Numeric Simulation of Long-term Orthodontic Tooth Movement using the Finite Element Method

N. Yoshida[1a], R. Hamanaka[2] and J.Y. Tominaga[1]

[1]Department of Orthodontics and Dentofacial Orthopedics, Graduate School of

Biomedical Sciences, Nagasaki University, 1-7-1 Sakamoto

Nagasaki, 852-8588 Japan

[2]Department of Orthodontics, Nagasaki University Hospital, 1-7-1 Sakamoto

Nagasaki, 852-8588 Japan

[a]nori@nagasaki-u.ac.jp

Abstract. Most of finite element (FE) studies on orthodontic tooth movement have been limited to simulation of initial tooth displacement. However, long-term tooth movement occurs after going through bone remodelling. Therefore, we attempted to establish simulation system for orthodontic tooth movement resulting from bone remodelling in two ways. Firstly, initial tooth displacement was performed by two steps; the first step is the same as the analysis of initial tooth displacement. And in the second step, a re-meshing of the bone element is performed to simulate bone remodelling process. Two steps were iterated. Secondly, we apply orthodontic force and deform the periodontal ligament (PDL) while the model is restrained at the outer surface of PDL. Then, PDL is restored to its original form and width by displacing nodes of outer surface of PDL. That procedure is iterated to carry out long-term tooth movement. Finally, a time-dependent FE model that enables the prediction of long-term orthodontic tooth movement could be developed.

Introduction

Many FE studies have been performed to simulate tooth movement to improve therapeutic efficiency in orthodontic treatment. Most were, however, limited to the analysis of initial displacement [1,2]. Although the initial displacement may be an indicator of the subsequent tooth movement after some bone remodeling, loading conditions change during tooth movement. It is therefore difficult to precisely predict overall tooth movement from the initial displacement. The purposes of the present study were to develop a method to simulate long-term orthodontic tooth movement after going through the bone remodeling process based on the FE method and to determine the force system acting on each tooth in sliding mechanics using a model with realistic bracket slot, archwire, and tooth dimensions.

Materials and methods

A three-dimensional (3D) model of a maxillary dentition including teeth and the surrounding periodontal tissues was developed based on the images of micro-computed tomography. We attempted to establish simulation system for orthodontic tooth movement resulting from bone remodelling in two ways. Firstly, initial tooth displacement was performed by two steps; for the first step, an orthodontic force is applied to a tooth model. Then, the initial displacement was produced reflecting the deformed PDL. For the second step, alveolar bone geometry was updated so that the PDL was restored to its original configuration and thickness, and a re-meshing of the bone element was performed to simulate bone remodelling process. These two steps were iterated (Fig. 1). Secondly, we apply an orthodontic force and deform the periodontal ligament (PDL) while the model was restrained at the outer surface of PDL. Then, PDL was restored to its original form and width by displacing nodes of outer surface of PDL. That procedure is iterated to carry out long-term tooth movement. The finite element model is shown in Fig. 2.

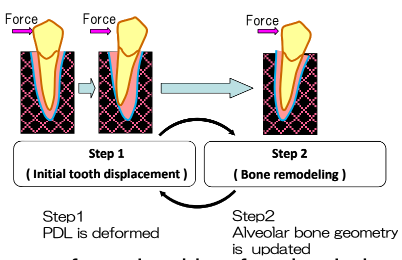

Fig.1 Diagram of an algorithm for simulation of long-term tooth movement.

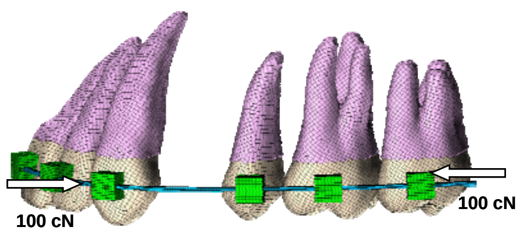

Fig. 2 Finite element model of upper dentition

An analysis of tooth movement during space closure using sliding mechanics was performed on the assumption that the case model was diagnosed as maxillary protrusion, and extraction of first premolars was indicated. The first premolar and its PDL were removed from the model.

Results

The extraction space was completely closed after the bone remodeling steps were iterated. In case no power arm was used in combination with sliding mechanics, anterior and posterior teeth were remarkably tipped into the extraction site, and bowing occurred as an undesirable side effect (Fig. 3). When a power arm of approximately 8 mm was used, no bowing effect was produced and teeth moved almost translatorily (Fig. 4).

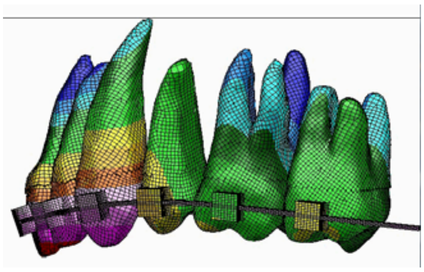

Fig. 3 Tooth movement pattern without power arm

Fig. 4 Tooth movement pattern with power arm

Discussion

Long-term tooth movement could be successfully simulated using a time-dependent FE model that enables the prediction of orthodontic tooth movement. Using this system, not only the tooth movement pattern but also the changes in the force system during space closure in sliding mechanics could be accurately determined.

Conclusion

We developed a novel method that could simulate the long-term orthodontic tooth movement and accurately determine the force system in the course of time using FE method. Also, the tooth movement pattern was visualized. The type of tooth movement after a long-term process of bone remodeling can be predicted, and treatment results will be greatly improved.

References

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