Finite element analysis of the first molar relationships after orthodontic treatment utilizing single-arch extraction of the upper first bicuspids

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[Received: March 29, 2001.]

Key Words: upper first bicuspid single-arch extraction, mesial rotation, distal angulation, finite element analysis, von Mises’ stress

Abstract: In order to evaluate the validity of Class II occlusal condition of the first molars after orthodontic treatment utilizing single-arch extraction of the upper first bicuspids, computer simulated biomechanical analysis was carried out. Four sets of setup models were produced. The setup models represented two occlusal conditions (Simple Class II: The Class II occlusal condition with the upper first molar displaced parallel in the mesial direction from a Class I occlusal condition and Modified Class II: The Class II occlusal condition in which mesial rotation and distal angulation were applied to the upper first molar), and two types of upper first molars which differed in terms of the developments of the distal cusps (Type 1: well developed and Type 3: poorly developed). Next, the surface shapes of the setup models were recorded, and the models of the teeth and the bolus (a small mass of food) were produced for the computer simulation. A finite element analysis was applied to the models and the von Mises’ stress that arose inside the bolus model was calculated as an index of destruction efficiency of the bolus. The results were as follows:

1. For the Type 1 upper first molars no remarkable change in the von Mises’ stress was recognized between Simple Class II occlusal condition and Modified Class II occlusal condition.
2. For the Type 3 upper first molars there was a significant change in the von Mises’ stress between Simple Class II occlusal condition and Modified Class II occlusal condition.
INTRODUCTION

For the adult patients with maxillary protrusion, where the growth of the mandible is discontinued, a single-arch extraction of the upper first bicuspids is often adopted for the orthodontic treatment. Bennet suggested that, in orthodontic cases requiring single-arch extraction of the upper bicuspids, it is necessary to rotate the upper first and second molars so that they occupy more space in the arch and thus better occlude with the lower teeth. As a routine practice, mesial rotation and distal angulation are applied to the upper first molar for a proper buccal overjet and tighter interdigitation with the lower molars. However, only a few reports elucidated the evaluation of the first molar relationships after orthodontic arch coordination. The aim of this study is to evaluate the validity of Class II occlusal conditions. The efficiency of food destruction, calculated from a computer simulation, was used as an index for the evaluation.

MATERIALS AND METHODS

The designation of the setup models of Class II occlusal conditions of various types

Each setup model was produced from a dental cast obtained from a healthy adult patient without caries or restorations. Two types of upper first molars, the Type 1 upper first molar with distal cusp well developed in the form of a parallelogram and the Type 3 upper first molar with a poorly developed distal cusp in the form of a rhombus, were selected according to Kamijoh’s classification. These two types of occlusal surfaces are typical ones for general upper first molars of Japanese. Therefore the validity of occlusal conditions performed by such kinds of upper first molars is worth evaluating.

The setup models produced from Type 1 and Type 3 upper first molars were designed as follows

a) "Simple Class II" is defined as:
Models of a Class II occlusal condition with the upper first molar displaced parallel in the mesial direction from a Class I occlusal condition (Fig. 2).

b) "Modified Class II" is defined as:
Models of a Class II occlusal condition with mesial rotation and distal angulation of the upper first molar in addition to Simple Class II occlusion (Fig. 3-1, Fig. 3-2).

The production of the models of the teeth and the bolus

The surface shape and occlusal condition of the setup models were scanned by a non-contacting three dimensional surface shape measurement system (XAl00S). Based on these data, models of the upper and lower teeth in each setup model and the bolus model (a small mass of food) between the upper and lower teeth were produced by CAD. The number of nodes and elements in each model is listed in Table 1.

The application of the finite element analysis

Finite element analysis was applied to each model, and the mean value of von Mises’ stress at the nodes of the bolus model was calculated. Von Mises’ stress is defined as a...
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Fig. 3-1 The designation of Modified Class II occlusion (occlusal view)
× : Occlusal contact

Fig. 4 Teeth models and bolus model for the finite element analysis

square root of shearing strain energy. In the field of mechanics of materials, it has been confirmed that a material is destroyed when the von Mises’ stress reaches a specific value inside the material. If the bolus was assumed to be an elastic and ductile material, it would seem possible to evaluate the destruction efficiency of the bolus. Therefore the value of von Mises’ stress, which arises inside the model of the bolus, serves as a useful index for evaluating masticatory function.

In the analysis, the Young’s moduli (tooth: $1.0 \times 10^{10}$ MPa, bolus: $1.0 \times 10^{6}$ MPa) and the Poisson’s ratios (tooth: $3.0 \times 10^{-1}$, bolus: $4.9 \times 10^{-1}$) were set to reflect the physical properties of teeth and bolus. For the loading condition, general multiple-point constraints (MPC) were applied to the maxillary base and a displacement of 0.1mm, perpendicular to the mandibular base, was applied to the mandibular teeth. NISA II (EMRC Co.) was used for the analysis.

RESULTS

Distribution of the von Mises’ stress inside the bolus model

In Simple Class II occlusal condition of the Type 1 upper first molar, as was seen from an occlusal view, the contour line of the stress inside the bolus model indicated that the stress was concentrated in the marginal ridge areas around the

| Table 1 The number of nodes and elements of each model for the finite element analysis |
|-----------------------------------|-----------------|-----------------|
| Simple Class II of Type 1         | 4722            | 3414            |
| Modified Class II of Type 1       | 4446            | 3153            |
| Simple Class II of Type 3         | 4544            | 2967            |
| Modified Class II of Type 3       | 4558            | 3321            |
proximal contacts between the lower second premolar and first molar (Fig. 5-1). In Modified Class II occlusal condition of the Type 1 upper first molar, concentration of stress relatively shifted towards the distal area as compared with the stress distribution in Simple Class II occlusal condition (Fig. 5-2).

In Simple Class II occlusal condition of the Type 3 upper first molar, stress decreased in the distal area compared to that of the Type 1 upper first molar (Fig. 6-1). However, in Modified Class II occlusal condition, there was a strong concentration of stress around the mesial pit of the lower first molar (Fig. 6-2).

The mean values of von Mises' stress inside the bolus models

In the Type 1 upper first molar, no significant difference was detected for the mean value of the stress inside the bolus mod-
els between Simple Class II and Modified Class II occlusal conditions. In comparison, in the Type 3 upper first molar, Modified Class II occlusal condition produces a much greater value of stress than Simple Class II occlusal condition (Fig. 7).

DISCUSSION

The mean values of von Mises’ stress inside the bolus models
According to the past report, the mean value of von Mises’ stress exerted at each node in the food bolus model reaches the maximum in Angle Class I of rigid interdigitation. In comparison, a minimum value was indicated in Angle Class II with half a cusp 5).

In Class II occlusal condition of the Type 1 upper first molar
There was no remarkable difference between the mean values of von Mises’ stress in Simple Class II and Modified Class II occlusal conditions. Even though the occlusal contact of the protocone (a mesiolingual cusp) of the upper first molar became insufficient, some contacts were recovered by mesial rotation of the upper first molar benefiting from the well developed hypocone (a distolingual cusp).

In Class II occlusal condition of the Type 3 upper first molar
The mean value of the stress was greater in modified Class II occlusal condition than in Simple Class II occlusal condition. This might be caused by the tight contacts (which were reflected from the stress concentration in the lingual portion of the bolus model) between the protocone of the upper first molar and the mesial pit of the lower first molar in Modified Class II occlusal condition.

CONCLUSION

The following two points were obtained from the biomechanical analysis. In orthodontic treatment utilizing single-arch extraction of the upper first bicuspids:

1. The application of mesial rotation and distal angulation to the Type 1 upper first molars in the Class II occlusal condition is necessary for the occupation of the space and correction of the buccal overjet, and thus the efficiency of food destruction may not be changed.

2. For the Class II occlusal conditions of the Type 3 upper first molars, the application of mesial rotation and distal angulation to the upper first molars in the last phase of arch coordination is effective in the viewpoint of the destruction efficiency of the bolus.

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