Comparison of Stresses generated by Different Bracket Debonding Forces using Finite Element Analysis

Tarulatha R Shyagali, Deepak P Bhayya, Amit Prakash, Nitin Dungarwal, Adit Arora

ABSTRACT

The purpose of the study is to evaluate the stresses generated at bracket-cement and the tooth continuum by different bracket debonding techniques commonly used in orthodontic clinic.

Materials and methods: Peeling, twisting and masticatory force of one Newton was applied on the finite element model of bracket-cement and the tooth assembly and the principle stresses were obtained through the ANSYS software. The validated three-dimensional finite element model of the bracket-cement-tooth system constructed for the study consisted of 40,536 nodes and 49,201 finite elements.

Results: The results showed that the debonding stresses generated by masticatory and twisting forces were 4.781 MPa and 4.140 MPa respectively on enamel, whereas peeling force produced 3.480 MPa stress on the enamel.

Conclusion: Peeling force produced less stress on enamel suggesting peel load is best to debond the orthodontic bracket.

Keywords: Stress, Bracket debonding, FEM, Peel load.

INTRODUCTION

Orthodontic treatment relays on the brackets bonded to the tooth surface for the effective application of the force to bring about the desired changes. Thus, the good bond strength of the bonded bracket becomes inevitable in day to day practice. However, when debonding of the bracket is ventured after the orthodontic treatment, one can either notice a remnant of resin on the enamel surface or else fractured enamel.1-4 Even though enamel is quite appreciable in thickness but removal of it’s superficial layer might be an alarming call, as the distorted surface texture of the enamel will lead to the harboring of the microorganisms, which further enhances the decalcification.4

Various methods of debonding have been studied with enamel fracture as a background and several studies have utilized stress analysis for the evaluation of the same.5-8 Earlier studies were done utilizing photoelastic stress analysis which had several limitations, of which the lack of photoelastic material which stimulates the physical properties of tooth is worth mentioning.9,10 Nevertheless, with the advent of new era of technology, stress analysis is been made easy, accurate and valid. Finite element method of stress analysis is the pioneer system in the field of stress analysis and its advantages are quite satisfactorily used in various fields of science and the field orthodontics is not an exception.

The primitive FEM studies were done with the objective to evaluate the stress generated in craniofacial complex due to the application of orthopedic forces.11,12 However, the finite element method has only recently been applied to the evaluation of orthodontic attachment and earlier studies were based on two-dimensional system finite element model of the bracket tooth interface to assess the stress distribution in the system when bracket removing forces are applied.8,13 The studies utilizing three-dimensional models are very few and the purpose of the present study is to compare the stress generated by three different loads (masticatory, peel and twisting) by employing a three-dimensional finite element computer model and to study the effect of variation of bracket base design on the stresses produced.

MATERIALS AND METHODS

AutoCAD (Autodesk Inc, USA) model of a maxillary first premolar was built utilizing a premolar scans obtained at 0.5 mm longitudinal section by CT scanner (General Electronics, USA). The model thus generated was transferred to a finite element...
packages as an IGES (initial graphics exchange specification) file format.

Using digital measurements of these sections, the three-dimensional coordinates of the tooth were recorded and a finite element mesh was generated using a commercial mesh generating programmer (ANSYS 7.0).

Using electronic slide vernier caliper, the measurements of maxillary 1st premolar bracket were made and the model of the bracket was generated. The data from the previous literature was used for the generation of cement layer and impregnated wire mesh (IWM). Thickness of approximately 271 µm was kept for the cement layer and IWM was considered as cement embedded in the wire base mesh.

The material parameters used in the computations are similar to those used in previous studies, which comprised of Young’s modulus and Poisson’s ratio (Table 1). As per the literature the Young’s modulus of the dental composite lie between 10000 and 16000 MPa, due respect to this, we took the cement’s Young’s modulus to be 11,721 MPa which lied within the mentioned range, allowing us the advantage of fulfilling the criteria of composite as well as the cement, it simultaneously allowed us better scientific comparison with the earlier studies which were based on the similar material properties. Poveda R et al, in their article on Poisson’s ratio of hollow particle filled composites state that despite being a fundamental elastic constant, reliable value of Poisson’s ratio of various types of composites is not readily available and they highlight the need for comprehensive understanding of Poisson’s ratio for the engineered composites. We have taken the Poisson’s ratio from the earlier literature related to FEM study, which enabled more accurate comparisons.

The complete three-dimensional finite element model of the bracket cement tooth system consisted of 40,536 nodes and 49,201 finite elements (Fig. 1). To keep the size of this complex model within reasonable limits, only the relevant areas of the tooth were modelled, the remainder being substituted by appropriate boundary conditions.

The bracket mesh was altered by keeping the wire spacing 300 µm as constant and the wire diameter was varied from 100 to 400 µm for comparison of stresses generated by different types of forces. The necessary peel force/masticatory/twisting force were applied to the bracket model at appropriate model positions (Figs 2 to 4). Finite element model of tooth–cement–bracket system which we have created is linear in nature, thus allowing us the freedom in applying the variable magnitude of force and we choose 1 Newton load for the analysis.

Table 1: Material properties

<table>
<thead>
<tr>
<th>Material</th>
<th>Young’s modulus (MPa)</th>
<th>Poisson’s ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enamel</td>
<td>46,890</td>
<td>0.30</td>
</tr>
<tr>
<td>Cement</td>
<td>11,721</td>
<td>0.21</td>
</tr>
<tr>
<td>Stainless steel</td>
<td>210,000</td>
<td>0.30</td>
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</tbody>
</table>

Fig. 1: Finite element model of tooth-cement-bracket continuum

Fig. 2: Tensile or Peel load case

Fig. 3: Masticatory load case

Fig. 4: Twisting load case
RESULTS

The stresses generated in the Tooth-IWM-Bracket continuum due to three different loads, i.e. masticatory, peel and twisting force (Table 2). The stresses generated varied from 1.200 to 1.170 MPa in enamel, for IWM stresses varied from 3.480 to 3.491 MPa and for the bracket it varied from 9.444 to 9.700 MPa for the peel force. For the masticatory force the stresses generated in enamel remained constant for different wire diameter at 2.247 MPa. In case of twisting force also the stresses generated remained constant for different wire diameter, at the enamel layer stresses was 4.410 MPa, at IWM it was 0.452 MPa and at bracket 6.500 MPa.

DISCUSSION

Evaluation of the bond strength of the bracket as so far lead to conflicting results and researchers have identified number of variables which might exert their influence on the bond strength of the bracket like, weld spots, weld spurs, location of weld spots and air entrapment.

Considering relative ease with which modelling of different object is possible with FEM, it is the tool of choice to generate bracket-cement-tooth continuum. The study utilized the bonded orthodontic bracket which was subjected to a range of forces, like peel, masticatory and twisting load during elective bracket removal. After this the stresses generated were obtained in the form of graphs and tables.

By comparing these three different load cases, we see that, the stresses generated at all the layers of tooth-cement-bracket interface remained high in case of peel load except for enamel. But stresses generated at the IWM and the brackets were low in case of twisting force. Thus, suggesting that the peel force is better for debonding of the bracket as it produced minimal enamel damage. Similar results were obtained by Rossouw PE and Terblanche E in their study on stress distribution during debonding. Twisting and masticatory forces almost generated same level of stress on the enamel, thus suggesting the chances of enamel breakage. According to Chen-Sheng Chen et al, there existed no significant difference in enamel fracture with different debonding forces (shear, torsion and tensile force).

It is not only the type of debonding force which influences the enamel damage, it also depends on the site of debonding and in the light of this the recent investigation has proved that there existed a significant difference in the shear bond strength at different debonding locations like bracket base (group A), ligature groove (group B), occlusal bracket wings (group C). Other factors like direction of the debonding force also influence the shear bond strength.

In case of ceramic bracket the bond failure occurs primarily at the bracket-adhesive interface, which is in contrast to the metal brackets, where the debonding occurred at the enamel and adhesive interphase. However, in one of the FEM studies on debonding in case of metal and ceramic brackets, it is found that, irrespective of the combination of brackets and composite materials used, debonding in the Y direction causes the least damage to the tooth structure. Nevertheless; one has to test the reliability of the results of virtual model in clinical situations. However, in a review article on the ceramic brackets, Bishara and Fehr, mention that the addition of grooves, recesses, or a rough surface by the manufacturer onto the base of the ceramic brackets to increase the surface area allowed more mechanical interlocking and less need for chemical adhesion between the bracket and the adhesive.

Same thing was also stressed by Guess et al, who stressed the need of banning additional chemical bond by the silane.

CONCLUSION

The peel force is better for debonding purpose as it produced less stresses at the enamel level, thus reducing enamel breakage. By varying the design of mesh base we can produce desired bond strength and stress at the enamel level.

Further studies need to be done in the orthodontic attachment area related to bracket base mesh designs as there are relatively few studies in this regarded. This study can be used as reference for further investigation.

<table>
<thead>
<tr>
<th>Diameter (μm)</th>
<th>Forces (1N)</th>
<th>Masticatory force (N)</th>
<th>Peel force</th>
<th>Twisting couple (N mm)</th>
<th>Peal force</th>
<th>Masticatory force (N)</th>
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<td>2.247</td>
<td>9.617</td>
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<td>4.140</td>
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μm: Micrometer; N: Newton; MPa: Mega pascal
Dr V Surendra Shetty, the former President of the Indian Orthodontic Society from the year 1995 to 1996 and Past Chairman of Indian Board of Orthodontics (2008-2009) has been designated as Pro Vice Chancellor of Manipal University, Manipal, with effect from July 1, 2012. He will be the in-charge of the Mangalore campus of the University and will oversee its development.

Dr Vorvady Surendra Shetty born on July 5, 1947 in Parkala, near Manipal in Udupi District, is a first batch graduate from the first private dental college of the country, College of Dental Surgery, Manipal. Dr Shetty received the Dr TMA Pai Blue Ribbon Gold Medal for best outgoing student in the year 1970. He was also the state award winner for topping in BDS in the University of Mysore. He continued at the institute as a faculty and also became a student of the institutes’ first batch of the Postgraduate Orthodontic Program.

In January 1987, he was appointed as the Director of the newly started Manipal College of Dental Sciences in Mangalore, the second dental college of the Manipal group. He has been heading the college as Director/Principal/Dean over 25 years from its inception till date.

He is widely regarded by his peers as an eminent academic and administrator, yet most important of all he is a much loved teacher.

REFERENCES

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Congratulations

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