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ORIGINAL ARTICLE

A new orthodontic force system for moment control utilizing the flexibility of common wires: Evaluation of the effect of contractile force and hook length

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Background/Purpose: The application of an appropriate force system is indispensable for successful orthodontic treatments. Second-order moment control is especially important in many clinical situations, so we developed a new force system composed of a straight orthodontic wire and two crimpable hooks of different lengths to produce the second-order moment. The objective of this study was to evaluate this new force system and determine an optimum condition that could be used in clinics.
Methods: We built a premolar extraction model with two teeth according to the concept of a modified orthodontic simulator. This system was activated by applying contractile force from two hooks that generated second-order moment and force. The experimental device incorporated two sensors, and forces and moments were measured along six axes. We changed the

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contractile force and hook length to elucidate their effects. Three types of commercial wires were tested.
Results: The second-order moment was greater on the longer hook side of the model. Vertical force balanced the difference in moments between the two teeth. Greater contractile force generated a greater second-order moment, which reached a limit of 150 g. Excessive contractile force induced more undesired reactions in the other direction. Longer hooks induced greater moment generation, reaching their limit at 10 mm in length.
Conclusion: The system acted similar to an off-center V-bend and can be applied in clinical practice as an unconventional loop design. We suggest that this force system has the potential for second-order moment control in clinical applications.

Introduction

Appropriate moment application is crucial for successful orthodontic treatment. Second-order control is especially important in most clinical situations, including extraction space closure, uprighting a tipped molar, and torqueing incisors during anterior retraction. A V-bend is a well-known force system used to apply moments that has been well studied[1,2]; these studies demonstrated that the position and degree of the bend and the wire material influenced the entire system.

Nickel-titanium alloy (Ni-Ti) archwires are mainstays in contemporary orthodontics because of their shape memory and superelasticity.[3,4] Although this material was first produced as an initial leveling wire, Ni-Ti wires are now being tried as working wires due to the light stable force that can be acquired.[5–8] Therefore, moment control using highly flexible Ni-Ti wire has gained attention. Moments produced by a V-bend in superelastic Ni-Ti wires have been reported to have different patterns than other linear elastic materials, such as stainless steel and titanium-molybdenum alloy (Ti-Mo).[9] However, the incorporation of a V-bend into a superelastic Ni-Ti closed-loop mechanism has demonstrated adequate moment-to-force ratio generation for bodily movement.[10]

For more accurate moment control, we attempted to develop new mechanics by taking advantage of the natural characteristics (namely, low stiffness and high spring-back qualities) of Ni-Ti wires. We pinched two crimpable hooks at certain distances on a straight wire and then applied a contractile force between the hooks for activation, which induced curved wire deformation (Figures 1A and 1B). This system acted similarly to a V-bend system that generates moments in the brackets in opposing directions without any burdensome bending procedure that requires an extra heat treatment machine for the Ni-Ti wire. However, in contrast to a V-bend system, which is simply affected by the bending degree and position, our system is related to multiple factors that act in a more complicated fashion.

Although our force system mainly focused on second-order moment control, unpredictable side effects in other directions frequently confuse clinical orthodontists.[11] To reveal the applied force from this newly designed orthodontic apparatus, a three-dimensional full-scale model is required for force measurements. Recently, various three-dimensional force measurement methods have been developed.[12–16] Among these studies, an orthodontic simulator (OSIM) incorporating multiple six-axis force sensors[16] was used in several experiments[17–20] to successfully measure orthodontic force and moment in three dimensions. A modified OSIM device designed to increase operability has also been reported and proved to be effective for evaluating orthodontic force systems.[21] Therefore, the aims of this study were to investigate how the components of the proposed force system affect the generation of moments and forces using a modified OSIM device and to put the knowledge into clinical practice.

Methods

Experimental model

A schematic of the experiment is shown in Figure 2A. This model was designed to simulate the conditions of lower second premolar extraction. Two artificial teeth were fixed with a distance of 15 mm between the two bracket centers based on the mean tooth diameter of the Mongolian population,[22] where the diameter of the first premolar, second premolar, and first molar were 7 mm, 6.5 mm, and 10 mm, respectively. A straight wire with two different hooks and lengths crimped in the wire next to the bracket was then engaged into the slots. A contractile force was finally applied between the hooks to activate the system with a superelastic Ni-Ti closed spring, which theoretically delivers constant force.[23] Variables that affect this system include L_A, L_B, *C*, *D1*, *D2*, temperature,[24] and the material characteristics of the wire (Figure 2B). The orientation is shown in Figure 2C.

Measurement device

We developed a device that incorporates two six-axis sensors (CFS018CA201a: Leptrino, Nagano, Japan) following the principles of the modified OSIM device. Two cylindrical artificial teeth fabricated from an acrylic compound (VeroClear RGD810; Stratasys, Eden Prairie, MN, USA) were linked to these sensors with custom-made aluminum action

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