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Photoelastic evaluation of Maxillary Posterior Crossbite Appliance

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This study was undertaken to demonstrate the forces in the maxillary alveolar bone generated by the activation of the maxillary posterior crossbite appliance in the treatment of posterior buccal crossbite caused by buccal ectopic eruption of the maxillary second molar. A photoelastic model was fabricated using a photoelastic material (PL-3) to simulate alveolar bone and ivory-colored resin teeth.

The model was observed throughout the anterior and posterior view in a circular polariscope and recorded photographically before and after activation of the maxillary posterior crossbite appliance.

The following conclusions were reached from this investigation :

1. When the traction force was applied on the palatal surface of the second molar, stresses were concentrated at the buccal and palatal root apices and alveolar crest area. The axis of rotation of palatal root was at the root apex and that of the buccal root was at the root 1/4 area. In this result, palatal tipping and rotating force were generated.
2. When the traction force was applied on the buccal surface of the second molar, more stresses than loading on the palatal surface were observed in the palatal and buccal root apices. Furthermore, the heavier stresses creating an intrusive force and controlled tipping force were recorded below the buccal and palatal root apices below the palatal root surface. In addition, the axis of rotation of palatal root disappeared whereas the rotation axis of the buccal root moved to the root apex from the apical 1/4 area.
3. When the traction force was simultaneously applied on the maxillary right and left second molars, the stress intensity around the maxillary first molar root area was greater than the stress generated by the only buccal traction of the maxillary right or left second molar.

As in above mentioned results, we should realize that force application on the palatal surface of second molars with the maxillary posterior crossbite appliance produced rotation of the second molar and palatal traction, which may cause occlusal interference. That is to say, we have to escape the rotation and uncontrolled tipping creating occlusal interference when correcting buccal posterior crossbite. For this purpose, we recommend buccal traction rather than palatal traction force on the second molar.

Key words : Posterior buccal crossbite, Stress, photoelastic stress analysis, Circular polariscope, Fringe order

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Ectopic eruption is a broad category referring to any abnormal or aberrant eruptive position taken by a tooth.[1] The eruption pattern of the upper second molar shows a tilting of the long axis of the tooth in a mesial-palatal direction.[2] In many cases, however, where there is excessive distobuccal inclination after distalization of the upper first molar, or where there is insufficient growth of the maxillary tuberosity, which produces a posterior arch length discrepancy, the tilting component of the eruptive movement will not be adequate enabling the second molar to reach an upright position.

As a consequence, the palatal cusp of the tooth may become too prominent, or, in more extreme cases, the second molar is in buccal crossbite. Heavy balancing side contacts will occur, which have been found to be detrimental to harmonious function of the masticatory system.[3] Therefore in many studies, efficient methods to correct upper second molar position were described.

Cureton[4] reported that incidence of malaligned second molars occurred in untreated individuals. In this study, more maxillary second molars erupted facially than the mandibular second molars, and the greatest number of the malposed maxillary second molars were inclined with roots to the mesial, and the crown to the distal. On the other hand, La kind[5] reported the case that treated ectopic maxillary second molars with the cemented bite plate to open the bite and allow the maxillary second molars to move palatally. The second molars were bonded lingually with elastic hooks for traction to the appliance.

Correction of posterior crossbite, although it involves a limited portion of the dental arch, can be difficult. The tooth in crossbite must be intruded and moved either lingually or buccally. Therefore, a modified transpalatal arch was used with a soldered spur and button bonded to the palatal or buccal surface of the second molar, and an elastic chain to correct buccal crossbite.[6,7,8]

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

The analytic methods of stress produced by orthodontic force application analysis are finite element analysis[9], laser holography[10], strain gauge[11], and photoelastic analysis. Among these methods, photoelastic analysis provides a method of visualizing and analyzing the forces exerted at the various areas of the tooth surface. The basis for this research method is the fact that most clear materials become doubly refractive to light when stressed.[12]

Photoelasticity is an experimental technique of stress analysis, which is effective in studying such a complicated force system. In 1816 Brewster found that when a piece of glass is strained it becomes doubly refractive.[13] This phenomenon, known as the "photoelastic effect," is true, to a varying degree, of almost all transparent materials. Thereafter Zak[14] introduced the technique of photoelastic stress analysis to dentistry by reporting the various effects of orthodontic mechanics within the supporting structures. Several authors[15,16,17,18,19,20,21,22] have used photoelastic analysis in their studies of orthodontic and orthopedic forces on the craniofacial complex.

The purpose of this investigation is to observe the effects of the force application within the alveolar bone by maxillary posterior crossbite appliance and to facilitate clinical selection and use of posterior crossbite appliance by determining the magnitude and distribution of the stresses produced at dentoalveolar system after force application.

MATERIALS AND METHODS

1. Photoelastic model

For the purposes of biomechanical testing, a photoelastic model was fabricated from birefringent alveolar bone simulant. (PL-3 ; Measurements Group, INC., U.S.A.) PL-3 is a room temperature curing two-component resin/hardener system for making contourable photoelastic plastic models.[17] The models used in this study were fabricated in the following manner.

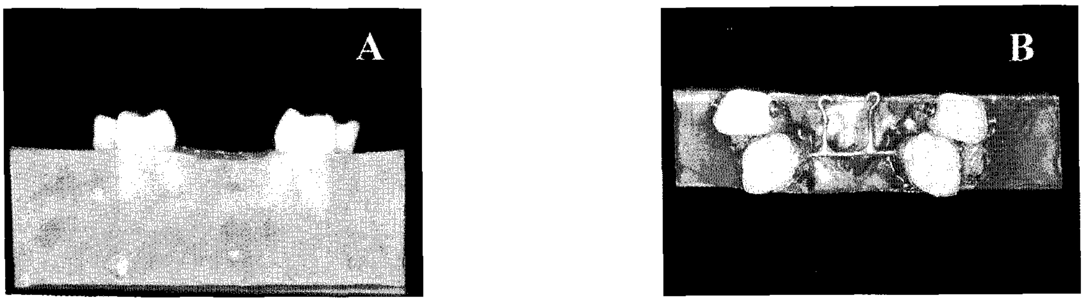

Fig. 1. A, photoelastic model to visualize forces produced by the force application. B, maxillary posterior crossbite appliance

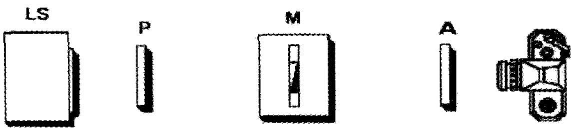

Fig. 2. Schematic reprentation of circular polariscope arrangement.(Ls, light source : P, polarizer : M, model : A, analyser)

The photoelastic model of the upper arch was constructed to simulate a malocclusion. We used the ivory-colored resin teeth. A wax mold was used to set up the malocclusion. A silicone impression of the simulated buccal crossbite was taken and the teeth were inserted separately into the dentoalveolar segment. After this process, wax was poured in to make the wax model. This was polished and then used for silicone impressions, which were cast with a photoelastic material (PL-3) (Fig. 1A).

2. Maxillary posterior crossbite appliance

We used a transpalatal bar as a maxillary anchorage unit. Transpalatal archwire was made with 0.036 inch stainless steel wire, and soldered to the palatal surface of the first molar band of each side. The lingual button was bonded to the buccal and palatal surface of the second molar of the each side. Two hooks that were each made from 0.032 inch stainless steel were soldered near each end of the transpalatal bar (Fig. 1B).

Before photoelastic testing, the model was examined in polarized light to ensure the absence of residual stresses. Loads were applied to the second molars in the field of a circular transmission polariscope. Elastomeric chain (Energy chain: Rocky mountain) was attached to the hook from a button bonded to either buccal or palatal surface of the maxillary second molars. In the first method, the elastomeric chain is attached to a button bonded to the palatal surface, so that the traction force can be applied to the palatal surface. In the second method, the elastomeric chain is attached to a button bonded to the buccal surface so that it runs through the fossa of the molar and over the crown. This resulted in the traction force to be applied to the buccal surface of second molars. In the last method, the elastomeric chain is simultaneously attached to a button to the buccal surface of both side second molars

3. Photoelastic stress analysis

The stressed models were then examined in a Sharples 15 inch diameter diffuse light polariscope, which employs a mercury and white light source. The polariscope used to make these observations, which consists of an illumination system, a pair of polarizers and a means of locating the specimen in a position between the polarizers (Fig. 2).

The illuminating source employed in this study was a white-light and mercury light incandescent projection lamp. The 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, same colors

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

are transmitted in the same proportions.[23)]

Fractional fringe orders, color patterns caused by stress distribution was measured and analyzed (Table 1).[24)]

RESULTS

Passive fit of the appliance was confirmed photo-elastically before the application of any forces (Fig. 3). 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 all posterior teeth. Primary stresses were seen radiating from apices of the first and second molars to alveolar structure. The initial effects of the force application were observed in the alveolus between the first molars and second molars.

Force application on the palatal surface of maxillary second molar

The stresses associated with force application on the palatal surface of the second molar were concentrated to both palatal and buccal roots. The largest group of stress fringes was shown at the palatal and buccal root apex and emanated along the root surface, whereas force application on the buccal surface was concentrated on both the apices and middle 1/3 of the palatal root (Fig. 4). The intensity of distributed stress in the alveolus was smaller than buccal traction. The color pattern of around the apices of buccal and palatal roots was yellow, which is equivalent to the fringe order of 0.6. The color pattern around the middle 1/3 of the palatal root was red, which is equivalent to a 0.9 fringe order. The axis of rotation of the palatal root was at the root apex and of the buccal root was at the apical 1/4 area.

Force application on the buccal surface of maxillary second molar

Fig. 5 illustrates stresses produced by the force application on the buccal surface, which were concentrated in the palatal and buccal root apices of the maxillary second molar. The stresses were generally emanating from both roots of the second molars. The stress intensity produced in this area was heavier than that of palatal traction. Stress of the palatal root apex was greater than that of the buccal root apex. The fringe order was increased along the palatal root surface from 0.9 to 2.2. The color pattern below the palatal root apex was red, blue-green and gradually repeated yellow, red, red-green, and green. The amount of stress was also increased in fringe order. Fringe order for below the palatal root apex was 0.9, the apex of the palatal root was 1.2, the apical 1/4 of palatal root was 1.75, middle 1/3 was 2.0, apical 3/4 was 2.2, whereas the stress of buccal root area was increased to 1.2 in fringe order. The axis of rotation of the palatal root disappeared whereas rotation axis of buccal root moved to root apex from the apical 1/4 area.

Simultaneous force application on both side upper second molars

Fig. 6 shows the stress distributions resulted from simultaneous force application on both side. A purple color (fringe order : 1.0) pattern of stress distribution was observed at the buccal root apex of the maxillary

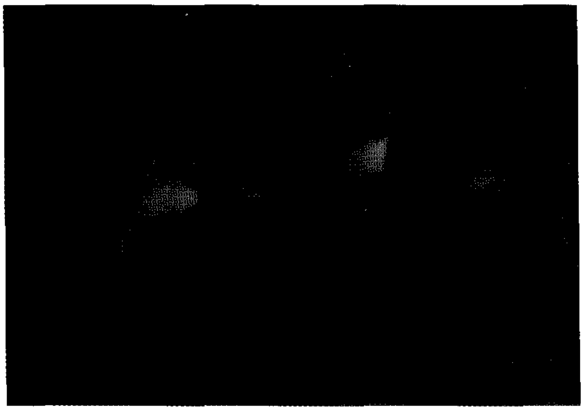

Fig. 3. Distal view of the photoelastic model. The photoelastic model located in polarized light before force application. A stress-free model with no force applied shows a minimal residual stress patterns.

Fig. 4. Distal view of stresses produced by force application on the palatal surface of right side second molar. The color fringes indicative of internal stress around the apices of the palatal and buccal roots. The red color pattern of small concentration was shown at middle 1/3 of the palatal root.

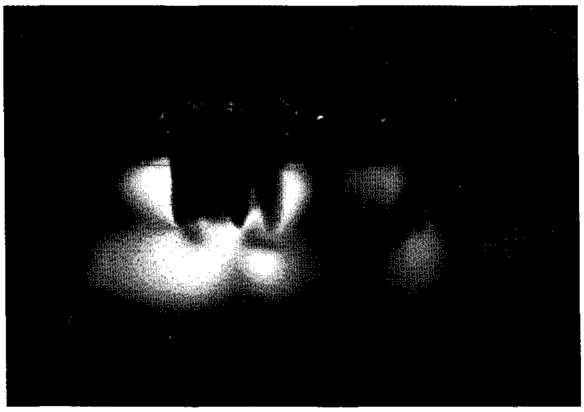

Fig. 5. Distal view of stresses produced by force application on the buccal surface of right side second molar. Stress concentration was showed at the both root apices of second molar. The stress of root furcation area was increased and moved to middle 1/4 of the palatal root.

Fig. 6. Distal view of stresses produced by simultaneous force application on the buccal surface of both side second molars.

right and left second molars and a blue-green color (fringe order : 1.2) pattern was observed at the palatal root apex of the maxillary right and left second molars. The stress intensity around the maxillary first molar root area was greater than the stress generated by only buccal traction of the maxillary right second molar.

DISCUSSION

1. Ectopic eruption of maxillary second molar

The area of immediate concern is the maxillary tuberosity and the space available for eruption of the maxillary second and third molars. During growth of the maxilla, space to accommodate the erupting first, second, and third molars must be created by growth in the posterior region of the tuberosity. The maxillary growth in this area must normally be downward and forward to create room for the eruption of each succeeding molar. If growth in this region is insufficient, abnormal eruption or lack of eruption will result. In absence of the required room to move the maxillary dentition posteriorly until a normal relationship with the cranial anatomy is restored, an impasse is often reached. The usual result is a buccal displacement of the maxillary third molars and, at times, a displacement of the second molar.

Therefore it is not unusual to see maxillary second molars erupting in buccoversion because of a lack of development in the tuberosity area. They must either erupt in this manner or be impacted, and this condition is magnified with respect to available room for eruption of the maxillary third molars.[25] This situation is accounted for in part by Weinmann and Sicher.[26] In the meantime, it may be possible to turn the discounted third molar to some advantage as a substitute for the second molar in certain situations and at the same time solve some of our problems in the maxillary tuberosity area. However, this method is very limited, as maxillary third molars must have fair size and shape with the possibility of good root development.

Theories proposed to explain the cause of dental crowding vary widely, embracing concepts of evolution[27], heredity[28], and environmental effects. In addition, many investigators studied the interrelationship of tooth size[27], arch size[29], and dental crowding and reported dissimilar findings. Two groups of investigators emerge.

As mentioned above, the etiology of ectopic eruption of the maxillary second molar is very variable and controversial.

2. Selection of photoelastic stress analysis

The photoelastic model developed for this study was designed to provide a reasonable estimate of stresses produced by the posterior crossbite appliance. 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 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 or regions where major biologic responses may be expected.

We were interested in assessing the direction and distribution of internal stresses rather than in quantitating 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.[30]

The photoelastic stress analysis can also examine the stresses throughout the entire model (whole-field observation). It should be noted that finite element analysis (FEA) and laser holography also have the characteristics of whole-field observation. While these techniques have the potential for high accuracy, their application is not an easy matter. For example, the anisotropic input data of the individual elements of the orofacial complex, which is required for utilization of the strengths of the FEA, are not known. On the other hand, laser holography, while inherently extremely accurate in measuring displacements, is complicated to apply in vivo because of the difficulty in fixating the head. In addition, this technique cannot predict any internal effects.[31]

However, the use of photoelastic materials for analysis of stress and strain has been criticized by Evans,[32] who suggested that these materials are different from bone. However, the validity of photoelastic model system as a simulator of oral structures has been demonstrated by Standlee, Collard, and Ca-puto,[33] Grickman and associates,[30] and Brodsky and coworkers.[34] Positive correlations were shown between the stresses developed in a photoelastic model and histologic specimens of a cat, whose canine was subjected to a tipping force. The authors concluded that a homogeneous isotropic photoelastic model is useful in visualizing stresses that cause various histologic responses.

Because of the above mentioned reasons, we used the photoelastic technique for this investigation. Photoelasticity has had a long history of applications in dentistry and has been shown to be predictive of many clinically observed phenomena.

3. Stress direction and distribution

Application of maxillary posterior crossbite appliance

Before photoelastic testing, the model was examined in polarized light to ensure the absence of residual stresses (Fig. 3). As observed in this investigation, forces derived from the maxillary posterior crossbite appliance caused various stresses on the dentoalveolar structures. In each instance, the maximum stress occurred at root surfaces. Stresses were seen to radiate from the root surface and apices of the maxillary second molar. The nature of the stress patterns elicited by the maxillary posterior crossbite appliance in the model implicated the direction of the force application.

Force application on the palatal surface of maxillary second molar

The stress was greater in the palatal root surface than the buccal root surface. The very heavy concentration of stress was observed in the apex, middle surface of palatal root and cervical area of palatal surface, it means that rotating force was added on the second molar. The axis of rotation of palatal root was at the root apex and that of the buccal root was at the root 1/4 area. Stress intensity of palatal root surface was heavier than buccal root surface. Fringe order of middle1/3 of the palatal root was 0.9 (red color) and middle of the buccal root was less than 0.6 (yellow color). These forces may result in the palatal traction of the maxillary second molars, producing an uncontrolled palatal tipping and rotating force on the molar.

Force application on the buccal surface of maxillary second molar

A great deal of stress was noted in both the buccal and palatal roots. When compared to the force application on palatal surface, more stress was observed in the palatal and buccal roots creating an intrusive force and a palatal traction for the maxillary second molars. The color of buccal root area was changed to red, blue-green and the color of palatal root area was gradually changed to yellow, red, red-green, and green. Fringe order of this area was also increased. In addition, the axis of rotation of palatal root disappeared, whereas the rotation axis of buccal root moved to the root apex. This finding confirms that in this type of force applications, the intrusion force would occur and greater stresses would appear on these teeth than when the loading occurs on the palatal surface, leading the possible development of controlled tipping and intrusion of teeth. The closer the lingual button is bonded to the edge of the crown, the more effective the intrusive force will be, although it may become uncomfortable for the patient. Consequently, the possibility of rotation and uncontrolled tipping of malpositioned second molars must be eliminated in the correction of posterior buccal crossbite. For this purpose, we recommend the buccal, rather than palatal, traction forces on the maxillary second molar.

Simultaneous force application on both side upper second molars

When we simultaneously applied the traction force on buccal surface of both sides of second molar, the stress intensity of anchoring units (first molars) was increased. It represents that the anchoring teeth received higher stresses when we simultaneously applied the traction force on buccal surface of both sides of second molars. Therefore it is important to note that the simultaneous traction of the second molar has to be avoided in order to prevent the harmful stress concentration at the anchoring tooth.

CONCLUSIONS

A photoelastic model was used to visualize the effects of maxillary posterior crossbite appliance in the treatment of posterior buccal crossbite. Through the use of this model, four observations were made. The photoelastic visualization for a given movement was found to be directly related to the direction of force application. The following conclusions were reached from this investigation :

1. When the traction force was applied on the palatal surface of the second molar, stresses were concentrated at the buccal and palatal root apex and alveolar crest area. The axis of rotation of palatal root was at the root apex and that of the buccal root was at the root 1/4 area. In this result, the palatal tipping and rotating force were generated.
2. When the traction force was applied on the buccal surface of the second molar, more stresses other than loading on the palatal surface were observed in the palatal and buccal root apices. Furthermore, the heavier stresses creating an intrusive force and controlled tipping force were recorded below the buccal and palatal root apices and below the palatal root surface. In addition, the axis of rotation of palatal root disappeared whereas the rotation axis of the buccal root moved to the root apex from the apical 1/4 area.
3. When the traction force was simultaneously applied on the maxillary right and left second molars, the stress intensity around the maxillary first molar root area was greater than the stress generated by the only buccal traction of maxillary right or left second molar.

As in above mentioned results, we should realize that the force application on the palatal surface of second molars with the maxillary posterior crossbite appliance produces an rotation of second molar and palatal traction, which may cause occlusal interferences. That is to emphasize the needs, for us as orthodontists, to exclude any possibility of the rotation and uncontrolled tipping would create occlusal interference, when correct buccal posterior crossbite. For this purpose, we recommend to use the buccal traction force on the second molar instead of the palatal traction.

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국문초록

Maxillary Posterior Crossbite Appliance의 적용시 응력 분포에 관한 광탄성법적 연구

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

1. 상악 제2대구치의 구개면에 힘을 가한 경우, 협측과 구개측 치근첨에는 무늬차수 0.6차와 치경부에는 무늬차수 0.9차의 응력이 집중이 되어 나타났고 회전중심이 구개측 치근은 치근첨에, 협측 치근은 치근 1/4부위에 발생하였으며 이로 인해

제2대구치에 구개측으로의 비조절성 경사이동 및 회전력이 발생하였다.
2. 상악 제2대구치의 협측면에 힘을 가한 경우에는 구개면에 힘을 가한 경우 보다 협측과 구개측의 치근첨에 더 많은 무늬차수 2.2차의 응력이 발생하였다. 또한 치근하방의 치조골 부위에 응력의 발생과 함께 구개측 치근의 회전중심은 사라지고 협측 치근은 치근첨으로 이동하여 이로 인해 구개측으로의 조절성 경사이동 및 함입력이 발생하였다.
3. 상악 제2대구치의 협측이나 설측에 힘을 가한 경우, 고정원인 제1대구치는 치근첨부위에 소량의 응력이 발생하였고, 편측의 제2대구치에만 힘을 가한 경우보다 양측의 제2대구치에 동시에 힘을 가한 경우에서 더 많은 양의 응력이 제1대구치에 발생하였다.

이상의 결과는 협측 이소맹출된 상악 제2대구치의 구치부 협측 반대교합을 개선하기 위해 사용되는 maxillary posterior crossbite appliance를 적용할 때, 제1대구치의 고정원 상실을 최소화하기 위해서는 편측의 제2대구치를 먼저 개선시키고 그 후 반대측 제2대구치의 개선을 도모하는 것이 바람직하다는 것을 의미한다. 또한 구개측면보다는 협측면에서 견인력을 가하여 제2대구치에 함입력과 구개측으로의 조절성 경사이동을 발생시키는 것이 구치의 정출 및 회전에 의해 야기될 수 있는 교합장애를 방지할 수 있으리라 사료된다.

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