Finite element analysis of orthodontic bracket tie wing deformation due to labial crown torque

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Abstract. To measure the tie wing deformation of conventional orthodontic bracket during applied archwire torque using finite element analysis (FEA). Maxillary (upper) right central incisor stainless steel (SS) conventional orthodontic bracket dimensions were obtained using profile projector. A three-dimension model of the bracket was done. A finite element (FE) model of the bracket was constructed. A SS archwire applied torque was obtained theoretically for the angles of twist from 5° to 40°. Rectangular archwire labial crown torque was applied as a couple in two positions into the bracket slot. Further, the SS bracket profile was considered as ceramic to study the effect of materials. The FE results showed that there was increased bracket tie wing deformation with increasing torque in both the materials. The tie wing deformation varies from 0.24 µm to 12.4 µm and 0.153 µm to 6.65 µm for SS and ceramic respectively. The deformation of occlusal side tie wings was more than the gingival side tie wings. Tie wing deformation leads to the loss of applied torque and might delay the tooth movement. This insilico study visualizes the orthodontic bracket tie wing deformation to clinicians.

Keywords. Finite element analysis, Orthodontic bracket, Torque, tie wing deformation, Stainless steel bracket, ceramic bracket

1. Introduction

The orthodontic bracket is an important component to align teeth by transferring the archwire torque to the teeth, thus correcting the improper alignment of teeth which is called malocclusion. Over bite, under bite, cross bite, crooked teeth, crowded teeth are the various problems addressed in the field of Orthodontics. Orthodontic fixed appliance and its components function with the principles of mechanics. Archwires apply constant pressure on the brackets, which moves the teeth to the correct position. When Orthodontic brackets transfer force, there might be bracket tie wing deformation. In the standard edgewise bracket (conventional), clinicians twist the archwire and ligates it in the slot, to
correct the root angulations of teeth for stable tooth positioning. Torquing of rectangular archwires is done commonly in the anterior teeth either for palatal root movement or labial crown movement. A couple or moment can be used to torque the archwire. The torque expression is affected by archwire stiffness, wire slot play, the modes of ligation and the design of bracket. Fewer experimental studies are available to quantify bracket tie wing elastic and plastic deformation [1-3]. The experimental methods require more time and expensive instruments. Through experiments, it is difficult to see the graphical display of deformation and stress pattern. Harikrishnan et al., studied the orthodontic bracket slot wall deformation using FEA, but not the tie wing deformation [4]. Magesh et al. studied the FE analysis of orthodontic bracket slot wall deformation [5]. FE studies on the bracket tie wing deformation were not reported in the literature. Thus, for the first time, the tie wing deformation in the commonly used SS and ceramic brackets were analysed using FE method. The aim of this study was to show the tie wing deformation of the bracket when the twisted rectangular archwire comes in contact with the bracket slot during labial crown torque i.e., holding the root of the teeth in the same place and moving the crown part forwards. Clinically, if there is a deformation of the tie wing, this will lead to changes in slot dimensions either temporary or permanent, which will affect the torque applied in the bracket for ideal tooth positioning.

2. Materials and methods

A conventional maxillary right central incisor bracket was considered with 0.558 mm x 0.711 mm slot. An optical profile projector was used to capture the profile of the bracket under 10x magnification (Mitutoyo®). The profile projector images were used in drafting package to measure the bracket dimensions. A 3D bracket model was done by the measured dimensions using software (CATIA®). Figure 1 shows a 3D model of the bracket. This study was done without considering the archwire, instead by applying force into the respective positions in the bracket slot where the archwire comes in contact. The FE model was obtained by software (HyperMesh®) as shown in figure 2. The finite element software was used for the analysis (Ansys®, AnsysInc, Pennsylvania, USA). The solid 185 elements were used in this study because of its suitability for structural analysis. Table 1 presents the material properties considered to the model [6]. An eight mm length of 0.482 mm x 0.635 mm SS wire was considered to simulate the clinical scenario. The equivalent torque for an SS archwire was ascertained by calculation. The torque (T) was obtained from the angle of twist of the rectangular archwire using the following theoretical formula [7].
Table 1. Material properties of bracket

| Properties          | Materials |        |        |
|---------------------|-----------|--------|--------|
|                     | SS        | Ceramic|        |
| Young’s modulus (MPa) | 210000    | 380000 |
| Poisson’s ratio     | 0.3       | 0.29   |        |

Shear modulus (G) of the SS archwire material is 86 Gpa, the cross-section dimensions of rectangular archwire are ‘d’ and ‘b’, ‘L’ is the length of archwire. The polar moment of inertia (J) was calculated by following formula [7].

\[ \theta = \frac{42 T L J}{G d^4 b^4} \]  
(1)

\[ J = \left( \frac{bd}{12} \right) \left( b^2 + d^2 \right) \]  
(2)

By substituting the respective values in the formulas, the torque (T) was obtained from the angle of twist. The force was calculated from the known torque values using T= F X D. The couple distance is ‘D’, and ‘F’ is the force. Table 2 presents the torque and force values. The obtained force values are applied as a couple in the bracket slot [8].

Table 2. Force and torque values

| Angle of twist (degree) | Torque (Nmm) | Force (N) |
|-------------------------|--------------|-----------|
| 5                       | 9.96         | 21.42     |
| 10                      | 19.92        | 42.85     |
| 15                      | 29.89        | 64.28     |
| 20                      | 39.85        | 85.71     |
| 25                      | 49.81        | 185.20    |
| 30                      | 59.78        | 222.25    |
| 35                      | 69.74        | 259.27    |
| 40                      | 79.71        | 296.33    |

The couple was applied in two positions. In position-1, the archwire twist was from 5° to 20°, couple distance was 0.566 mm from the slot base of the occlusal side wall and at a distance of 0.101 mm from the slot base of gingival side wall. In position-2, it was from 21° to 40°, the couple distances were 0.203 mm from the slot base of the occlusal side wall and at a distance of 0.471 mm from the slot base of gingival side wall. All degrees of freedom in the bracket base was completely arrested. The bracket under loading was shown in figure 3. The tie wing deformation was measured from the middle of the slot to the center of each tie wing.
3. Results and discussion

Torquing in clinical orthodontics is carried out for anterior teeth crown or root movement. Torque is incorporated in the bigger size rectangular archwires by twisting the required segment of the wire. The ligatures are used to hold the twisted archwire inside the bracket, thus transferring the forces to the teeth. It is of much clinical relevance to study the tie wing changes in the commonly used bracket materials. The SS and ceramic bracket tie wings deformation for the applied archwire torque were presented in Table 3. The deformation of all the four tie wings for an applied 40° angle of twist in SS and ceramic bracket were shown in figures 4 and 5. The SS bracket tie wings deformation varies from 0.24 µm to 12.4 µm. Similarly, the ceramic bracket tie wings deformation varies from 0.15 µm to 6.65 µm. The comparison of SS and ceramic bracket deformation for tie wings were shown in figures 6 and 7. In general, the clinically used torque ranges from 5° to 40° and thus this study was designed to evaluate this range. The mathematically calculated archwire torque values are much closer to the experimentally calculated values [1].

Table 3. Tie wing deformation of SS and ceramic bracket

| Angle of Twist (Degree) | SS Tie wing 1 (µm) | SS Tie wing 2 (µm) | SS Tie wing 3 (µm) | SS Tie wing 4 (µm) | Ceramic Tie wing 1 (µm) | Ceramic Tie wing 2 (µm) | Ceramic Tie wing 3 (µm) | Ceramic Tie wing 4 (µm) |
|-------------------------|-------------------|-------------------|-------------------|-------------------|-------------------------|-------------------------|-------------------------|-------------------------|
| 5                       | 0.24              | 0.24              | 0.92              | 0.91              | 0.15                    | 0.15                    | 0.56                    | 0.56                    |
| 10                      | 0.58              | 0.58              | 2.13              | 2.14              | 0.30                    | 0.30                    | 1.12                    | 1.12                    |
| 15                      | 0.86              | 0.87              | 3.19              | 3.18              | 0.45                    | 0.45                    | 1.60                    | 1.60                    |
| 20                      | 1.15              | 1.15              | 4.25              | 4.25              | 0.60                    | 0.61                    | 2.24                    | 2.24                    |
| 25                      | 4.00              | 3.99              | 7.72              | 7.74              | 2.11                    | 2.04                    | 3.99                    | 4.08                    |
| 30                      | 4.79              | 4.75              | 9.25              | 9.28              | 2.42                    | 2.47                    | 4.81                    | 4.75                    |
| 35                      | 5.59              | 5.56              | 10.70             | 10.80             | 2.95                    | 2.95                    | 5.71                    | 5.71                    |
| 40                      | 6.40              | 6.42              | 12.40             | 12.30             | 3.38                    | 3.39                    | 6.65                    | 6.54                    |
Ryan et al., reported the relative deformation of bracket tie wings during torque expression using experimental technique [1]. Our study also showed the bracket deformation by directly analysing the individual tie wings for various angles of the twist as similar to the clinical condition. We show that there is varied deformation to various degrees of torque applied in these different bracket materials in all the tie wings. During loading, the couple distance was varied from position-1 to position-2 as archwire twists inside the bracket.
Figure 6. Comparison of tie wings deformation in SS bracket

Figure 7. Comparison of tie wings deformation in ceramic bracket

The change in deformation is gradually increasing in both bracket materials to varying torsional loads. There was a uniform increase in the deformation from 5° to 20°. When the torque angle changed from 20° to 25° in both materials, there was almost 3.5 times increase in deformation in tie wings 1 and 2 and 1.8 times increase in deformation in tie wings 3 and 4. This was due to the increase in torque and decrease in the couple arm. Clinically, if there is deformation in a tie wing, this might lead to changes in slot dimensions either temporary or permanent affecting the applied torque. Torque expression also varies based on the bracket slot sizes, wire material and cross-section. Our results show that for the lesser angle of twist, the deformation of the tie wings were less. At the same time when the angle of twist was more or when the archwire had more contact force on the slot walls, the deformation of tie wings were high.

When the angle of twist is less in magnitude, the engaging archwire position in a bracket slot is high on the occlusal side, and this happens when less amount of torque would be applied due to increased couple arm acting in the bracket slot. When 25° to 40° are considered as in position-2, this would result in the higher magnitude of torque because of decreasing couple arm. In both the bracket materials the tie wings 3 and 4 show more deformation than tie wings 1 and 2 because of the applied labial crown torque. The deformation pattern of tie wings in the gingival and occlusal
sides was similar (i.e. tie wings 1 and 2, tie wings 3 and 4) because of the same applied force in the bracket wings. In both the materials, the maximum deformation was seen in the edges of the occlusal tie wings. This was expected as the forces applied were labial crown torque and the cantilevered nature of the tie wings. Our results showed that the deformation of SS bracket tie wings are 50% more than the ceramic bracket tie wings. The Young's modulus is influencing the deformation of the material. The material which has a higher value of Young's modulus is stiffer than the material which has lesser one. Hence, it is hard to stretch the material which has higher Young's modulus than the material which has lower Young's modulus. SS bracket has the lesser amount of Young's modulus than ceramic, so the deformation of ceramic was less when compared to SS. There was no deformation in the bracket base because of the rigid attachment of the base of the bracket to the tooth surface which will resist the deformation. The values and graphical display of orthodontic bracket tie wings changes will help clinicians to visualise the deformation. The measurement of these micro level deformations are challenging with experimental methods.

4. Conclusion

In this work, we studied the tie wing deformation in SS and ceramic orthodontic bracket. We conclude that orthodontic bracket tie wings deform for an applied archwire angle of twist. The SS bracket tie wings deformation was more than the ceramic bracket tie wings. Thus tie wing deformations will have clinical implications in the torque applied by the orthodontists.

5. References

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