Effect of patterns of stainless steel ligation on orthodontic bracket with contact boundary conditions using finite element analysis

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Abstract. The objective of this work was to analyse the stress and deformation in the orthodontic bracket and archwire with different patterns of ligature tying namely full round pattern I (P-I), the figure of eight pattern II (P-II) and figure of eight pattern III (P-III) using finite element analysis (FEA). A standard edgewise stainless steel (SS) maxillary right central incisor orthodontic bracket was measured using profile projector. Solid models of the bracket, archwire and three patterns of ligature tie were done. The archwire was modelled and assembled into the bracket slot. The FE model of the assembly was done. Effect of three patterns of ligation on the archwire and bracket was analysed by applying archwire torque as a couple. The stress in the bracket and archwire for the patterns of ligation P-I, P-II and P-III were noted. The maximum deformation of the bracket and archwire for the patterns of ligation P-I, P-II and P-III were obtained. From the analysis, it was concluded that the magnitude of stress in the archwire and the deformation value in the bracket was high in P-I pattern. Ligature pattern P-II developed the least amount of stress and deflection in the bracket and archwire.

Keywords. Orthodontic bracket, stainless steel ligature, ligation pattern, finite element analysis

1. Introduction

Fixed orthodontic appliance treatment involves alignment of irregular teeth to achieve a good functional and cosmetic occlusion (bite). Currently, due to cosmetic awareness, the number of people wearing orthodontic brackets is significantly increasing. The fixed orthodontic appliance consists of orthodontic brackets, archwires, and ligatures. Orthodontic brackets are bonded to the teeth surface, and the archwire is held in the bracket slot tied by a ligature. The archwire is twisted and inserted into the bracket slot which moves the teeth crown or root to the desired position in the final stages of the treatment. Ligatures are used to hold the archwire inside the bracket slot. Hence archwire twist (torque) is successfully transmitted to tooth via the bracket. Metal ligature wires and elastomeric modules are available. The main advantage of using metal ligature is to reduce the friction between the bracket and
the archwire. There are many studies available to show the frictional resistance during the contact between ligature, bracket, and archwire. Thorstenson et al., showed that the resistance to sliding would differ based on ligature patterns [1]. Venancio et al., experimentally studied the effects of frictional forces on orthodontic bracket and archwire when elastomeric ligatures used [2]. Al fakir et al., concluded that SS ligatures reduces the plastic deformation of bracket [3]. Most of the studies were done by experimental techniques which need extensive instrumentation and cost. The aim of this work was to analyse the stress and deformation developed in the bracket and archwire while a twisted archwire is held with different patterns of SS ligation such as P-I, P-II, and P-III. Up to our knowledge there are no finite element (FE) studies available to show the effect of different patterns of SS ligation on bracket and archwire for an applied archwire torque. FEA is an approximation technique which is used to predict the behavior of orthodontic systems and used in the field of orthodontics in different studies [4-6]. Thus, we have planned to study the stress and deformation distribution in the archwire and bracket with different patterns of SS ligation.

2. Materials and methods

A standard edgewise maxillary right central incisor SS bracket (ORMCO®, California, USA) with 0.558 mm x 0.7112 mm slot was used in this study. The profile points of the SS bracket were obtained using optical profile projector (model: ph 3515F, Mitutoyo® South Asia Pvt. Ltd, Japan) under 10x magnification. The profile points were imported to drafting package (AutoCAD®, Autodesk, Inc, San Rafael, California, USA) to draw the profile of the bracket and its dimensions were measured. A 3D model of the bracket, archwire (0.482 mm x 0.635 mm) and patterns of SS ligature tie P-I, P-II and P-III were constructed and assembled using modelling software (SolidWorks®, Dassault Systems, Villacoublay, France). The SS ligature wire diameter was 0.304 mm. The FE model was generated using software (HyperMesh®, Altair Engineering, Michigan, USA). All the components were meshed with isoparametric four-noded tetrahedral solid elements. The number of elements used for meshing each component was presented in Table.1.

| Component | Number of elements |
|-----------|-------------------|
| Bracket   | 25632             |
| Archwire  | 6115              |
| P-I       | 15348             |
| P-II      | 32509             |
| P-III     | 23289             |

Table 1. Number of elements in 3D FE model

The meshed pattern was imported to FEA software (Ansys®, AnsysInc, Pennsylvania, USA). A static structural analysis was carried out. The material properties used in this study was presented in Table 2. The linear elastic isotropic material properties were used in this analysis. The material properties were obtained from previous studies [7].

| Component      | Material | Young’s modulus (MPa) | Poisson’s ratio |
|----------------|----------|-----------------------|-----------------|
| Orthodontic bracket | SS       | 200000                | 0.3             |
| Archwire       | SS       | 200000                | 0.3             |
| Ligature       | SS       | 200000                | 0.3             |

Table 2. Material properties of components

In the boundary conditions of the FE model, all degrees of freedom of base of the orthodontic bracket and both ends of the archwire were arrested. In loading conditions, a couple of 5Nmm was
applied in a labial crown torque fashion in one segment of the archwire. Labial crown torque is holding the roots of the teeth in the same place and tilting the crown of the teeth labially (forward). The loading condition of the bracket was shown in figure 1. The surface to surface contact was established between bracket, archwire and ligature surfaces. The coefficient of friction of 0.2 was used in all the contacts.

![Figure 1. Loading conditions of bracket](image)

3. Results

The maximum stress and deformation of the bracket and archwire were obtained for different patterns of ligation. The von Mises stress in the bracket for the patterns of ligation P-II, P-III and P-I were 5.562 N/mm², 7.846 N/mm² and 10.079 N/mm² respectively. The magnitude of stress in the archwire for the patterns of ligation P-II, P-III and P-I were 53.29 N/mm², 55.90 N/mm² and 60.30 N/mm² respectively. The analysis for the pattern of ligation P-I was shown in figure 2 a, for P-II in figure 2 b and for P-III in figure 3.

![Figure 2 a. Pattern of ligation P-I](image)  ![Figure 2 b. Pattern of ligation P-II](image)

The maximum deformation obtained in the bracket for the patterns of ligation P-II, P-III and P-I were 0.0096 µm, 0.0105 µm and 0.0140 µm respectively. The obtained stress and deformation values for the different patterns of ligation in the bracket and archwire were presented in table 3. The maximum deformation obtained in the archwire for the patterns of ligation P-II and P-III was 2.31 µm.
Table 3. Stress and deformation for different patterns of ligation

| Pattern of ligation | Stress (N/mm$^2$) | Deformation (µm) |
|---------------------|-------------------|------------------|
|                     | Bracket           | Archwire         | Bracket | Archwire |
| P-I                 | 10.079            | 60.307           | 0.0140  | 3.124    |
| P-II                | 5.562             | 53.293           | 0.0096  | 2.314    |
| P-III               | 7.846             | 55.900           | 0.0105  | 2.314    |

The maximum deformation in the archwire for the pattern of ligation P-I was 3.12 µm. The developed stress for the different patterns of ligation in the bracket and archwire were shown in figure 4. The comparative deformation of the archwire and bracket for different patterns of ligation were shown in figures 5 and 6 respectively.

![Pattern of ligation P-III](image)

**Figure 3.** Pattern of ligation P-III

![Stress values](image)

**Figure 4.** Stress values of different patterns of ligation in the bracket and archwire.
4. Discussion

The ligature is an important component of the orthodontic fixed appliance which holds the archwire in the bracket slot and thus transfers the forces to the teeth for movement. The different patterns of ligation were used by clinicians depending upon the needs. This study visualizes the effect of different patterns of SS ligation on orthodontic bracket and archwire. Al Fakir et al., suggested brackets ligated with SS ties exhibited greater torque expression and less plastic deformation than brackets without SS ties [3]. Clinicians ligate in the figure of eight fashion to enhance the tight seating of the archwire in the bracket slot. Our study showed that that the different patterns of ligation developed various deformation and stress levels in the bracket and archwire. Similar to our results, Venancio et al., also noticed the varied friction levels between bracket and archwire in different patterns of ligation [2]. Our results revealed that the increasing order of stress in the bracket and archwire were in P-II, P-III and P-I as shown in figure 4. The maximum stress was in the occlusal wing of the bracket in all the patterns of ligation, which is due to the labial crown torque fashion. The increasing order of deformation in the bracket and archwire was in P-II, P-III and P-I as shown in figures 5 and 6. The maximum deformation was noted in the bracket slot in all the patterns of ligation. Pattern P-II developed the least stress and deformation in the bracket and archwire when compared to the other ligation patterns. This is because the contact area of the ligature on the archwire is less and only in the middle of the archwire. The stress
levels and deformation were maximum in ligation pattern P-I. Thus, pattern P-I holds the archwire more rigid in the bracket slot and best suited for finer tooth movements. Clinically P-I is the commonly used SS wire ligation pattern and our study also proves that as the most efficient pattern of ligation. This in-silico study also helps clinicians to visualize the effect of different methods of SS ligation and their effect on the bracket and archwire.

5. Conclusion
The conclusion of our finite element analysis is, there were variations in the stress and deformation of the archwire and bracket in all the three patterns of ligation. Ligature pattern P-II developed the least amount of stress and deformation in the bracket and archwire. Ligature pattern P-I developed more amount of stress and deformation in the bracket and archwire. Among the three patterns of ligation, the ligature pattern P-I holds the archwire more rigid in the bracket slot and best suited for finer tooth movements.

6. References
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