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Original article

A method for evaluation of the effects of attachments in aligner-type orthodontic appliance: Three-dimensional finite element analysis

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ABSTRACT

Purpose: Many patients require esthetic orthodontic treatment. Aligners have recently become widely used in such cases. However, orthodontic treatment occasionally causes unexpected tooth movement called the bowing effect. For example, when premolars are extracted during treatment, molars tend to tip toward the extracted area. Recently, small composite attachments have been recommended with the aim to generate effective orthodontic force to prevent the bowing effect. However, the mechanism of tooth movement with attachments of aligner-type appliances is not yet clear.
Materials and methods: In this study, we evaluated the effects of attachments on aligner treatment with finite element analyses.
Results: In this study, the computational results with finite element analyses show that the shape and position of attachments have no influence on tensile force and tipping moment. Differences in delicate positioning of attachments changed the analytical results.
Conclusions: We suggest that appropriate model setting is important to evaluate the effect of attachment by finite element analyses.

1. Introduction

Orthodontic treatment has traditionally been performed with wires and braces. Many patients require esthetic orthodontic treatment, and aligners have been used for this purpose. In recent years, aligner treatment has become popular worldwide for orthodontic therapy as an alternative to fixed labial braces [1–4]. Thermoplastic appliances have recently been used widely in such cases.

In orthodontic treatment with aligners, the appliance covers the entire tooth crown. Therefore, it is difficult to judge where force and moment are applied. Many mechanical

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analyses of wire treatment have been performed using finite element (FE) methods [5–9]. However, few studies have performed mechanical analyses of aligners. We reported the behavior of the bowing effect with computer simulation [10].

Recently, in some cases, it is recommended to use of resin attachments to aid rotational movement and improve the predictability of orthodontic movement (Fig.1) [11]. Boyd and Vlaskalic [12] and Boyd [13] suggested the use of labial and lingual attachments to aid rotational movement with aligner. Using FE analysis, Gomez showed that greater bodily tooth movement is likely to occur in the presence than in the absence of attachments [14]. However, they did not analyze the contribution of differences in the shape and position of attachments to tooth movement behavior. Moreover, FE analysis was performed with only the canines. Conversely, Kravitz et al.'s investigation showed that attachments did not significantly improve the accuracy of tooth rotation [15].

Therefore, the aim of this study was to use the force theorem to analyze the force system introduced by resin attachments in aligner treatment. We report changes in tooth movement resulting from differences in configuration and position of attachment.

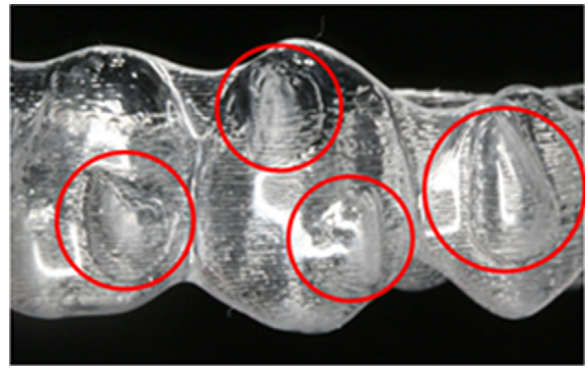

Fig. 1 – Aligner with attachments denoted by circles.

2. Materials and methods

Thermoplastic appliances, such as Invisalign® (Align Technology, Santa Clara, Calif.), have recently been used widely. The Invisalign® aligner was developed by Align Technology Corporation in 1999, and has been widely adopted for orthodontic therapy [1]. In this system, three-dimensional models of patients' dentition are constructed, and the movement of each tooth to the target position is simulated using a computer. After dentists approve the simulation, serial aligner stages are produced from thermoplastic resin and multiple aligners are prepared. Tooth movement of 0.25 mm is automatically produced with each aligner. Each aligner is worn for 2 weeks during the treatment. Such treatment is more uniform than wire treatment. Invisalign has the advantages of being transparent, inconspicuous, and removable. However, in some cases, the actual tooth movement differs from that predicted by the pretreatment analysis (Clincheck®). This unexpected movement may be attributed to the fact that the mechanism of tooth movement with aligners differs markedly from that of the conventional wire method. More difficult movements, such as bodily movement for extraction space closure, were less successful [1]. In particular, in cases involving premolar extraction, adjacent teeth may incline toward the extraction space—a phenomenon called the "bowing effect".

Recently, Align Technology Inc. recommended the use of resin attachments to aid rotational movement and improve the predictability of orthodontic movement [11]. Attachments in the form of bumps are set on the tooth surfaces in order to provide a 3-dimensional shape to the crown morphology using composite resin and to strengthen the retentive force of the aligner. The aim is to achieve the optimal orthodontic force of the aligner.

To investigate the orthodontic force induced by aligners, contact areas between the tooth crown and aligner were evaluated using FE analysis. We performed FE analysis with two tooth models: the canine and second premolar. Construction of the basic FE model was based on computed tomography (CT) scans (80 kV, 20 μA [crown area], 90 μA [root area], 600 slices/scan, and 48-μm slices; ScanXmate-L080HT, Comscantecno Corporation, Kanagawa, Japan) of teeth models. Two artificial teeth (canine and second molar) were fixed at 2.5 times the size of actual teeth (B10-330, Nissin Dental Products, Kyoto, Japan). A FE model was subsequently created from CT DICOM data based on the artificial tooth model. Analysis was performed using mechanical analysis software (Marc V2011 [Advanced Nonlinear Simulation Solution], MSC Software Corporation, Sunnyvale, CA, USA). For numerical calculation, Marc V2011 (Advanced Nonlinear Simulation Solution) was used. For the preprocessor and postprocessor, Mentat V2011 was used. The crown heights of the tooth models are presented in Fig. 2.

The periodontal ligament (PDL) was assumed to be a layer with a constant thickness of 0.2 mm—a widely adopted convention in existing literature [16–19]. Since the height of the periodontal ligament is different between the actual canines and premolars, this difference was simulated in the FE model. Although the actual morphology of the periodontal ligament is a complex curve, it was presented as a straight line in the models for convenience.

Four materials were used in this study. The material properties were determined from the values documented in the literature (Table 1) [15,16]. Then the material properties were assigned to teeth, attachments, the aligner, and PDL. The aligner was produced from shell elements that occupied the same coordinates of the tooth crown. The thickness of the aligner was set at 0.5 mm, and Coulomb's friction coefficient of the aligner and tooth coronal surface was set at 0.5.

The mechanism of producing an orthodontic force by covering the teeth with an aligner was reproduced following the analytical procedure described below on the assumption of canine distal retraction. The tooth models of the canine and premolar before movement are shown in Fig. 2. In the initial setting, the canine and premolar were arranged with a 3.2-mm interval at the maximum bulged region. The covering aligner was set so as to acquire the best fit when the interval narrowed by 0.25 mm from the initial interdental distance. When this aligner is applied, the 2 tooth models are drawn towards each other. To analytically present the behavior of covering the