Stress Distribution Produced by the Correction of the Mandibular Second Molar in Lingual Crossbite

Young-Jooh Yoon, DDS, MSD, PhD; Won-Jung Jeong, DDS, MSD; Sung-Ho Jang, DDS, MSD; Gab-Woon Hwang, PhD; Kwang-Won Kim, DDS, MSD, PhD

Abstract: The purpose of this study was to evaluate the stress distribution produced in the dentoalveolar system by a mandibular posterior crossbite appliance used for the correction of mandibular second molars in lingual version. A photoelastic model was fabricated using a photoelastic material (PL-3) to simulate alvelolar bone and ivory-colored resin teeth. The model was observed anteriorly and posteriorly with a circular polariscope and photographically recorded before and after activation of mandibular posterior crossbite appliances. An uncontrolled tipping and an extrusive force were generated when the traction force was applied on the buccal surface of the mandibular second molar. A controlled tipping and an intrusive force were generated when the traction force was applied on the lingual surface of the mandibular second molar. We concluded that to escape the extrusion and uncontrolled tipping that creates occlusal interferences associated with the correction of mandibular second molars in lingual version, the lingual traction force is more useful than the buccal traction force. (Angle Orthod 2002;72:593–598.)

Key Words: Stress distribution; Photoelastic analysis; Lingual crossbite; Ectopic eruption

INTRODUCTION

Growth of the mandible is necessary to create enough space to accommodate the erupting first, second, and third mandibular molars. Normal downward and forward mandibular growth must be attained to create room for the eruption of the succeeding molars. But if enough space is not developed, abnormal eruption or impaction will result. One of the immediate concerns, therefore, is whether the available space is enough for the eruption of mandibular second molars.

Although the incidence of correct vertical and axial positioning of the second molar is relatively higher in the mandible compared with the maxilla, it is not unusual to observe mandibular second molars erupting in lingual version because of a lack of development in this area. The buccal cusp of the mandibular second molar may become too prominent, and in more extreme cases, lingual version may be caused. Furthermore, heavy contacts on the balancing side may lead to a functional disharmony of the masticatory system. Cureton suggested three options for the correction of malaligned mandibular second molars: (1) band the second molar and drop back to a lighter continuous arch wire, which usually lengthens treatment time, (2) place a large, straight, rectangular nickel titanium arch wire, which could affect the arch form, and (3) place a boot loop in the rectangular arch wire, or place a sectional arch wire from first to second molar if an auxiliary tube is available, which shortens treatment time and minimizes patient discomfort. A boot loop decreases the load-deflection ratio so that a more constant force is placed on the second molar. On the other hand, cross-elastics or a precision lingual arch made from 0.032 × 0.032 inch titanium-molybdenum alloy (TMA) can be used. There are, however, some limitations in clinical application because temporomandibular joint (TMJ) problems may be caused by eccentric occlusion resulting from the extrusion of the mandibular second molar.

Although it involves a limited portion of the dental arch, a mandibular second molar in lingual version is clinically difficult to correct. A lingual ectopically erupted mandibular second molar must be intruded and moved buccally to avoid damaging the TMJ. A second molar in lingual version may be corrected with a sectional loop made from TMA or stainless steel wire with a helix used with a passive lingual arch or a button bonded to the buccal or lingual surface of the mandibular second molar and an elastomeric chain. Many possible techniques have been applied for the correction of a mandibular second molar in lingual version. The literature, however, lacks biomechanical studies eval-
FIGURE 1. Mandibular posterior crossbite appliance. (A) Buccal traction. (B) Lingual traction.

Evaluating their mode of action. The purpose of this study was to evaluate the stress distribution produced in the dentoalveolar system by a mandibular posterior crossbite appliance when it is used for the correction of mandibular second molar lingual crossbites.

MATERIALS AND METHODS

For biomechanical testing, a photoelastic model was fabricated using a birefringent alveolar bone simulant (PL-3; Photoelastic Inc., Malvern, Pa). PL-3 is a two-component room temperature curing resin/hardener system for making contourable photoelastic plastic models. Photoelastic resins have varying sensitivity and can be cast, shaped, or cut into models. They can also be calibrated according to the stress value associated with each fringe; with proper instrumentation, accurate stress measurements can be made at any point within a model.

The experimental photoelastic model of the lower arch was constructed to simulate a second molar in lingual version relative to the corresponding maxillary arch. Ivory-colored resin teeth were used. A wax mold was used to set up the malocclusion. A silicone impression of simulated lingual crossbite was made, and the teeth were inserted separately into the dentoalveolar segment, which was poured in wax to make the wax model. The model was polished and used for silicone impressions, which were cast in a photoelastic material (PL-3). Both the resin and hardener were warmed to 115°F to 125°F. The mold and casting table were also warmed with the same technique. This allows the mixed plastic to flow properly after pouring. Then the hardener was added to the resin and stirred with a stem thermometer. It is very important to achieve a uniform mixture before pouring the resin on the casting plate. We stirred slowly using a circular motion. As stirring progressed, the temperature rose by the exothermic reaction. When the temperature reached 130°F, we poured the resin keeping the cup as close as possible to the surface of the casting plate. After the resin was poured, the mold was covered with a plexiglas cover to keep out dirt and to avoid dust settling on the plastic during its polymerization.

The passive lingual arch was used as a mandibular anchorage unit. It was made with a 0.036 inch stainless steel wire and soldered to the lingual surface of the mandibular first molar band on each side. A lingual button was bonded to the buccal and palatal surfaces of the mandibular second molar. The sectional loop was made from 0.017 × 0.025 inch TMA wire and inserted into the auxiliary tube on the first molar brackets. The end of the sectional loop was bent to use as a hook for attaching the elastomeric chain (Figure 1).

Before photoelastic testing, the model was examined in polarized light to ensure the absence of residual stresses. Loads were applied to the mandibular second molars, and the model was viewed in the field of a circular transmission polariscope. Elastomeric chain (Energy chain: Rocky Mountain Orthodontics, Denver, Colo.) with a force of 8 to 10 ounces was attached to the hook from a button bonded to either the buccal or lingual surface of the mandibular second molars. Three types of force were applied to the mandibular second molars (1) the elastomeric chain was attached to a button bonded to the buccal surface, so that the traction force could be applied to the buccal surface, (2) the elastomeric chain was attached to a button bonded to the lingual surface, so that it ran through the fossa of the molar and over the crown, and (3) the elastomeric chain was simultaneously attached to a button bonded to the lin-
MANDIBULAR SECOND MOLAR IN LINGUAL CROSSBITE

FIGURE 2. Schematic representation of the circular polariscope arrangement. LS indicates light source; D, diffuser; P, polarizer; M, model; and Q, quarter-wave plate.

The loaded model was subjected to a temperature of 135°F and subsequently cooled at room temperature. The stressed model was then examined using a diffuse light polariscope, which employs a mercury and white light source. The polariscope consists of an illumination system, a pair of polarizers, and a means of locating the specimen in a position between the polarizers. The illuminating source employed in the present study was a white-light and mercury-light incandescent projection lamp. The resultant stress patterns, therefore, show the colors of the spectrum rather than a single color, as in the case of a monochromatic light source. White light produces stress patterns of colored fringes in such a way that, with relative retardation of the same value, the same colors are transmitted in the same proportions. Color patterns, caused by stress distribution, were identified by fractional fringe orders. An unloaded photostress coated part, observed with a reflection polariscope, will usually be obvious by its black color. Assuming that the coated test part has a free square corner, the stress there will always be zero. The black zero-order fringes, regarded as a neutral rotational axis, are usually isolated spots, lines, or areas surrounded by or adjacent to higher-order fringes. As a load is gradually applied to the part, the most highly stressed region begins to take on color: first a gray appears, then a white, and when the violet is extinguished, a yellow. With further load, the blue is extinguished, producing orange, and then green is extinguished, producing red. The next color to vanish with increasing load is yellow, leaving a purple color. Orange is then extinguished, producing a deep-blue fringe. The purple fringe is easily distinguished from the red and blue on either side and is very sensitive to a small change in strain level. Continuing to increase the load on the test part and producing additional relative retardation, the red is extinguished from the white-light spectrum, and the fringe color is blue-green. With still greater load, the relative retardation reaches the level where it corresponds to twice the wavelength of violet, extinguishing this color for the second time and starting the fringe cycle over again.

RESULTS

A passive fit of the appliance was photoelastically confirmed before the application of any force. As the force was applied, stress patterns developed throughout various regions of the photoelastic model and stresses were observed at the apices of the roots of the posterior teeth. Primary stresses were seen radiating from the apices of mandibular first and second molars to the alveolar structure. The initial effects of force application were observed in the alveolus between the mandibular first and second molars.

FIGURE 3. Distal view of stresses produced by force application. (A) Buccal traction of mandibular right second molar. (B) Lingual traction of mandibular right second molar. (C) Lingual traction of mandibular right and left second molars.

Force application on the buccal surface of the mandibular second molar (Figure 3A)

The stresses produced by force application on the buccal surface of the mandibular second molar were concentrated on the mesial and distal root apaxes. The intensity of the distributed stress of the lingual root surface in the alveolus was heavier than that of the buccal root surface. The largest group of stress fringes was shown at the lingual alveolar crest area and emanated along the lingual root surface, whereas a small concentration of stress was observed at the buccal root surface. The rotational axis was at the middle.
one-third of buccal root surface and root apex, producing an uncontrolled tipping and an extrusive force. The color pattern around the lingual alveolar crest was blue-green, which is equivalent to a 1.2 fringe order; root apex was 0.9.

**Force application on the lingual surface of the mandibular second molar (Figure 3B)**

The high stresses produced by force application on the lingual surface were concentrated in the alveolus area below the root apex of the mandibular second molar. The stresses were generally emanating from the apices and cervical area of the mandibular second molar. The stress intensity of the lingual traction was heavier at the buccal root surface and apex area than that of the buccal traction. The color pattern around the apices of the buccal and lingual roots was in the order black, yellow, red, purple, blue-green, and yellow. The fringe order was increased from 0.0 to 1.5. The amount of stress was also increased in the fringe order at the cervical areas of the buccal and lingual sides. In these areas, the color pattern was repeated to blue-green, which is equivalent to a 1.2 fringe order. The rotational axis at the middle one-third of the buccal root surface and root apex disappeared, producing a controlled tipping and an intrusive force.

**Simultaneous force application on mandibular right and left second molars (Figure 3C)**

The stress intensity of the right mandibular second molar was heavier than that of the left mandibular second molar. The color pattern around the root surface was changed from yellow to red, purple, blue-green, yellow. As the color pattern changes, the fringe order was also increased to 1.5. On the other hand, the color pattern around the cervical and root apex area of the left mandibular second molar was red, which is equivalent to a 0.9 fringe order. The intensity of the distributed stress of the lingual surface was heavier than that of the buccal surface, and the intensity of the alveolar crest area was also heavier than that of the root apex area. The color pattern around the root area of the mandibular first molars, anchoring units, was similar to the initial color pattern before the force application.

**DISCUSSION**

**Ectopic eruption of the mandibular second molar**

Ectopic eruption is a broad category referring to any abnormal or aberrant eruptive position taken by a tooth. Various causes of ectopic eruption and dental crowding have been proposed embracing concepts of evolution, heredity, and environmental effects, etc. Howe et al. suggested that dental crowding may result from continued interbreeding between physically dissimilar ethnic groups. He also emphasized environmental factors, reasoning that the modern, refined diet may have played a role in reducing muscular stimulation, hence the full expression of facial bone growth. Mills and other investigators also have studied the interrelationship of tooth size, arch size, and dental crowding and reported dissimilar findings. Consequently, the etiology of ectopic eruption of mandibular second molar is very variable and controversial.

**Selection of photoelastic stress analysis**

Stress analyses produced by orthodontic force application can be evaluated using finite element analysis, laser holography, strain gauge, and photoelastic analysis. Finite element analysis has the capacity of including anisotropic mechanical properties, whereas laser holography has the potential for in vivo examinations. But the anisotropic input data of the individual elements of the orofacial complex, which are required for utilization of the strengths of the finite element analysis, are very difficult to precisely determine. On the other hand, laser holography is extremely accurate in measuring displacements, but is complicated to apply in vivo because of the difficulty in fixing the head. In addition, this technique cannot predict any internal effects.

Of the various experimental techniques used for studying stress response, photoelastic stress analysis is particularly useful as a predictor of biologic response. In contrast to strain gauges that measure surface strains only at discrete points, the photoelastic technique permits the visualization of the global state of stress within a structure. Photoelasticity is the property exhibited by some isotropic solids that become doubly refracting when subjected to stress. Polarized light, when passed through a transparent plastic under stress, will split into two polarized beams traveling in the planes of the principal stress. These beams have different velocities, and the phase difference shift can be observed by viewing the light through a polarizing filter. The resultant stresses are seen as colored fringes within the photoelastic resin. Photoelastic analysis provides visualization and permits analyzing the forces exerted at the various areas of the tooth surface. It can reproduce three-dimensional and complicated shapes, which provides individual simulation of dentoalveolar structure, visualization of stresses under load, and stresses throughout the entire model. The photoelastic model developed for this study was designed to provide a reasonable estimate of stresses produced by mandibular posterior crossbite appliances. Color patterns developing under loading of the photoelastic model manifest the relative magnitude and distribution of the internal stresses. In addition, the redistribution of stresses following alterations in loading patterns or resistance is easily visualized and recorded. This photoelastic information has important clinical implications because stress concentration areas in-
dicate the regions of potential weakness as well as areas requiring major biologic responses. We assessed the direction and distribution of internal stresses rather than quantifying their intensity because quantifying the internal stresses needs to determine the fringe value of the material as well as the order of the fringe. The fringe value depends on the kind of material used, its thickness, the wavelength of the light employed, and the temperature of the model.19

**Stress direction and distribution**

*Application of the mandibular posterior crossbite appliance.* Before photoelastic testing, the model was examined in polarized light to ensure the absence of residual stresses. Forces derived from the mandibular posterior crossbite appliance cause various stresses on the dentoalveolar structures. The nature of the stress patterns elicited by the mandibular posterior crossbite appliances indicates the direction of force application. Stresses occurred at the alveolar crest and root apex area of the first and second mandibular molars.

*Force application on the buccal surface of the mandibular second molar.* The stress concentration was observed at the lingual alveolar crest area of the second molar and root apex area. Stress intensity of the lingual root surface was heavier than that of the buccal root surface. This indicates that the stresses increased greatly in the area where a tension force was generated. The rotational axis existed at the middle one-third of the buccal root surface and root apex. This means that the mandibular second molar may rotate when the rotational force is applied, producing an uncontrolled tipping and an extrusive force. As a result, the lingual cusp of the mandibular second molar will be prominent and an occlusal interference may be caused. To avoid occlusal interferences, therefore, the buccal traction should be accompanied with an intrusive force.

*Force application on the lingual surface of the mandibular second molar.* When compared with the buccal traction, more stresses were observed in the mesial and distal roots of the mandibular second molar. The order of the color pattern of the root surface was changed to yellow, red, purple, blue-green, and yellow. This indicates that stress intensity was increased and intrusive force was generated. Some stresses were also increased at the cervical area of the lingual root surface. The fringe order of this area was increased to 1.2 (blue-green color). In addition, the rotational axis at middle one-third of the buccal root surface and root apex disappeared. When compared with the buccal traction, these forces may result in the intrusion of maxillary second molar, producing a controlled tipping and an intrusion. Consequently, for the elimination of possible extrusion and uncontrolled tipping of malpositioned mandibular second molar, we recommend lingual traction forces rather than buccal traction on the molar.

*Simultaneous force application on mandibular right and left second molars.* We made a photoelastic model that differed in the degree of lingual inclination of the mandibular second molars. The right mandibular second molar was more inclined than the left mandibular second molar for identifying the differences of the stress intensity. When the traction force was applied simultaneously on the lingual surface of the mandibular right and left second molars, the stress intensity of the right mandibular second molar was heavier than that of the left mandibular second molar. This indicates that the longer the distance between the extension bar and the lingual button bonded to the lingual surface of the teeth, the heavier the stress concentrations that are developed in the mandibular second molars. In addition, the greater the degree of lingual inclination of the mandibular second molar, the higher the stress intensity.

*Stress distribution at anchoring units (mandibular first molars).* When the traction force is applied on either the buccal or lingual surface of the mandibular second molar, the color pattern was similar to the initial color pattern before the force application. This indicates that the anchoring units (first molars) were a little stressed, and the passive lingual arch is effective in reinforcing the anchorage.

**CONCLUSIONS**

In the present study, we demonstrated the following: (1) When the traction force was applied on the buccal surface of the mandibular second molar, stresses were concentrated at the lingual alveolar crest and root apex area. The rotational axis was at the middle one-third of the buccal root surface and root apex, producing an uncontrolled tipping and an extrusive force. (2) When the traction force was applied on the lingual surface of the mandibular second molar, the stress intensity of the lingual traction was heavier at the buccal root surface and apex area than that of the buccal traction. Stress intensity was increased below the root apices and the rotational axis at the middle one-third of the buccal root surface and root apex disappeared, producing a controlled tipping and an intrusive force. (3) When the traction force was simultaneously applied on the lingual surface of mandibular right and left second molars, a higher stress intensity was generated around the root area of the right mandibular second molar by the longer distance from the extension bar to the lingual button and by the greater degree of lingual tipping of the mandibular second molar. Consequently, to escape the extrusion and uncontrolled tipping that creates an occlusal interference of the mandibular second molar during lingual version correction, the lingual traction force is more useful than the buccal traction.

**REFERENCES**


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