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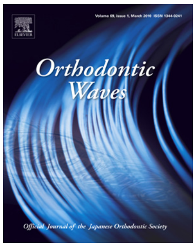

Original article

Optimization of orthodontic bracket base geometry for planar enamel surface teeth: A finite element study

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ABSTRACT

Purpose: The bonding strength of bracket-adhesive tooth system should be high enough to withstand different loads applied either for treatment purpose or by patient. Different parameters affect the bond strength of bracket-adhesive-tooth system; however, only a few studies have reviewed the effect of orthodontic bracket base on bond strength of bracket-adhesive-tooth system. In this study, optimization of the bracket base geometry for teeth with planar enamel surface was investigated in order to increase the shear, tensile and torsional bond strength of bracket-adhesive-tooth system.

Materials and methods: Rectangular bracket was primarily bonded on maxilla central tooth to measure stress distribution of bracket-adhesive-tooth system with applying shear and tensile forces and torsional moment. Trapezoidal, hexagonal and elliptical brackets were then modeled for this planar enamel surface tooth. All of these brackets were bonded to tooth separately and similar loading conditions were applied on the bracket of each system. Stress distributions of bracket-adhesive-tooth systems were calculated and compared to each other.

Results: It was observed that for hexagonal bracket-adhesive-tooth system, adhesive layer and enamel, and for elliptical bracket the bracket and enamel layer were of more symmetric and appropriate pattern of stress distribution and lower maximum stress. Therefore, these shapes of bracket are more proper than the other two shapes for a planar enamel surface tooth.

Conclusion: Bracket base geometry was confirmed to crucially affect the bond strength of bracket-adhesive-tooth system through finite element analysis approach.

1. Introduction

Fixed orthodontic treatment relies on effective bonding of orthodontic bracket to enamel surface. Bracket debonding during treatment is an undesirable incident both for patient and orthodontist [1], and results in the increase of period and expense of treatment [2]. It has been shown that there are a lot of factors which control the efficacy of bond strength such as tooth surface preparation, type of adhesive, cement thickness

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and uniformity, the location and direction of load application, bracket material, bracket base design, curvature of enamel and storage time and conditions before testing [3,4].

Although various experimental tests exist to investigate different factors affecting bond strength of bracket–adhesive-tooth system, determining the exact amount of bond strength with common mechanical tests is not possible. Because of diversity of current designs it is difficult to generalize the results of these tests and one of the best ways to overcome these limitations can be using three dimensional finite element analyses [6]. When a load is applied on bracket–adhesive-tooth system, stress distribution can be identified with this method [1,4]. Identification of stress distribution pattern would help to recognize the areas with high stress concentration and prone to failure [7].

Primary studies in finite element method have analyzed two dimensional models but they did not reflect the reality of tooth structure because of its irregularity and asymmetry [5–7,9,10]. Subsequent studies performed three dimensional analysis that were more accurate, nevertheless most of these efforts led to low quality three dimensional models. Most of these studies have used anatomical information listed in dental literature or plastic models of digital images for reconstruction of tooth structure [5,6], but they were not accurate images. The most accurate three dimensional model of tooth structure can be obtained by micro-scale computed tomography [7,11,12,13] that has been utilized in this study. According to previous studies [5,9,14] anatomical details of dentin and pulp do not affect the results of this study so they can be ignored.

Some factors that might affect shear bond strength have not been examined yet. Bracket base geometry has not been clearly investigated in previous studies [5], while it might alter the stress distribution on bracket–adhesive-tooth system. Sharp corners act as points with high stress because of providing less surface area and abrupt change in surface area. Therefore, the aim of this study is to examine whether different bracket base geometries change stress distribution. It was hypothesized that the sharper the corners of bracket base configuration, the higher the stress concentration would be.

2. Methods and materials

Micro CT scans of maxilla central tooth and bracket were prepared by Sky-Scan1172 High Resolution Micro CT device (Sky-Scan, Kontich, Belgium). Images of tooth and bracket were imported in Mimics10 (an image processing software package for three dimensional designs, Materialise software). Three dimensional layers of tooth and bracket were reconstructed in this software. Mimics also has the susceptibility of omitting the noises that are developed during scanning, thresholding and segmenting of tooth layers (enamel, dentin and pulp). Each 3D layer of tooth and bracket were exported as STL files.

STL files are a set of manual surface meshes. These surface meshes of tooth and primary rectangular bracket were edited and optimized in CATIA v5R20 (CAD/CAM/CAE commercial software suite developed by the French company Dassault Systems) and they were exported as STL files. Modified STL files of bracket and tooth layers were imported in HyperMesh (HYPERWORKS version 10, Altair Engineering, Troy, Minn). Primary rectangular bracket was bonded on enamel according to the standard distance from the enamel incisal. The standard distance is 4.5 mm for maxilla central tooth. Space between enamel surface and bracket base was filled with orthodontic adhesive. Contact surfaces for the contact between dentin and enamel, enamel and bracket; and bracket and adhesive were generated in separate components. Surface mesh of all the layers of the system was edited for the last time. Finally 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. Number of three dimensional elements for enamel, adhesive and bracket are denoted in Table 1.

All of the materials were assumed to be homogenous, isotropic and linear elastic. Mechanical properties of materials were obtained from previous studies as summarized in Table 1 [5,9,10].

Proper boundary conditions were applied to the system. As in oral environment, dentin is fixed by the alveoli bone apically 1.5 mm below cementoenamel junction (CEJ), so all six degrees of freedom of the nodes in this area were constrained in order to simulate the oral condition. Three different linear static loading conditions including inciso-gingival 5 N shear force, 5 N tensile force and 5 N mm torsional torque were applied to the base of each bracket by using a load distributing element RBE3, in three different steps. Constrained areas and applied loads to bracket are observed in Fig. 1.

Primary bracket had rectangular cross section. As the purpose of this study was optimization of bracket base geometry for maxilla central tooth, three other shapes of bracket base were modeled for this tooth in CATIA while they had the same cross sectional area as the primary rectangular bracket. These three other shapes of bracket including trapezoidal, hexagonal and elliptical shapes were bonded to tooth with an adhesive layer in Hypermesh. Proper boundary conditions in accordance with what was explained for primary rectangular bracket were applied on each system. Fig. 2a–c shows the new modeled shapes of bracket for maxilla central tooth.

OptiStruct software (HYPERWORKS version 10, Altair Engineering, Troy, Minn) was applied to analyze the primary and new modeled bracket–adhesive-tooth systems and results

Table 1 – Mechanical properties of materials and number of tetragonal elements for bracket–adhesive-tooth system.

	Young's modulus (MPa)	Poisson's ratio	Element numbers
Enamel	7.9×10^4	0.30	119,977
Adhesive	5×10^3	0.38	5357
Bracket (stainless steel)	20×10^4	0.27	46,337