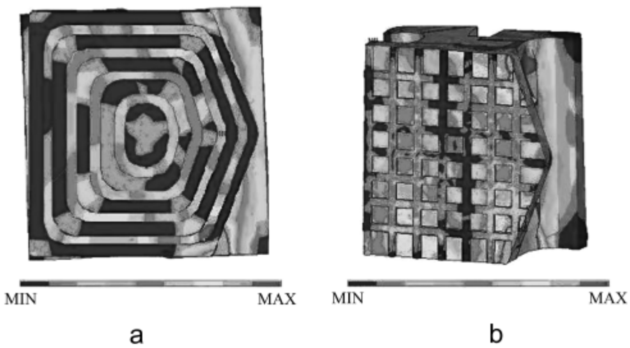

Figure 6 Finite element analysis: bracket with the mesh base (a) and concentric base (b) brackets. The mesh-base bracket shows a higher stress distribution than the novel design.

base, the debond interface was located at the bracket adhesive interface and the ARI score for this type of bracket was lower. The novel base of group 1 showed fractures located between the enamel and composite resin, which increased the risk of removal of the hydroxyapatite from the enamel surface during debonding. This was due to the higher stress values that the conventional base of group 3 is capable of transferring to the material and is consistent with the FEA results.

Conclusion

The concentric grooves of the base of the R-system bracket provide higher bond strength value but lesions to the enamel substrate are possible.

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