

Electron microscopy analysis of different orthodontic brackets and their adhesion to the tooth enamel

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Abstract

This study proposed to evaluate the surface morphology of different types of orthodontic brackets and the characteristics of their adhesion to the tooth enamel. There have been taken into study six metallic, five ceramic and one polymeric bracket from different brands (Ormco, Lancer, Leone, Damon, 3M, Ultradent, American Orthodontics, Rocky Mountain). The surface base of the each bracket it have been ESEM analyzed using scanning electron microscope Phillips XL-30 ESEM. There have been investigated several parameters that have a potential influence of the bracket-bonding agent interface joint: chemical composition, roughness, surface morphology and wideness. After ESEM analysis, the same metallic and ceramic brackets have been afterwards collated on extracted teeth and subjected to mechanical tests. After the mechanical testing, the samples were once again ESEM investigated. All fractures occurred in the area of the adhesive system, recording adhesive fractures of the tooth-composite resin and composite-bracket, cohesive fractures and both. The metallic brackets surfaces that are optima for a good adhesion is that of a mesh sand blasted and acid etched. From the esthetic brackets, the ceramic ones are superior to polymeric ones regarding bonding to teeth.

Keywords: surface texture, ceramics brackets, metallic brackets, ESEM.

Introduction

Adhesive materials and techniques have revolutionized most specialties in dentistry. Continue research in this field have made it possible in orthodontics to use fixed appliances with anchorage elements size becoming smaller and smaller – the brackets. Development and evolution of these systems on medical devices market has grown so much in recent years that there is currently insufficient comparative studies between different types of brackets used that can be objectively assessed their clinical effectiveness.

However, accidental debonding of the brackets still remains one of the most frequently encountered problems [1]. Many factors can affect the bond strength between tooth enamel and the orthodontic brackets, including the type, composition, and mode of curing of the adhesive; etching time and concentration of the etchant; bracket material and base design; loading mode, and oral environment [2].

Effectiveness of orthodontic treatment achieved with fixed appliances depends on the strength and possibilities of their anchorage. *In vitro* investigations on hybrid bond strength between orthodontic brackets and tooth enamel are quite a few in the current literature. This may be due to the need for interdisciplinary analysis or to the increased number of variable elements that implies a higher increased number of brackets that should be

analyzed so as findings to be considered statistically significant. For this reason, we conducted studies in collaboration with the Faculty of Materials Science and Engineering and the Centre for Technological Electronics and Interconnection Technique, Faculty of Electronics and Telecommunications of the Polytechnic University of Bucharest, Romania.

Aim of the study

This study proposed to evaluate the objective clinical efficiency of different types of metallic, ceramic and polymeric brackets. Using same luting agent, it is expected that some brackets present a surface treatment more suitable than others for the same appliance.

Materials and Methods

Twelve types of orthodontic brackets with different kinds of materials and from different manufacturers have been taken into study:

- six metallic brackets (Avex Mx Metal – Opal Ultradent, Damon Q – Ormco, Gemini – 3M Unitek, Nexus Metal – Ormco, Praxis – Lancer, Victory – 3M Unitek);
- five ceramic brackets (Inspire Ice – Ormco, Avex CX Ceramic – Opal Ultradent, Clarity – 3M Unitek, Nexus Clear – Ormco, Intrigue – Lancer);
- one polymeric bracket – metallic insert (Spirit MB – Ormco).

Each bracket has undergone imaging and spectral investigations of a Phillips XL-30 ESEM scanning electron microscopy device. This mode of investigation, ESEM (Environment Scanning Electron Microscopy), has the advantage to be able to obtain images with a special order of magnitude of $\times 2000$ without requiring sample preparation and without damaging the sample that is investigated.

To get statistically significant results, a total of 36 brackets (three of each type) were investigated.

Through collaboration with the Department of Oral and Maxillofacial Surgery, Faculty of Dental Medicine, "Carol Davila" University of Medicine and Pharmacy, Bucharest, Romania, were harvested permanent human teeth, included wisdom molars, with no indication of conservative treatment. Patients whose teeth were surgically removed were aged between 16 and 40 years. The tested enamel surfaces were at least twice as large as the surface of the adhesion brackets. Teeth without enamel dental caries surfaces and with the appearance of normal tooth enamel without mineralization defects, decalcification or cracks were chosen to take part into investigation.

Immediately after extraction of teeth, their surface was washed under running water and cleaned by blood and soft tissue attachments. Immediately after extraction and purification, extracted teeth were kept for two weeks in bacteriostatic solution of 0.5% Chloramine T at room temperature ($23\pm 2^{\circ}\text{C}$). Afterwards, they were transferred to distilled water in accordance with DIN ISO 3696, grade 3, in a refrigerator ($4\pm 2^{\circ}\text{C}$) [3]. The teeth were used in tests for a maximum of five weeks after extraction.

For all investigated brackets the same adhesive (TransBond Plus, 3M Unitek) and the same light-cured composite (Transbond XT, 3M Unitek) have been used (Figure 1).

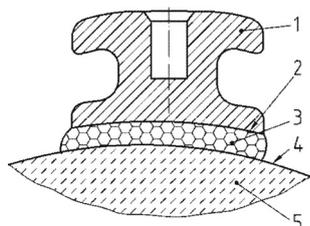


Figure 1 – Cross section of the bracket–composite–enamel assembly: 1 – Bracket, 2 – Bracket-adhesive interface, 3 – Adhesive, 4 – Adhesive-enamel interface, 5 – Enamel [4].

The steps for mounting the bracket on the surface of the enamel of each tooth extracted (Figure 2) were:

- cleaning of the enamel surface;
- adhesive application onto the enamel surface by moisturizing for 20 seconds;
- resin application on the bracket surface;
- bracket fixation to the enamel surface;
- polymerization, 20 seconds (the metal brackets tangential direction of the light beam, each 10 seconds mesial and distal to them).

After fixing the brackets, each assembly tooth–bonding agent–bracket was added to and maintained in a solution of distilled water, at room temperature.

At 24 hours after fixation, each assembly tooth–adhesive–bracket system was prepared and subjected for specific investigations of detachment shear test.

All of the brackets have been investigated before and after mechanical test using the Phillips XL-30 ESEM scanning electron microscopy device.



Figure 2 – Curing of the adhesive system after applying on the bracket surface.

Results

A total of 36 tests were made for this application, resulting in fracture values of all tooth–adhesive–bracket for each of the samples. All fractures occurred in the area of the adhesive system, recording adhesive fractures of the tooth–composite resin and composite–bracket, cohesive fractures and both (Figures 3 and 4).

Nexus Met bracket is a metal bracket obtained by casting and has a surface morphology totally different from other brackets. It has retention hooks of 0.33 mm width, which according to the manufacturer's specifications increases collage retention power by 30%. Electron microscopy images, at $2000\times$ magnification, shows that the surface between the retentions is polished, inappropriate for an adhesive agent. Under the action of orthodontic forces, it holds until a thrust average of 2.45 daN, the surface of the fracture is a mixed adhesive–cohesive fracture at the interface between the bracket and adhesive agent.

Gemini bracket is a metal bracket, made of stainless steel whose collage surface has an oblique net with sides of 0.166 mm. In terms of micromorphology, the surface appears to not be treated with acid and the surface roughness is less than that of other metal brackets with similar morphologically, as Avex Met and Damon Q. Surface separation takes place at an average force of 2.22 kgf, the type of fracture being an adhesive fracture between the metal surface and that of the fixing agent.

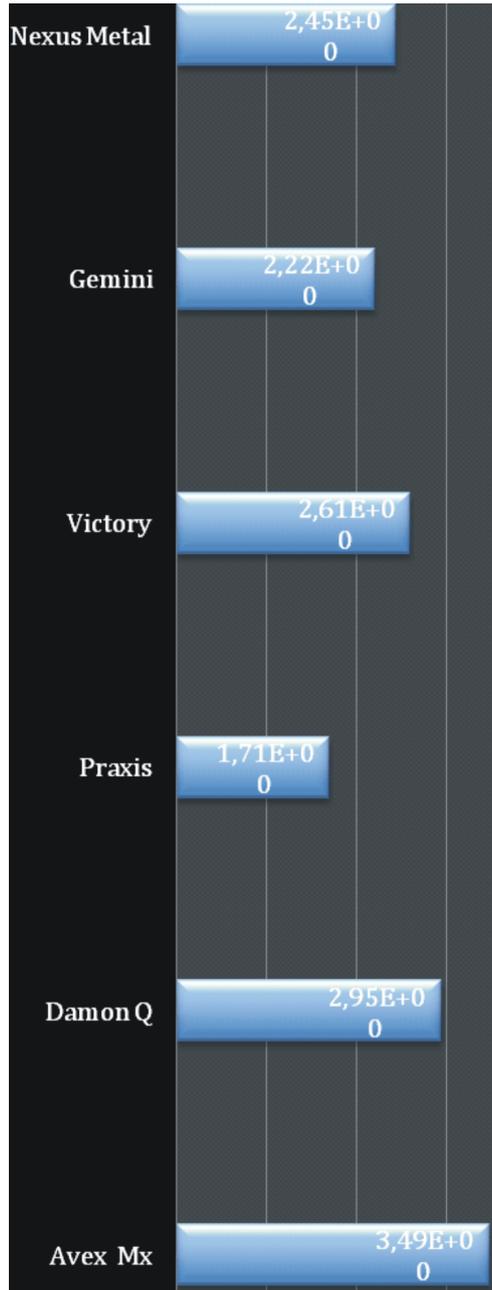
Victory bracket is a metal bracket from stainless steel, supplied in a pre coated form with a patching agent. Macromorphologically, the collage surface has an oblique net with a quadrilateral mesh and the side 0.2 mm. Micro-morphologically the surface is sandblasted and acid etched, the acid attack depressions have a diameter ranging between 1 and $10\ \mu\text{m}$. The metal surface is silanized and the diacrylate resin composite is closely applied to the metal surface, this being a hybrid, it presents ceramic silica and alumina inclusions with sizes ranging between 1 and $10\ \mu\text{m}$. The manufacturer's choice of resin composite fastening system, the method of surface preparation and silane conditioning of the metal may be the key elements why this bracket has an adherence with average link values of 2.61 daN to the substrate.

Praxis bracket is a bracket completely made of stainless steel that has the collage surface morphology of a net

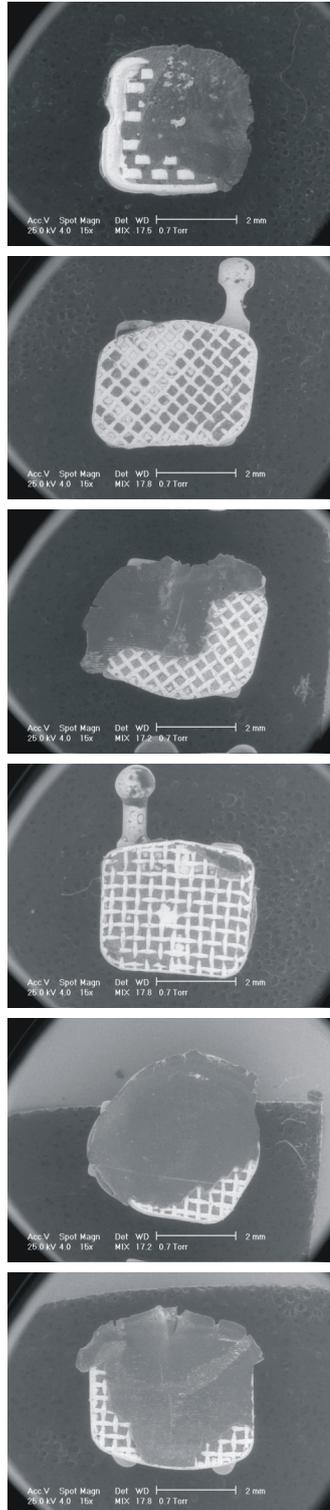
with large meshes, about 0.25 to 0.3 mm, mixed and with multiple defects in the structure, and at $\times 2000$ magnification we can see that the surface is smooth, being neither sandblasted nor acid etched. Among those investigated, so far it seems to have the worst area of collage, confirmed by mechanical stress tests, because it has the lowest value of the detachment force with an 1.71 kgf average, the fracture being exclusively adhesive at the metal interface surface.

Damon Q brackets and Avex MX are two metal brackets with similar surface morphology. Macro-morphologically, the collage surface presents a similar longitudinal net with quadrilateral mesh of side 0.166 mm, while it is observed that the surface micro-morphology Damon Q bracket seems to be acid-treated and roughness appears slightly lower than bracket Avex Met.

Mean bonding force of metallic brackets



Macroscopic aspect



Microscopic aspect

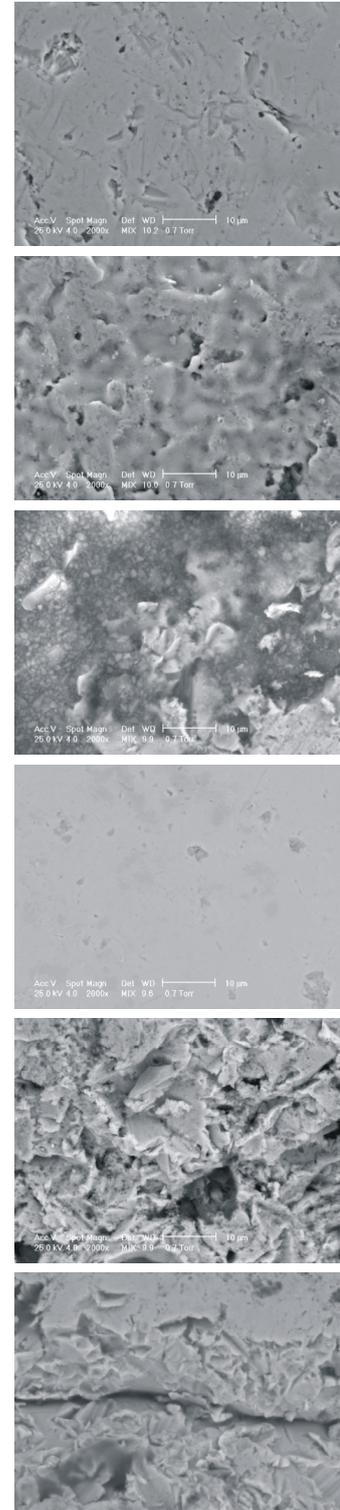


Figure 3 – Imagistic representation of mean adhesion force and surface morphology of metallic brackets.

Mean bonding force of polymeric and ceramic brackets

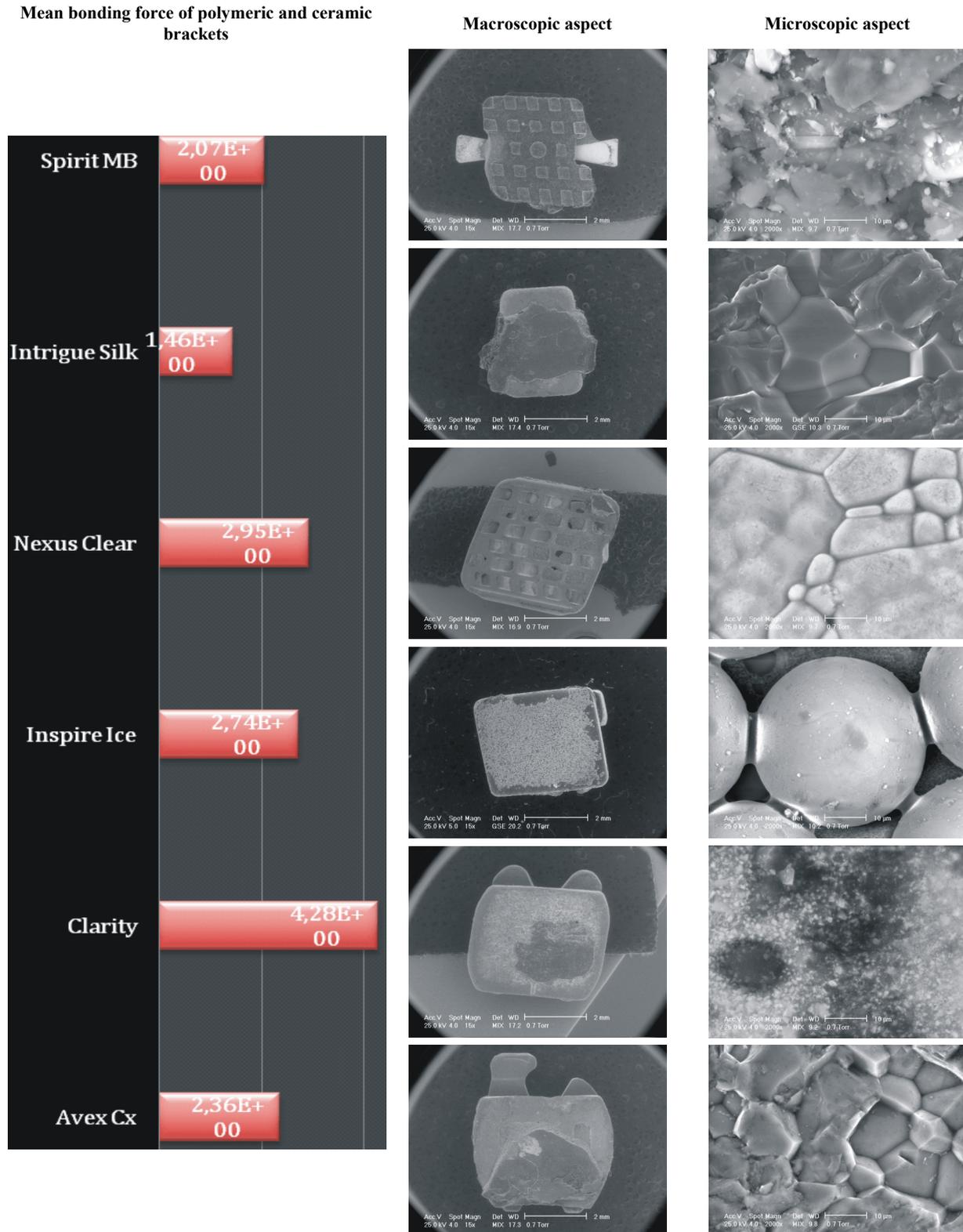


Figure 4 – Imagistic representation of mean adhesion force and surface morphology of polymeric and ceramic brackets.

Avex CX and Intrigue Silk are ceramic sapphire brackets. They present a low number of micro-roughness pits of 10 μm , resulted from the crystallizing processes. Although the manufacturers have been tried to increase the relative surface of these brackets by designing them with transversal grooves in case of Intrigue Silk bracket or chamber, as is the case of Avex CX bracket, the resistance of their bond to hard dental tissues has a median value between 2.07 and 2.36 kgf, the fracture

being and adhesive one at the interface with collating agent.

Nexus Clear bracket is a ceramic bracket obtained also from Al_2O_3 (alumina–sapphire). The surface to be collated presents also macro-retentions with the shape of polygonal chambers with 0.4 mm and micro-retentions of the crystallizing net of alumina with medium diameter of 25 μm , bigger than Avex CX bracket. This could be the reason for high values of median resistance joint up to 2.95 kgf that these brackets present.

Clarity bracket is also a sapphire ceramic bracket, Al_2O_3 , but delivered in a preconditioned silanised and adhesive pre coated. Composite resin is covered on the bracket base. Silanising and adhesive material selection make that this bracket to reach the highest value of adhesion from the ceramic ones studied of 4.28 kgf (cohesive fracture through adhesive).

Inspire Ice is a bracket obtained from Zr_2O (zirconium oxide) yttrium stabilized. On the collating surface, it can be seen big rounded micro-retentions of 30 μm diameter agglutinated in-between. Median value of the adhesion resistance of these brackets is 2.74 daN and the fracture analysis reveals an adhesive-cohesive failure.

Spirit MB is a polymeric bracket. At the base surface, it can be seen the also the polymeric matrix and filling particles formed by oxides crystals of silica, magnesium and calcium. Although has the premises of obtaining an chemical adhesion to collating agent from all the investigated brackets, the mean value of the mechanical joint resistance is extremely low, 2.07 kgf, ESEM images showing a lack of bond between this surface and adhesive (interface adhesion fracture).

Discussion

All the tested brackets correspond from clinically point of view, being reliable of obtaining a bond to adhesive agent [5, 6], but the differences in the values of the adhesion force and the modalities they are attached are quite important. This fact has a tremendous importance for the new researches for the continuous attempt of reducing brackets size, making them more esthetic and easier to be cleaned.

Many studies from literature shows that current composites materials and modern adhesives that include 7th generation adhesives corresponds from biomechanical point of view to all orthodontic clinical requirements [5–8]. Transbond XT is already a well-known product utilized in orthodontics. Many *in vitro* and *in vivo* studies already showed its clinical efficiency in the majority of clinical situations [9–12]. As in selected readings [13–15], we noticed the vulnerability of the bracket-adhesive-tooth system at the bracket-adhesive interface.

The variables associated with shear bond strength are amongst others the surface treatment of the adhesive contact surface, the size and the design of the bracket bases [16].

Nowadays, there are many types of treatment that may be applied to bracket bases such as micro-etching, sandblasting, polymer coating or a spray with fine particles of molten metal [17]. In our study, we found out that the metallic brackets surfaces that are optima for a good adhesion is that of a mesh sand blasted and acid etched. Sandblasting also appears to be an effective method of cleaning bracket bases before rebonding.

Literature data show that the design of the bracket base adhesive pad has been found to be a significant factor in mean shear bond strength [16], while 75% of brackets with a simple foil mesh base undergo bond failure at the bracket adhesive interface [18]. However, single- and double-mesh bracket bases have comparable shear bond strength and bracket failure modes [19]. The brackets with the larger mesh size produced greater bond strength than the brackets with smaller mesh sizes [20].

In other studies [21], have been investigated Victory series (3M Unitek), Upper Molar (GAC) and Optimesh XRT (Ormco) brackets, the shear bond strengths of all Ormco bracket/adhesive resin combinations (5.8–6.8 MPa) were significantly lower ($p < 0.05$; Kruskal–Wallis test) than the other bracket/adhesive combinations (9.4–12.1 MPa). The different adhesive types are not mainly responsible for the low shear bond values found for the Ormco bracket. The 3M Unitek combinations of the Victory series bracket and Transbond XT adhesive showed high shear bond strength without enamel damage. Another study comparing three ceramic brackets (Allure[®], InVu[®], and Clarity[®]) and one metallic bracket (Geneus[®]), bonded with Transbond XT[®] did not found any statistically significant difference in relation to the shear bond strength loads. However, Clarity[®] brackets were the most affected in relation to the surface topography and to the release of mineral particles of enamel (Ca^{2+} ions) [22].

Enamel acid etching plays an important role in treatment on direct bracket bonding. Several studies have been carried out concerning the damage this procedure causes to the enamel. A valuable alternative seems to be the use of photopolymerizable resin-reinforced glass ionomer without acid etching of enamel [23]. The success of the bracket bonding procedure also depends on the surface characteristics of the enamel. The teeth with hypomineralized defects usually show high failure rates of adhesives because the surface characteristics of the involved enamel prevent from achieving the etching patterns observed in sound enamel [24].

Conclusions

The correlations between imagistic results obtained using scanning electron microscopy before and after mechanical tests and numerical results of the shear test permitted a carefully evaluation of the parameters implied to the brackets adhesion to enamel. The metallic brackets surfaces that are optima for a good adhesion is that of a mesh sand blasted and acid etched. From the esthetic brackets, the ceramic ones are superior to polymeric ones regarding bonding to teeth. From the sapphire brackets analyzed, Nexus Clear establishes a better bond possible due to different type of surface treatment than Intrigue Silk and Avex CX. Both the case of metallic and ceramic brackets the highest values of the adhesion forces are obtained when the surfaces are conditioned by silanising and protected immediately after by adhesive resin.

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