Quantification of Orthodontic Loads on Teeth in Correction of Canine Overeruption Cases Using Different Archwire Designs

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ABSTRACT

Objectives: This study quantifies the effects of material, size of the continuous archwires, and level of overeruption on the loads on teeth in correction of overerupted canine cases.

Materials and Methods: An orthodontic force test (OFT) was used to measure the three-dimensional (3D) loads delivered by the archwires to the brackets attached to the maxillary right incisors, canine, and premolars. Dentoforms, simulating canine overeruptions at the 0.5 and 1mm levels, were made from CT scans. Archwires with two types of material, stainless steel (SS) and

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Nickel titanium (NiTi), and two sizes, 0.014-in and 0.016-in, were tested, respectively, on the 0.022×0.028-in brackets through elastomeric ligatures.
Results: The forces were dominantly intrusive on the canines and extrusive on the 1st premolars and lateral incisors. The magnitudes of the extrusive forces were about 74% and 52% that of intrusive force on the canines, which range from -0.48N (S.D. 0.01N) to -5.70N (S.D. 0.14N) depending on the wire material, size, and severity of overeruption ($P<0.01$). The canine intrusive forces created by SS wires were about 3 times higher than that of NiTi wires with the same sizes; 0.016-in archwires were about twice higher than that of 0.014-in with the same materials; and 1mm overeruption level double with respect to 0.5 mm. Significant 2nd order moment as coupled with the intrusive/extrusive forces.
Conclusions: The intrusive and extrusive forces on teeth in correction of canine overeruption cases can be quantified by the in-vitro OFT and the effects of the three factors significantly affect the loads on the teeth.
Key words: Orthodontic force tester; Overeruption; Archwire material; Orthodontic load

INTRODUCTION

Human teeth have a life-long potential to erupt unless they are opposed by the antagonist teeth. In cases where an antagonist tooth is lost, teeth continue to erupt, and result in occlusal interferences and malocclusion.[1] According to Craddock and Youngson (2004),[2] 83% of unopposed teeth were likely to overerupt, and the range of this overeruption was up to 5.39 mm. Besides this physiologic overeruption, a pathologic overeruption can occur due to the periodontal attachment loss.[3]

Overerupted teeth need to be treated by applying an orthodontic intrusive force. Generally, this force is created by the elastic deformation of archwire. To reduce chair time, modern orthodontics prefers continuous archwires and prescription brackets.[4-6] Effective treatment requires applying adequate orthodontic load on the target teeth[7] with minimum side-effects, like root resorption,[8,9] and minimum reacting load on the anchorage teeth. Therefore, quantification of the loads acting not only on the targeted tooth, but on the whole dentition is crucially important. However, when a continuous archwire is used, it creates a static-indeterminate force system,[10,11] which makes the quantification using analytical methods difficult.

An orthodontic load on tooth is three dimensional (3D). The load has three force (Fx, Fy, and Fz) and three moment (Mx, My, and Mz) components. The magnitudes of the components are affected by multiple factors including, archwire material, archwire size,[12,13] bracket design,[14,15] and ligation method.[16-18] In the overeruption case, the level of overeruption also affects the load's magnitude. To quantify the loads, experimental methods, such as orthodontic force test (OFT) and orthodontic simulator (OSIM) were used. Studies showed that these devices accurately measure the direction and magnitude of orthodontic forces.[19-22] However, the previous version of OFT only measures loads on two target teeth.[23,24] Although OSIM[16,17] can measure loads on multiple teeth, the teeth's crown shape were replaced by cylindrical poles and the teeth are not in the clinical positions, [25,26] which generate errors. To ensure more clinically relevant data, when the load is measured experimentally, the following two conditions need to be met: 1) clinical dentitions should be preserved, including crown shape and teeth's relative positions, and 2) clinical protocols to install the appliance should be followed.

Effective canine intrusion requires an adequate intrusive force on the canine and minimized forces on the neighboring teeth, which has been studied extensively.[27-30] Research has been focused on the optimal range of intrusion force[27 30]; effects of ligation methods on forces on the canine and neighboring teeth[31]; and effects of aligner on the intrusive force on canine. [29] These studies are either focused on one tooth, or investigated using computational model without experimental validation, or using different appliance. There have been limited quantitative knowledge on the loads delivered by an archwire with different designs for treating canine overeruption case. Therefore, the objectives of this study were to 1) develop a reliable and accurate method to experimentally measure the orthodontic loads on the teeth using continuous archwire, 2) quantify the loads experimentally for various appliance designs, 3) quantify the effects of wire material, size, and level of overeruption on the loads.

MATERIALS AND METHODS

Clinical canine overeruption cases were simulated using dentition from a Cone-beam computed tomography scan of an anonymous patient. The teeth were segmented using MIMICS (version 17.0; Materialise, Belgium) and 3D printed (Form 3B; Formlabs Inc, Somerville, Mass) to ensure the clinical tooth positions. Two dentoforms, one with the right canine being overerupted by 0.5 mm and the other by 1.0 mm, were digitally assembled and printed. A new orthodontic force tester OFT (Figure 1) was used to measure the 3D loads delivered to the following five teeth: the maxillary right central incisors, lateral incisors, canines, 1st and 2nd premolars (FDI tooth numbers 11,12, 13, 14 and 15). The dentoform was installed on the OFT. Five Industrial Automation Nano17 load cells (ATI Industrial Automation, Apex, NC) were attached to the five teeth to measure the load on them (Figure 2A). The rest of the teeth were also fixed to the OFT in their clinical positions (Figure 2B). The load cells of OFT are stationary. Their relative positions with respect to their associated teeth are determined from the CT scan data, which are used to transform the 3D load from the load cells to the brackets. For each tooth, an adaptor is attached to it digitally and printed with the crown (Figure 2C). This assembly can be easily installed to the load cell and maintain the tooth's clinical position. After all teeth are assembled on the OFT, clinicians can perform orthodontic treatment on the simulated dentoform that are instrumented for force measurements.

A clinician mounted the brackets and archwires to the dentoform on the OFT following well-established clinical protocol. One set of 0.022 × 0.028-inch slot size Roth brackets (Orthoforce G4 nickel-titanium Europa I, G&H Orthodontics) and Trueform II archwires (Orthoforce G4, G&H Orthodontics) with two types of materials, stainless steel (SS) and Nickel-titanium (NiTi), and different wire sizes, 0.014-in, 0.016-in, were tested. Canines with different levels of overeruption (LOO), 0.5 mm and 1 mm, were simulated. Thus, eight experimental groups were formed (Table 1).

The OFT was calibrated each time before testing. The load cell readings can be transformed to the load on the bracket. The transformation was validated by applying a known force (100g weight) on the bracket and comparing it with the transformed load measured using the load cell. The known force was applied in each axis, respectively to assess the errors. The error of the six force and moment components in tested teeth was below 5% (Table 2).

The load cells were initially zeroed. The load cells simultaneously measured force and moment components on the teeth, which were recorded by data acquisition software (Department of Mechanical Engineering, Indiana University–Purdue University, Indianapolis, Ind). The forces and moments were represented in a coordinate system shown in Figure 2A. The sign conventions and associated tooth movements are shown in Table 3. The experiments of each group were repeated four times using new archwires and elastomeric ties. Three-way analysis of variance (ANOVA) was used to examine the effects of archwire material, size, and LOO. The level of significance was set at 5% ($P<0.05$).

RESULTS

Means and standard deviations of forces and moments on the five teeth were calculated for each group of wires (Tables 4 and Table 5). In general, among the 5 teeth, the load distributions follow similar patterns (Figure 3). Among the 6 load components, F_z and M_y were dominant comparing with the others in the force and moment component categories (Tables 4 and Table 5). The magnitudes of other force components, F_x and F_y, were only less than 6% of the maximum Fz and the magnitudes of other moment components, Mx and Mz, were only less than 20% of the maximum My. Therefore, Fz and My were the focus of this study.

Fz distributions on the five teeth were similar among the eight groups (Figure 4). The canine received the highest intrusive force. The 1st premolar and lateral incisor received extrusive forces, which are on average 74% and 52% that of intrusive force on the canines, respectively. For example, for the SS 0.016-in archwire group, the intrusive force, Fz, acting on the canine (-5.70N) had 2 coupled extrusion forces on the 1st premolar (4.27N) and the lateral incisor (3.65N). The coupling forces further reduced on the 2nd premolar and central incisor, which received intrusive forces of -1.84N and -0.63N, respectively (Table 5). In general, the magnitudes of Fz on the 2nd premolar and central incisor were significantly lower compared to the other three teeth (Table 6).

The moments, My, were positive on the 2nd molar, canine, lateral and central incisors and negative on the 1st premolar (Figure 5). The magnitude of My on the canine was the highest and the magnitude of My decreased drastically on the central incisor and 2nd molar. For example, for the SS 0.016-in archwire group, the My on canine (5.16 N-mm) were 5 times larger than on the 2nd premolar and central incisor. The My on canine and lateral incisor (3.48N-mm) tend to cause distal crown tipping, while My on the 1st premolar (-4.83N-mm) tends to generate mesial crown tipping. The similar patterns can be observed for the other archwire groups (Tables 4 and Table5). In general, the magnitudes of My on the 2nd premolar and central incisor were significantly lower compared to the other three teeth (Table 7).

The three factors, LOO, archwire size, and archwire materials had significant impact on the loads on the teeth. Three-way analysis of variance indicated significant effects of LOO ($P<0.01$), archwire material ($P<0.01$), and archwire size ($P<0.01$) for Fz and My on canine. For the two LOO cases, with the same material, the Fz and My on the canine using the 0.016-in increased approximately 2 times and 1.2 times as high as the 0.014-in archwire, respectively; with the same size, the Fz and My on the canine from the stainless steel archwire were about 3 times and 1.4 times as high as that of NiTi wire, respectively. When LOO increased from 0.5 to 1 mm, the Fy and My on the canine doubled and increased1.2 times, respectively.

DISCUSSION

The new OFT allows invitro measuring orthodontic loads on teeth in simulated clinical cases. The accuracy of dentition printed with the 3D printer, Form 3B, has been proven to meet the requirements of clinical applications.[32,33] The OFT enables simulating clinical case by reconstructing the dentoform from patient's CT scans, allows appliance installation following clinical protocol, and can measure 3D loads on multiple teeth simultaneously, which ensures that the data are more reliable and clinical relevant.

Although the load distribution from archwire in treating canine overeruption case was qualitatively described, the magnitudes of the load components in clinical setting have not been reliably quantified. Our study has confirmed that using archwire to treat canine overeruption case results in a major intrusive force on the canine, extrusive forces on the 1st premolar and lateral incisor, and much less intrusive forces on the 2nd premolar and central incisor. The extrusive forces on the 1st premolars and lateral incisors were significant, which were on average 74% on the 1st premolar and 52% on the lateral incisor, thus should be considered. This treatment will also be coupled with moments. The dominant moment, My, mainly resulted in distal crown tipping of the canine, lateral and central incisors as well as the 2nd premolar; and mesial crown tipping of the 1st premolars. The effects were local and the coupled moments on the other teeth were diminishing as the distant from the canine increases. However, the level of actual tipping depends on the space between the teeth. Therefore, the existence of My may not actually generate significant tipping. The load distributions reported in our study were in agreement with the previous study,[17] with slight differences in load magnitudes. These are expected due to difference in dentoforms, appliances, and installation methods.

The LOO of the canine has a significant impact on the intrusive force on the canine. The relationship looks linear for the Fz on canine, which agree with results from some previous studies[16,17]. When the LOO increases from 0.5 to 1 mm, which are often used experimentally,[15,18,34] the intrusive force on canine doubles. However, the Fz on the immediate neighboring teeth also increases, but seems nonlinearly, which were also reported by other studies[15,18], which might be due to the difference in materials, wire size, experimental protocols, and appliances. In general, the ratio of the extrusion force on the neighboring teeth and the intrusion force on canine remains consistent relatively. The impact of LOO on My on the canine is less significant than Fz. When LOO increases from 0.5 to 1 mm, My on canine increases about 20%. However, the magnitudes on the neighboring teeth are also high, which may cause tipping in case there are space between the canine and neighboring teeth.

The archwire material affects the load on the teeth. With the same LOO and wire size, SS archwires significantly increased the magnitude of the intrusion and extrusion forces on the affected teeth. These results showed that the stiffer archwire results in higher intrusion/extrusion forces and Fy on the canine and its neighboring teeth, which agree with Ricardo's research[24]. The results from our study indicate that you can triple the intrusion force simply by replacing NiTi archwire with stainless steel wire.

The archwire size also impacts the load on the teeth. With the same LOO and archwire material, increasing the archwire diameter from 0.014-in to 0.016-in almost doubles the intrusive forces on the canine. However, the impact on the My is much less. The thicker wire increases My by about 20%. The relationship between the diameter of the wire and the magnitude of the forces and moments was not linear. When the diameter of the arch wire was increased by a factor of 1.1, the magnitude of the force increased by a factor of 1.6-2. The nonlinear relationship is due to the physics behind. The force is proportional to the wire stiffness, but the stiffness is not proportional to the wire's diameter.

The results of this study quantify the magnitudes of the loads on the teeth, which may help clinicians choose proper archwire for clinical use. The magnitudes are important for clinicians to know because an archwire performs properly only if it is used within its elastic range. The knowledge of the three factors, LOO, archwire size, and archwire material and their effects on the load may help improve treatment in the future.

CONCLUSIONS

1. The orthodontic loads on the teeth in a clinical treatment of canine overeruption case can be measured using the new OFT in-vitro.
2. Intruding an overeruption canine using a continuous archwire affects primarily the canine and its immediate neighboring teeth.
3. The intrusive forces acting on canines are coupled with moments that tend to tip the canine and lateral incisor distally and tip the 1st premolar mesially.
4. The magnitude of the intrusive force and 2nd order moment, My, can be adjusted effectively by altering the size and material of the archwire.

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