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Photoelastic evaluation of Mandibula Posterior Crossbite Appliance

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This study was undertaken to demonstrate the forces in the mandibular alveolar bone generated by activation of the mandibular posterior crossbite appliance in the treatment of buccal crossbite caused by lingual eruption of mandibular second molar. A three-dimensional photoelastic model was fabricated using a photoelastic material (PL-3) to simulate alveolar bone.

We observed the model from the anterior to the posterior view in a circular polariscope and recorded photographically before and after activation of the mandibular posterior crossbite appliance.

The following results were obtained :

1. When the traction force was applied on the buccal surface of the mandibular second molar, stress was concentrated at the lingual alveolar crest and root apex area. The axis of rotation also was at the middle third of the buccal root surface and the root apex, so that uncontrolled tipping and a buccal traction force for the mandibular second molar were developed.
2. When the traction force was applied on the lingual surface of the mandibular second molar, more stress was observed as opposed to those situations in which the force application was on the buccal surface. In addition, stress intensity was increased below the root areas and the axis of rotation of the mandibular second molar was lost. In result, controlled tipping and intrusive tooth movements were developed.
3. When the traction force was applied on either buccal or lingual surface of the second molar, the color patterns of the anchorage unit were similar to the initial color pattern of that before the force application. So we can use the lingual arch for effective anchorage in correcting the posterior buccal crossbite.

As in above mentioned results, we must avoid the rotation and uncontrolled tipping, creating occlusal interference of the malpositioned mandibular second molar when correcting posterior buccal crossbite. For this purpose, we recommend the lingual traction force on the second molar as opposed to the buccal traction.

Key words : Posterior buccal crossbite, stress, photoelastic stress analysis, circular polariscope, fringe order

During growth of the mandible, space to accommodate the erupting first, second, and third molars must be created by growth of the

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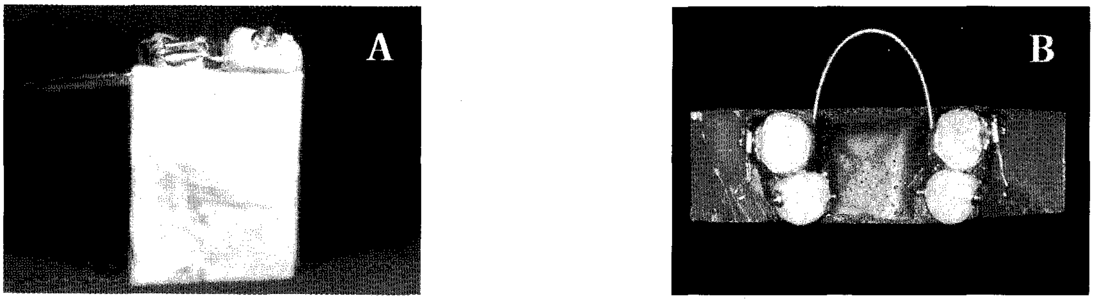

Fig. 1. A. photoelastic model to visualize forces produced by the force application. B. mandibular posterior crossbite appliance

mandible. Normally, the mandibular growth in this area should be downward and forward to create room for the eruption of each succeeding molar. If the growth in this region is insufficient, abnormal eruption or lack of eruption will occur. It is not unusual to see mandibular second molars erupting lingually because of the lack of development in this area. They must either erupt in this manner or be impacted, and this condition is magnified with respect to available space for eruption of the mandibular third molars.[1] Ectopic eruption is a broad category referring to any abnormal or aberrant eruptive position taken by a tooth.[2] The area of immediate concern is the space available for eruption of the mandibular second and third molars.

Cureton[2] reported the incidence of malaligned second molars in untreated individuals. In that study, more mandibular second molars erupted lingually than maxillary second molars. The greatest numbers of the malposed mandibular second molars were inclined with the roots to the mesial and the crown to the distal. In addition, he concluded that the charts presented in his study can be used as a guide to correct the second molar position and the boot loop is an effective appliance to adjust the direction and magnitude of the force.

On the other hand, we can also use the cross-elastics or precision lingual arch (PLA) made of .032*.032 inch TMA arch wire to correct the malposed mandibular second molar. But cross-elastics may cause the extrusion of mandibular second molar. As a result, TMJ problem may be caused due to eccentric occlusion.[3] Correction of the mandibular posterior crossbite, although it involves a limited portion of thedental arch, can be difficult. The tooth in crossbite must be intruded and moved either lingually or buccally. Therefore, a posterior crossbite appliance was introduced by several authors.[4,5]

Although many orthodontic appliances have been used in the treatment of posterior crossbite for many years, explanation of the mode of their action is still left without definitive answer. While several studies have reported the effectiveness of the treatment by posterior crossbite appliance, there has been no investigation dealing with the nature of the forces delivered by this appliance.

MATERIALS & METHODS

1. Photoelastic model

For the purpose of biomechanical testing, a photolastic model was fabricated from birefringent alveolar bone simulant (PL-3 : Measurements Group, INC., U.S.A.). PL-3 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 model used in this study was fabricated in the following manner : A Photoelastic model of a lower arch was constructed to simulate a malocclusion. We used ivory-colored resin teeth. A wax model was made to set up the malocclusion by the following method: A Silicone impression of a malocclusion modelwas taken and the teeth were inserted separately into the dento-alveolar segment. After this process, this was poured

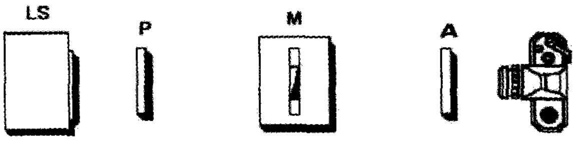

Fig. 2. Schematic reprentation of circular polariscope arrangement.(Ls. light source : P. polarizer : M. model : A. analyser)

in wax to make the wax model. This was polished and then used for the silicone impression, which was cast with a photo-elastic material (PL-3)(Fig.1A).

2. Mandibular posterior crossbite appliance

We used a passive lingual arch as a mandibular anchorage unit. The passive lingual arch was made with 0.036 inch stainless steel wire, and soldered to the lingual surface of the first molar band of each side. A Lingual button was attached to the buccal and palatal surface of the mandibular second molar of each side. The sectional loop that was made of stainless steel wire was inserted to the auxiliary tube on the mandibular first molar brackets. The end of the sectional loop was bent to create a hook for attaching an elastomeric chain (Fig.1B).

Before photoelastic testing, the model was examined in polarized light to ensure the absence of residual stress. Loads were applied to the mandibular second molars in the field of a circular transmission polariscope. The elastomeric chain (Energy chain ; Rocky Mountain Orthodontics, U.S.A.) was attached to the hook from a button bonded to either the buccal or the lingual surface of the mandibular second molars. Firstly, the elastomeric chain was attached to a button bonded to the buccal surface of the right side mandibular second molar, so that the traction force could be applied to the buccal surface. Secondly, the elastomeric chain was attached to a button bonded to the lingual surface of the right side mandibular second molar so that it ran through the fossa of the molar and over the crown. This resulted in the traction force being applied to the lingual surface of the mandibular second molar.

Table 1. Dominant isochromatic fringe colors for fullfield interpretation

Color	Approximate fringe order
black	0.0
yellow	0.6
red	0.9
purple (tint of passage)	1.0
blue-green	1.2
yellow	1.5
red	1.75
red-green transition	2.0
green	2.2
yellow	2.5
red	2.8
red-green transition	3.0

3. Photoelastic Stress Analysis

The equipment used to make these observations was the polariscope, which consists of an illumination system, a pair of polarizers, and a means of locating the specimen in position between the polarizers (Fig.2).

The illuminating source employed in this study was a white-light and mercury light by an incandescent projection lamp. The resultant stress patterns thus show the colors of the spectrum rather than a single color as in the case of a monochromatic light source. White light produces a stress pattern of colored fringes in such a way that, with relative retardation of the same value, the same colors are transmitted in the equal proportions.[20]

Fractional fringe orders and color patterns caused by stress distribution, were measured and analyzed (Table 1).[21]

RESULTS

Stress patterns developed in various regions of the photoelastic model. Before photoelastic testing, the model was examined in polarized light to ensure the absence of residual stresses (Fig.3). The initial effects of the force application were observed in the alveolus of the mandibular first and second molars. Primary

Fig. 3. The photoelastic model located in polarized light before force application. A stress-free model with no force applied showed minimal residual stress patterns.

Fig. 4. Distal view of stresses produced by force application on the buccal surface of the mandibular second molar. The axis of rotation of this tooth appeared at the middle third of the buccal root surface. Note the small concentration of stresses at the cervical area of the lingual surface and root apex.

stresses were seen radiating from the apices of mandibular first and second molars to the alveolar structure.

Force application on the buccal surface of mandibular second molar (Fig.4)

The stress associated with force application on the buccal surface of the mandibular second molar was concentrated on both the mesial and distal root apices. The heavier stress concentration was observed at the lingual surface than at the buccal surface of the mandibular second molar.

The axis of rotation existed at both the middle third of the buccal root surface. The fringe order of lingual alveolar crest area was 1.2 (blue-green color pattern) and root apex was 0.9.

Force application on the lingual surface of mandibular second molar (Fig.5)

High stresses were developed in the alveolus area below the root apex. The stresses were greatest at the apices and cervical area of the mandibular second molar and generally emanating from these areas. The lingual traction also produced more stress concentration at the buccal root surface and apex area contrast to the force application on the buccal surface. Thus, the stress intensity of the buccal surface was similar to the lingual surface of the mandibular second molar. Color patterns of the buccal and lingual root surface were black, yellow, red, purple, blue-green and yellow, in this order. It represents that fringe order was increased from 0.0 to 1.5. The increased stress was also noted at the cervical areas of both the buccal and lingual side. In this area, color patterns were identical upto the blue-green color (fringe order : 1.2). In addition, the axis of rotation of the buccal root surface of the mandibular second molar disappeared.

Stress distribution at mandibular first molars

When we applied the force on either the buccal or lingual surface of the mandibular second molar the stress observed was minimal at cervical area of the lingual surface of the opposite mandibular first molar. The color patterns were similar to initial color pattern before the force application.

DISCUSSION

1. Photoelastic stress analysis

The photoelastic model developed for this study was designed to provide a reasonable estimation of the

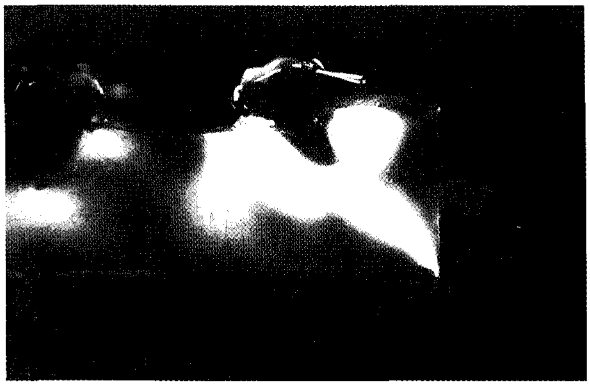

Fig. 5. Distal view of stresses produced by force application on the lingual surface of the mandibular second molar. The color fringes indicated internal stress around the root apex. The larger group of stresses were shown below the root apex.

stresses produced by mandibular posterior crossbite appliance. Of the various experimental techniques[22] 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 visualization of the global state of stress within a structure. Color patterns developing under loading of the photoelastic model manifest the relative magnitude and distribution of the internal stresses elicited. Additionally, the redistribution of stresses following alterations in loading patterns or resistance is easily visualized and recorded. This photoelastic information has important clinical implications, because areas of stress concentration indicate regions of potential weakness as well as those regions where major biologic responses may be expected. The use of photoelastic materials for analysis of stress and strain has been criticized by Evans,[23] who suggested that these materials are different from bone. However, the validity of a photoelastic model system as a simulator of oral structures has been demonstrated by many authors.[24-26] They concluded that a homogeneous isotropic photoelastic model is useful in visualizing stresses that cause various histologic responses. If one is aware that plastics are not identical to bone, but instead that they are only a model resembling bone, conclusions can still be reached and valuable information gained from their use. Although the vital factor of cellular bone response is absent in a non-living plastic material, the pressures that exist at the adjoining tooth-alveolar bone surfaces also occur in the experimental model. The direct contact of tooth and bone socket surfaces thus permits externally applied forces to be measured by the strain patterns. The size, shape, color, and location of the stress bands all serve to indicate the distribution of the force along the root/bone junction.

We were interested in assessing the direction and distribution of internal stresses rather than in quantifying their intensity. For the latter purpose it is necessary 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.[25]

It was because of the reasons mentioned above that we used the photoelastic technique for this investigation.

2. Stress direction and distribution

Force application on the buccal surface of the mandibular second molar

Fig. 4 shows that the stress concentration when the buccal traction force was applied on the buccal surface of the mandibular second molar was located at the lingual alveolar crest area of the second molar and root apex area. The stress intensity of the lingual surface was higher than the buccal root surface. The axis of rotation also existed at the middle third of the buccal root surface. This means that the rotational force applied to the second molar may cause the tooth to rotate as well as increasing the possibility for the uncontrolled tipping tooth movement. We have to consider that the buccal traction should be accompanied with the intrusive force when we try to correct the buccal posterior crossbite. The clinician should realize that, with force application on the buccal surface of mandibular second molars, he or she is producing rotation of the second molar and buccal traction, which may cause occlusal interference.

Force application on the lingual surface of the mandibular second molar

The stresses generated by force application are shown in Fig. 5. More stresses were observed here than in the first method at both the buccal and lingual root of the tooth. Yellow, red, purple, blue-green, yellow color patterns, when force was applied, were noted in order below both the buccal and lingual root surface of the second molar. It represents that stress intensity was increased and intrusive force was generated. Some stresses were also increased at the cervical area of lingual root surface. The fringe order of this area was increased to 1.2 (blue-green color pattern). In addition, the axis of rotation of the mandibular second molar was not observed. This finding confirms that in this type of force application, an intrusive force would occur and great stresses leading to the possible development of controlled tipping and intrusion of teeth would appear on these teeth. In comparison with the result of the first method, we can know that the stress created an intrusive force when buccal traction for the mandibular second molars was applied, and that is to say controlled tipping and intrusive tooth movements were developed.

Stress distribution at the mandibular first molars

The color patterns were similar to the initial color pattern before the force application when the traction force was applied on either the buccal or the lingual surface of second molar. In this result, we can realize that anchoring units (first molars) were a little stressed and passive lingual arch wire is effective in reinforcing the anchorage.

CONCLUSIONS

A photoelastic model was used to visualize the effects of mandibular posterior crossbite appliance in the treatment of posterior buccal crossbite. The photoelastic visualization for a given movement was found to be directly related to the direction of the force applied. The following conclusions were reached from this investigation :

1. When the traction force was applied on the buccal surface of the mandibular second molar, stress was concentrated at the lingual alveolar crest and root apex area. The axis of rotation was also at the middle third of the buccal root surface and the root apex, so that an uncontrolled tipping and a buccal traction force for the mandibular second molar were developed.
2. When the traction force was applied on the lingual surface of the mandibular second molar, more stress was observed as opposed to those situations in which the force application on the buccal surface. In addition, stress intensity was increased below the root areas, and the axis of rotation of the mandibular second molar was lost. In result, controlled tipping and intrusive tooth movements were developed.
3. When the traction force was applied on either buccal or lingual surface of the second molar, the color patterns of the anchorage unit were similar to the initial color pattern of that before the force application. So we can use the lingual arch for effective anchorage in correcting the posterior buccal crossbite.

As in above mentioned results, we are able to realize that the force application on the buccal surface of the mandibular second molar with the mandibular posterior crossbite appliance produced rotation and buccal traction of the second molar, which may cause occlusal interference. We have to deviate the rotation and uncontrolled tipping, creating occlusal interference of mal-positioned second molar and apply the controlled tipping and intrusive force when correcting buccal posterior crossbite. For this purpose, we recommend the lingual traction force on the mandibular second molar instead of buccal traction.

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국문초록

Mandibular Posterior Crossbite Appliance의 적용시 응력 분포에 관한 광탄성법적 연구

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본 연구는 설측 이소맹출된 하악 제2대구치의 협측 반대교합을 개선하기 위해 사용되는 mandibular posterior crossbite appliance에 의해 하악 제2대구치의 치근단과 그 주위의 치조골에 발생되는 응력분포를 알아보기 위해 광탄성법을 이용하여 분석하였다. 하악의 치조골을 재현하기 위해 PL-3 형의 epoxy resin과 PL-3 보다 경질인 레진치아를 사용하여 설측 이소맹출된 하악 제2대구치를 광탄성모형으로 재현하였다. 광탄성 모형상에 mandibular posterior crossbite appliance를 적용하고 힘을 가하기 전과후의 응력분포를 알아보기 위해 원형편광기를 사용하여 모형의 전후방에서 관찰하였다. 이상의 연구를 통해 얻어진 결과는 다음과 같다.

1. 하악 제2대구치의 협측면에 힘을 가한 경우, 설측 치조정과 치근첨 부위에 응력이 집중되어 나타났고 회전중심이 치근 협측면의 중간 1/3부위와 치근첨 부위에 발생하였으며 이로 인해 제 2대구치에 협측으로의 비조절성 경사이동 및 회전력이 발생하였다.
2. 하악 제2대구치의 설측면에 힘을 가한 경우에는 협측면에 힘을 가한 경우 보다 치근첨에 더 많은 응력이 발생하였다. 또한 치근하방의 치조골 부위에 응력이 증가하였으며 치근의 협측면과 치근첨 부위의 회전중심도 없어져 이로 인한 협측으로의 조절성 경사 이동 및 함입력이 관찰되었다.
3. 하악 제2대구치의 협측이나 설측에 힘을 가한 경우, 고정원인 제1대구치의 치근첨 부위는 힘을 가하기 전의 초기 응력상태와 비교할 때 응력의 증가는 보이지 않아 구치부 협측 반대 교합의 개선시 하악의 설측 호선은 효과적인 고정원으로 사용될 수 있다.

이상의 연구 결과는 설측 이소맹출된 하악 제2대구치의 구치부 협측 반대교합을 개선하기 위해 사용되는 mandibular posterior crossbite appliance를 적용할 때, 제2대구치의 협측면보다는 설측면에서 힘을 부여하는 것이 교합장애를 야기시킬 수 있는 비조절성 경사이동과 구치의 회전을 피하면서 협측으로의 조절성 경사이동 및 함입력을 적용시킬 수 있음을 의미한다.

주요 단어 : 구치부 협측 반대교합, 응력, 광탄성법, 원형편광기, 무늬차수