Effect of bracket base design on shear bond strength of bracket- adhesive - tooth system: FEA study

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Introduction

Human teeth are generally of importance in chewing foods, articulation of primary sounds in phonation and also in face aesthetics Orthodontic braces are a device used in orthodontics to align teeth and their position with regard to a person's bite. They are often used to correct malocclusions such as underbites, overbites, cross bite and open bites, deep bites, or crooked teeth and various other flaws of teeth and jaws, whether cosmetic or structural. Orthodontic braces are often used in conjunction with other orthodontic appliances to widen the palate or jaws or otherwise shape the teeth and jaws [1].

Most of problems in dentistry can be investigated from a biomechanical point of view. Fixed appliance therapy in orthodontics relies on the effective bonding of brackets to enamel surface. The occurrence of bracket bond failure (debonding) is one of the most frustrating aspects during orthodontic treatment; because it results in increased treatment time, additional costs in materials and personnel, additional visits by patient and increased vulnerability of enamel to fracture and crack. Recently challenge is to develop a bond between orthodontic attachments and enamel surface that is strong enough to accomplish treatment but can be broken for debonding without damage to enamel surface. Orthodontic bond tests are usually carried out with enamel and orthodontic bracket being bonded with an orthodontic adhesive [2,3].

There are a lot of factors which control the efficacy of bond strength such as tooth surface preparation, type of adhesive, cement thickness and uniformity, the location and direction of load application, bracket material, bracket base design, curvature of enamel and storage time and conditions before testing [2,4].

The most of studies up to now just considered a simplified geometry, so comparing the obtained results with real clinical results were beyond of the fact. Therefore, in this study the real shape of a tooth was considered using micro CT scans of bracket and tooth, so the geometry (shape, curvature,..) are the most similar to the real ones and can be compared with the clinical results.

Problematic & objective

Problematic: Different factories produce bracket sets with different bracket base configurations for teeth. It makes the question in minds that which of these bracket sets generates the most bond strength.

The finite element method is a state- of- the- art engineering analysis tool developed and refined during the last 30 years. In dentistry, its application has been in the calculation of stresses and strains within structures associated masticatory system (jaws, teeth, restoration). The FEM is based on dividing initiate(in shape or material) composition object into groups of appropriately connected small basic elements whose mechanical behaviors (stress- strain relationships) we can characterize [5].

Objective: Orthodontic bracket can be bonded to tooth with a thin adhesive layer. Using finite element method stresses and strains distribution can be found in bracket- adhesive- tooth system.

Difference between this study and previous studies is that it has used micro CT scans of bracket and tooth, so the geometry (shape, curvature,..) of them are the most similar to the real ones and can be compared to the clinical results.

Method and Materials

Micro CT scans of central tooth and bracket were provided to resemble the real configuration of them. Slices of Micro CT scans of tooth and bracket were imported in **Mimics10**. 3000 horizontal slices of tooth were reconstructed. The layers of tooth were separated as enamel, dentin and pulp layers. Each 3D layers of tooth and bracket was exported as **STL** files. The length of tooth was 29 mm and the length of enamel was 9 mm.

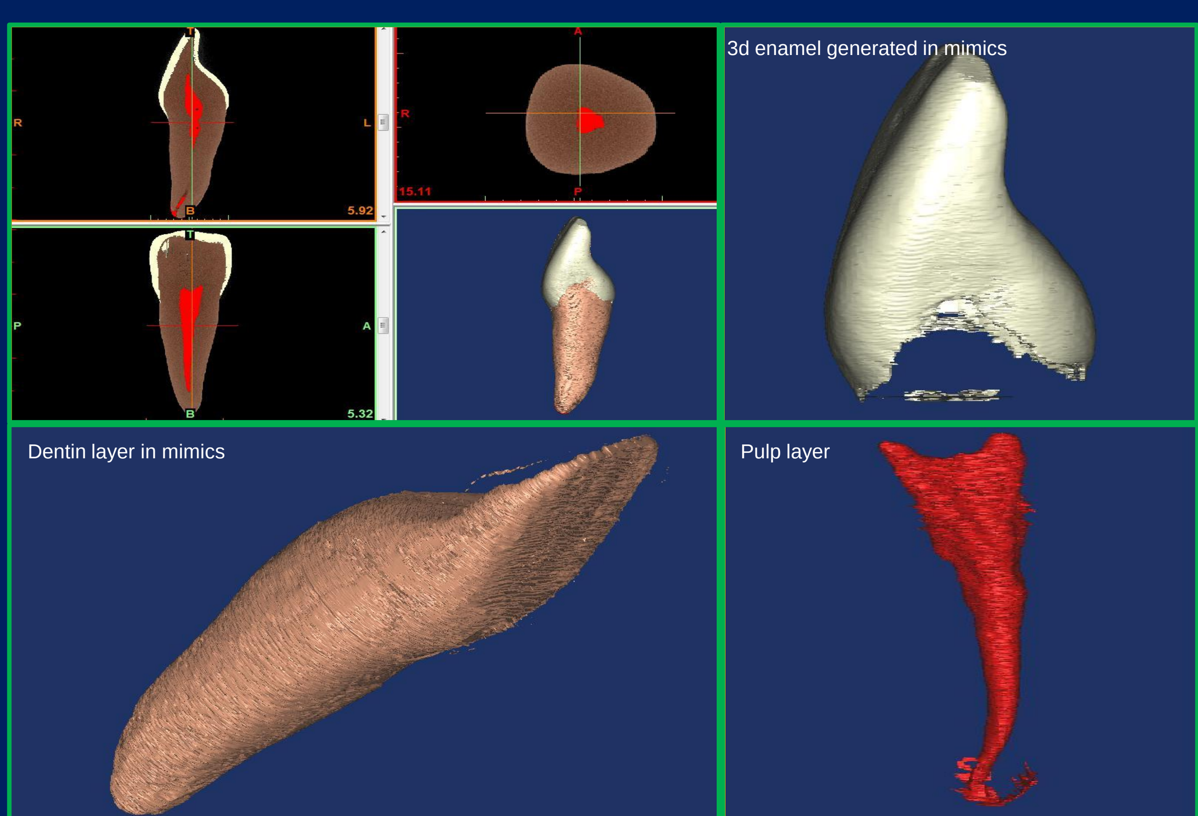

Figure 1: Three layers of tooth obtained in Mimics

CATIA V5r18 was used to edit these STL files of enamel, dentin, pulp and bracket. An optimized surface mesh of each layer (without smoothing) was obtained in CATIA and they were exported as **STL** files.

STL files of bracket and tooth layers were imported in **HyperMesh**. Space between enamel surface and bracket base was filled with orthodontic adhesive and set to 0.17 mm at thickest part and 0.05 mm at thinnest part. Bracket was bonded on enamel with 4 mm distance from the enamel head. contact elements for the contact between dentin and enamel, enamel and bracket; and bracket and adhesive were each generated in a component. High quality 3D mesh was generated for all components including dentin, enamel, adhesive and bracket. Tetragonal element type (Tet4) was used as 3D elements simulation geometry of them. Three dimensional finite element models consists of 119779 elements for enamel, 178830 elements for dentin, 15503 elements for adhesive layer, 144647 elements for bracket.

To calculate stress and strain in the bracket- adhesive- tooth system, **OptiStruct** software was applied and results was plotted and processed with **HyperView.**

Despite the viscoelasticity of periodontal and dental structures all of the materials were assumed to be homogenous, isotropic and linear static. The mechanical properties of materials were obtained from previous studies and are summarized in table below, and the outlines of models and boundary conditions are given in figure below.

Table 1: Mechanical properties of materials [6]

	E (MPa)	ρ (g/cm^3)	ν
Enamel	79000	2.9	0.3
Dentin	19000	2.2	0.3
Adhesive	5000	1	0.38
Bracket (stainless steel)	200000	7.9	0.27

By using a load distributing element RBE3 a 5 Newtons shear load was applied to the bracket. Analysis was presumed to be linear static. At last the results of bonding of bracket on tooth were obtained. Stress and strains that generates in bracket- adhesive- tooth system would be comparable with clinical results. It is assumed that different parameters affect the bond strength of the system such as thickness of adhesive layer, direction of applied load, adhesive material and bracket base configuration [7]. This study also would helps to investigate the affect of changing these parameters with a finite element method.

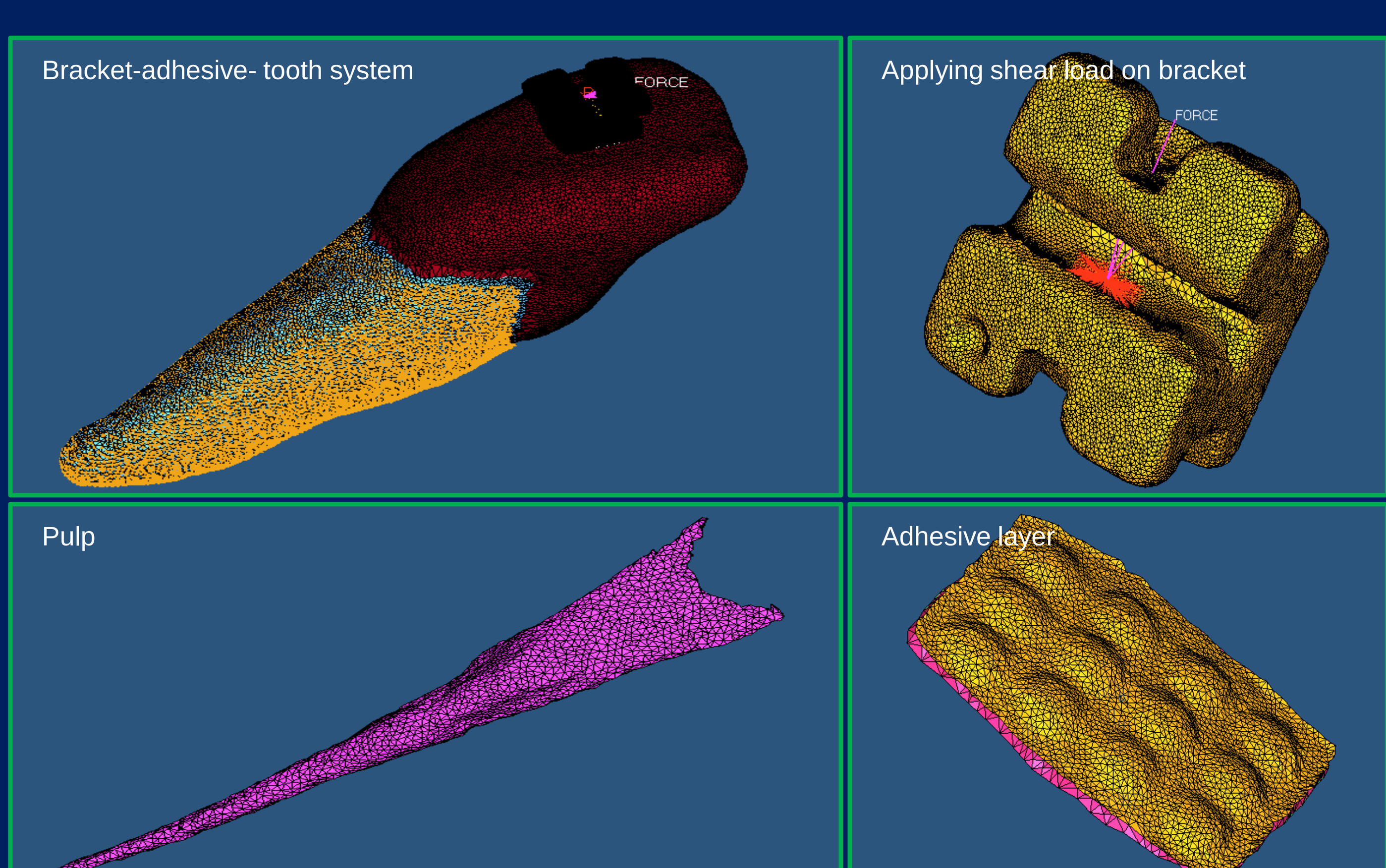

Figure2: Bracket- adhesive- tooth system , applied boundary conditions and different layers

Methods and Materials

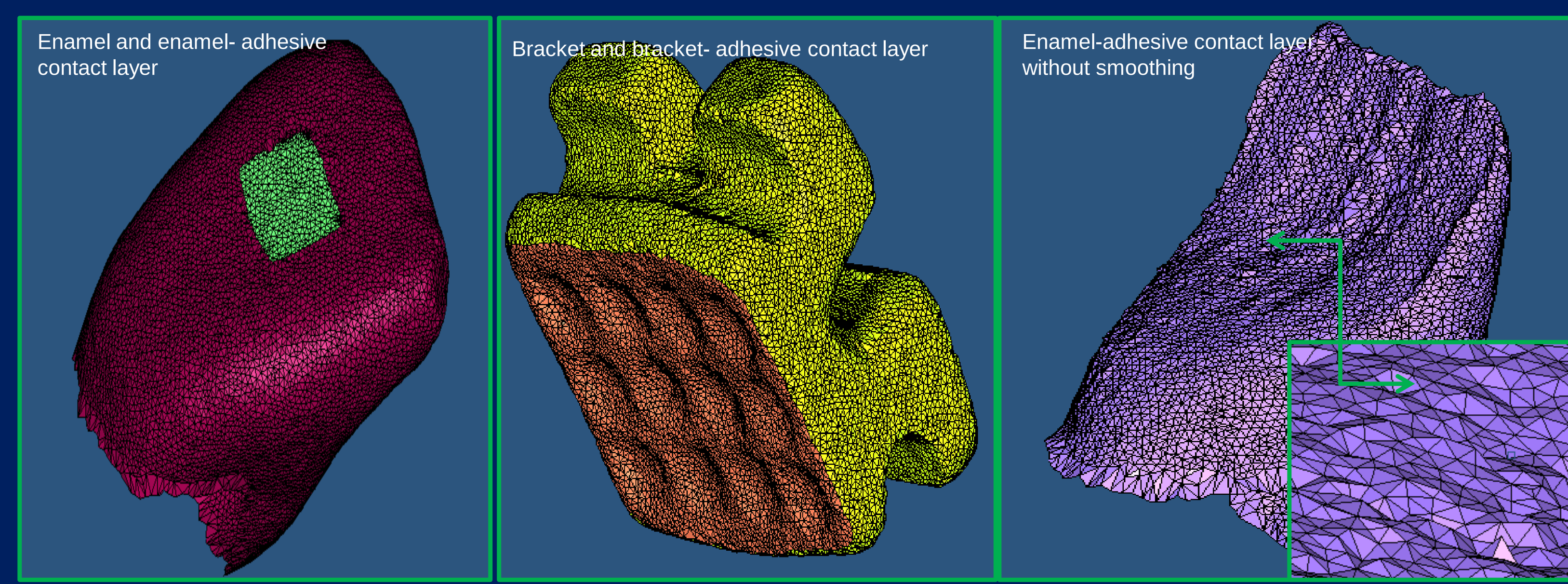

Figure 3 : Different layers of bracket- adhesive- tooth system

Results

The Vonmises stress distribution of enamel, dentin, bracket and adhesive layer was obtained. Results were plotted in Hyperview. In the bracket the highest stresses generates on the slot where the shear load was applied. Stresses in bracket was between (3-13) MPa in the lower half of bracket. Stresses on the base of the bracket was more toward the periphery of it (1.8- 6.8) MPa and stresses in other places were lower (0.0003- 1) MPa. figure 3 shows the stress distribution in bracket.

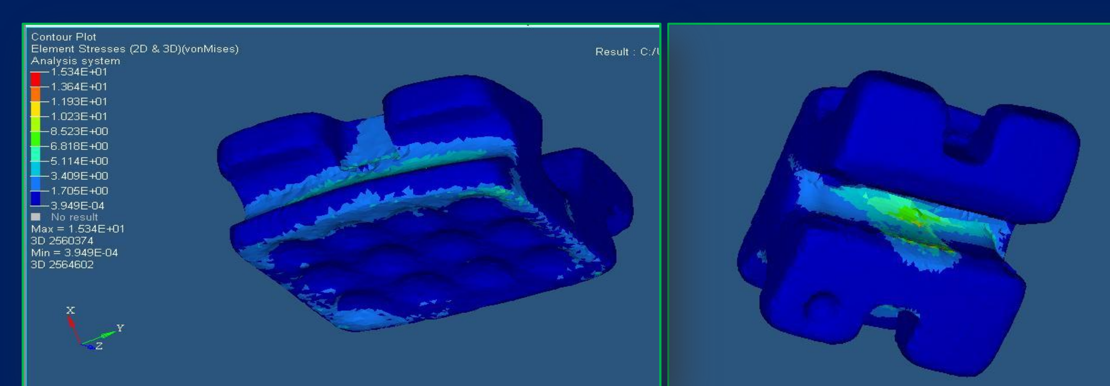

Figure 4: Contour of stress within the bracket

Adhesive layer plays an important role in bracket- adhesive- tooth system. It is connected to bracket base on one side and enamel surface on the other side. Adhesive has the weakest mechanical properties in the system to debond from the tooth before the enamel damages. Stress distribution on the adhesive layer was similar to bracket base. Stress was between (1.5-6.8) MPa around the periphery of adhesive layer. Its magnitude was higher at lower half of the adhesive. figure 5 shows the stress distribution in adhesive layer.

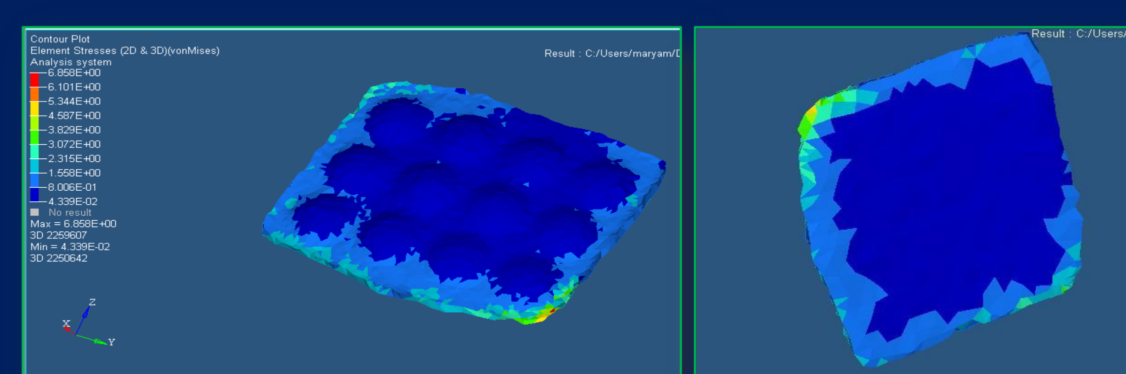

Figure 5: Contour of stress within the adhesive layer

Stresses generated in enamel layer was between (2-3) MPa around the surface where adhesive was attached to it. It was between (0.004- 2) MPa at other points according to figure 6.

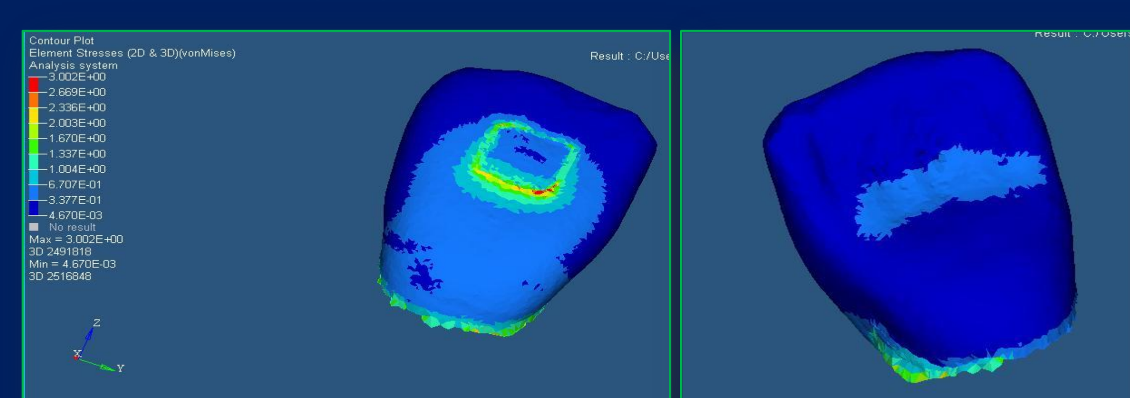

Figure 6: Contour of stress within enamel

Applying load on the bonded bracket generates stresses within dentin layer too. Stresses generates at the lower part of contact between enamel and dentin and near the part that constraints have been applied to dentin. Its magnitude is between (0.2-1.6) MPa.

Stresses also generates right under the place where the bracket was bonded to enamel with a lower magnitude between (0.1- 0.3) MPa.

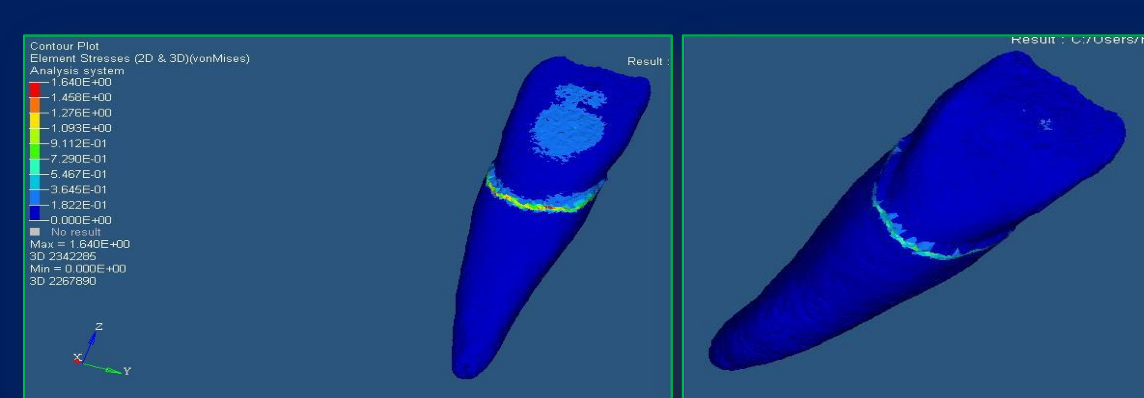

Figure 7 Contour of stress within dentin layer

Conclusions

It is absolutely important for orthodontics to understand bond strength of different orthodontic bracket- adhesive- tooth systems to the end of selecting the optimal one for the clinical situation. To evaluate the bond strength of a complicated three dimensional model and stress distribution generated within different layers of the system are usually difficult [4]. This study uses FEM analysis to investigate stress distribution within the system. A fine FE mesh was used to represent material interface as fine mesh size insures convergence of FE solution. Stresses that generates within layers are inversely proportional to bond strength. It means that the zones with higher stresses would be more prone to fracture. These zones were determined in this study. In this way these zones can be reinforced to sustain more stresses.

The configuration of base of bracket in this study caused that the stresses distributed around the periphery of bracket and adhesive. Stresses generated in enamel also had higher magnitude around the place where bracket was bonded on them. So it can be concluded that mesh spacing of bracket base, size and shape of barcket may affect the shear bond strength of the system.

References

1. Kuhlberg Andrew, Nanda Ravindra. Biomechanics and esthetic strategies in clinical orthodontics, principles of biomechanics, chapter 1,pages 1-15.
2. Powers JM, Kim HB, Turner DS. (1997). Orthodontic adhesives and bond strength testing. *Seminars in Orthodontics*, NO 3, 147-156
3. Rajagopal R, Padmanabhan S, Gnanamani J. (2003). A Comparison of shear bond strength and debonding characteristics of conventional, moisture- insensitive and self-etching primer. *Angle Orthod*, 74, 264- 268
4. Hioki M, Shin-Ya A, Nakahara R. (2007). Shear bond strength and FEM of a resin-modified glass ionomer cement —Effects of tooth enamel shape and orthodontic bracket base configuration. *Dental Materials journal* , 26(5), 700-707.
5. Katona Thomas R.,Moore Keith. The effects of load misalignment on tensile load testing of direct bonded orthodontic brackets- a finite element model, **A**M **J O**RTHOD **D**ENTOFAC **O**RTHOP, 1994, 105:553-51.
6. Dorow Christina, Sander Franz-Gunter (2005), Development of a model for the simulation of orthodontic load on lower first premolars using the finite element method. Journal of orofacial orthopedics, 66:208-218
7. Chalgren R, Combe EC, Wahl AJ. (2007). Effects of etchants and primers on shear bond strength of a self-ligating esthetic orthodontic bracket. *Am J Orthod Dentofacial Orthop*, 132, 577.