Stress Distribution Under High-pull Extraoral Chin Cup Traction

A photoelastic study

J. Alfredo de Alba, Spiro J. Chaconas, Angelo A. Caputo and Wes Emison

Dr. de Alba is an Assistant Professor and Clinic Director in the Section of Orthodontics, School of Dentistry, at the University of California at Los Angeles (UCLA). He holds a B.S. degree in Biology from the University La Salle, Mexico City, a D.D.S. degree from the University of Mexico, an M.S. degree in Oral Biology from UCLA, and a Certificate in Orthodontics from the same institution.

Dr. Chaconas is Professor and Chairman of the Section of Orthodontics at the UCLA School of Dentistry. He holds D.D.S. and M.S. (Anatomy) degrees and a Certificate in Orthodontics from Marquette University at Milwaukee, Wisconsin.

Dr. Caputo is Professor and Chairman of the Section of Biomaterials Sciences in the UCLA School of Dentistry. He holds a B.S. degree from Brown University and an M.S. degree from Notre Dame in Civil Engineering, and a Ph.D. in Applied Mechanics from the University of Southern California.

Dr. Emison is a postdoctoral student in the Department of Oral and Maxillofacial Surgery at Louisiana State University. He holds a B.A. degree in Biochemistry from the U.S. International University at San Diego, California, and a D.D.S. degree from UCLA.

Address:
Dr. Alfredo de Alba
Orthodontic Section
UCLA School of Dentistry
Los Angeles, CA 90024

Photoelastic stress analysis of a three-dimensional model of craniofacial structures is used to identify the areas of ultimate stress distribution under high-pull chin cup traction. Greatest concentrations outside the dentition are in the retromolar area and condylar process of the mandible.

Orthopedic traction using extraoral forces is a well-accepted method for the treatment of Class II malocclusion, but relatively few practitioners treat developing Class III or vertical skeletal dysplasias with extraoral traction to the mandible.

Anterior open bite is generally considered more difficult to treat when a vertical skeletal discrepancy is also a factor in the malocclusion. Vertical orthopedic forces applied during early growth may help. Altering the direction of mandibular growth and so decreasing the ensuing vertical discrepancy could ease the problems of subsequent correction of dental relationships.

Much controversy still exists among clinicians over the effectiveness of extraoral chin cup appliances in altering vertical malrelationships in the openbite patient, with many questions still unanswered. Reasons cited for avoiding such methods include concern about possible unfavorable iatrogenic effects on the temporomandibular joint and overall doubt about exactly what may occur when such forces are applied to the mandible.

The objective of this study was to examine the location, magnitude, and direction of stresses produced within the craniofacial complex by high-pull orthopedic traction applied to the mandible with an extraoral chin cup. Three-dimensional photoelastic analysis provided the basis for this evaluation.

Literature Review

Early reports on the value of extraoral force and its possible use in the correction of an anterior open bite were made by Lind[1] in 1915 and by Dewey and Anderson[2] in 1942. Those early investigators already recognized the limitations of tooth-borne appliances in those open bites with severe skeletal dysplasias.

The manner in which the mandible grows has been an ongoing enigma that still arouses controversy. Weinmann and Sicher[3] believed that the condyle is the primary growth center of the mandible, endowed with a specific genetically determined potential.

That view is less widely accepted today, and is strongly contested by Moss[4-6] and others. These investigators take the position that the condyles are not primary growth sites responsible for initiating most mandibular growth, but rather that they act as secondary centers responsible for growth only in the condylar region. Moss states in his functional matrix theory that the growth of other regions of the mandible is controlled by their own intrinsic growth processes, independent of those of the condylar centers.[4]

With such basic questions about the details of mandibular growth still unanswered, it is little wonder that many questions about the effects of orthopedic force still remain.

The potential importance of the external pterygoid muscle in orthopedic therapy has been demonstrated by Petrovic and associates[7,8] in their experiments on young rats. They state that "The wearing 8-12 hours a day of the so-called 'passive' hyperpropulsion device, leading to a postural hyperpropulsion, provokes in the young rat: a) a decrease in the number of serially arranged sarcomeres of the lateral pterygoid muscle; b) an increased proliferation of the condylar cartilage prechondroblasts; c) an increase in length between posterior edge of the condyle and the mental foramen. The opposite changes occur when the mandible is drawn backwards with a chin cup. The evidence favors our hypothesis that variations in contractile activity of the lateral ptetrygoid muscle influence multiplication of the homolateral condylar prechondroblasts."

The phenomenon described as mandibular rotation during normal mandibular growth must be dealt with if any headway is to be made in the understanding of the effect of extraoral forces on the mandible. Odegaard[9] has made significant contributions to the understanding of mandibular rotation with growth. His studies, based on cephalometric analysis using metal implants in human subjects, have demonstrated that "The degree of rotation is related to the direction and the magnitude of condylar growth."

Investigations by Schudy[10] have confirmed the relationship between mandibular rotation and the development of open bite. His work has clearly shown that when vertical growth in the molar region exceeds that of the ramus, the mandible tends to rotate open anteriorly.

Studies and observations of human subjects under chin cup therapy are relatively few. However, there is documentation in the literature of extraoral forces being applied to the mandible for purposes unrelated to dental therapy.

One such study was conducted by Alexander[11] on the effects of the Milwaukee brace used in the treatment of idiopathic scoliosis. Much of the mechanical support for early forms of this orthopedic brace came from a pad below the submental portion of the mandible, resulting in application of an upward force of about four pounds to the region.

Although the forces used with orthodontic chin cup therapy are much lighter and oriented more posteriorly, the following findings from his study still have possible relevance to such treatment.

a) The anterior facial height was reduced, with the greatest change in the lower face. Upper molars were found to be depressed slightly, while the mandibular molars were depressed even more.

b) The distance between articulare and gonion decreased significantly. This was suggested as support for the assumption that the mandibular condyle was being pushed superiorly and posteriorly in the glenoid fossa.

c) The gonial angle decreased an average of 4.5 degrees, with individual reductions ranging from 1.5 to 7 degrees.

In summary, little is known yet about exactly what occurs when the mandible is subjected to extraoral force. One means of studying the potential effects of such forces is to visualize the internal force distribution through the use of photoelasticity.[12]

Photoelastic materials were first used to study extraoral forces by Chaconas, Caputo and Davis,[13] who used this method to evaluate the effects of cervical-pull and high-pull facebow devices on the maxilla. More recently, de Alba, Chaconas, and Caputo[14-16] have evaluated the stresses produced in the mandible by a chin cup activated for correction of a Class III relationship, and in craniofacial structures by Class III intermaxillary traction.

Methods and Materials

Various birefringent materials were used to construct a three-dimensional model reproducing the teeth, periodontal ligaments, and bones of a human skull. The techniques and methods were those employed by de Alba and associates[14] in a previous study.

The model was supported by an eight-inch diameter hinge stand attached through the foramen magnum by a one-inch round aluminum rod. Additional stability was achieved with a ¾ × ½-inch curved steel bar joining the calvarium and cranial base unit.

The external pterygoid muscle was simulated by a .009″ × .036″ (.22 × .9mm) closed coil spring.

Force was applied by a chin cup activated by 500 gm weights attached to each side with .040″ (1mm) copper wire. In order to give the appliance a high-pull vector, the copper wires were angled approximately parallel to the long axes of the rami to a pulley twelve inches above the condyles (Fig. 1).

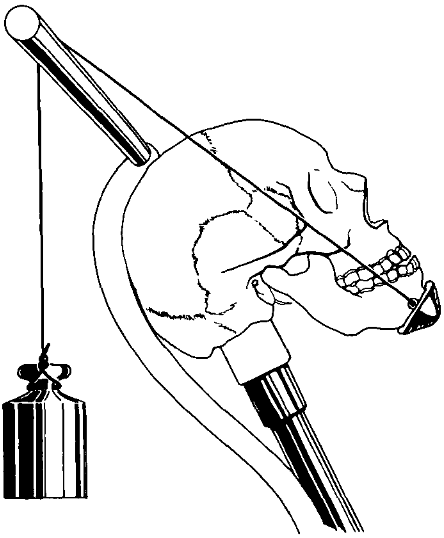

Fig. 1 Test setup illustrating mode of force application to the vertical chin cup appliance.

Once the assembly of the skull was completed, it was examined with polarized light to be sure that it was initially stress-free. The chin cup appliance was then activated, and the entire assembly put through a stress-freezing cycle by heating to 180° F. (82° C.) and then slowly cooling to room temperature.

After stabilization at room temperature, the model was again examined under polarized light and the areas of stress noted. One half of the model mandible was sectioned, using a high-speed circular saw cooled with water to prevent heating of the model. The sections, intact hemimandible and other parts of the skull were then photographed, using a circular transmission polariscope, to record the resultant stress patterns (Fig. 2).

Results

The greatest density of stress patterns was found in the mandible, with relatively little stress in the upper craniofacial structures. The following are the significant observations in each region.

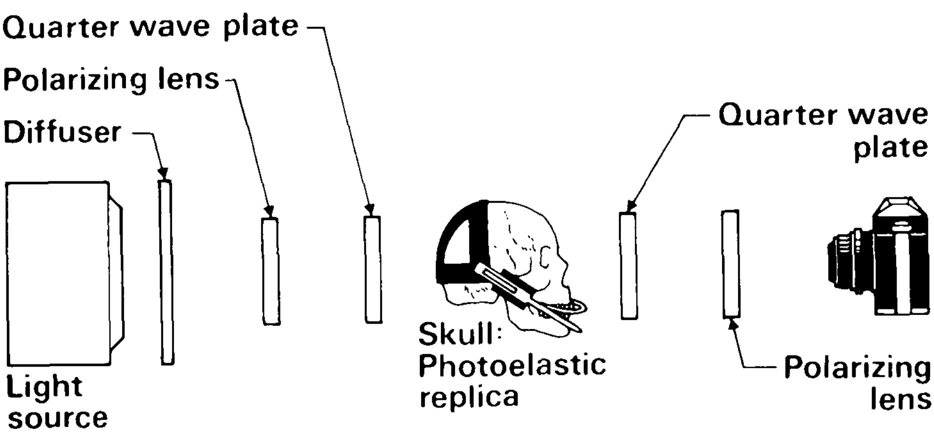

Fig. 2 Diagram of the circular transmission polariscope arrangement.

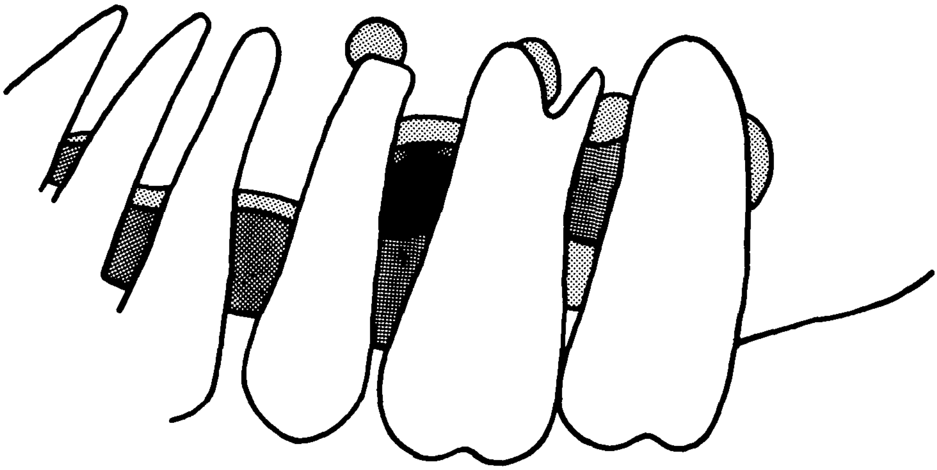

Fig. 3 Diagram of areas of stress in the upper posterior region.

Upper Craniofacial Structures

The various sutural areas of the upper craniofacial complex showed no visible stress effects. Stress patterns were observed radiating from the apices and periodontal ligaments of the maxillary bicuspids and first molars (Fig. 3). These patterns were attributable to the forces applied by the chin cup, transmitted through the occlusal contacts of the dentition.

The lateral pterygoid plates exhibited stress fringes emanating from the points of attachment of the coil springs simulating the lateral pterygoid muscles (Fig. 4).

Stress patterns were observed in the posterior portion of the glenoid fossa, and even higher stresses were found superiorly (Fig. 5).

Mandible

Patterns of stress found at various locations throughout the mandible readily attest to the concentration of chin cup forces there.

It was noted that the greatest stress concentrations appeared in the alveolar process from the second bicuspid to the retromolar region (Fig. 6). Stresses were also observed at the apices of the roots of all posterior teeth. The occlusal photograph of the posterior teeth illustrates these observations, showing concentrically radiating fringes of stress (Fig. 7). Direct occlusal forces transmitted by contact

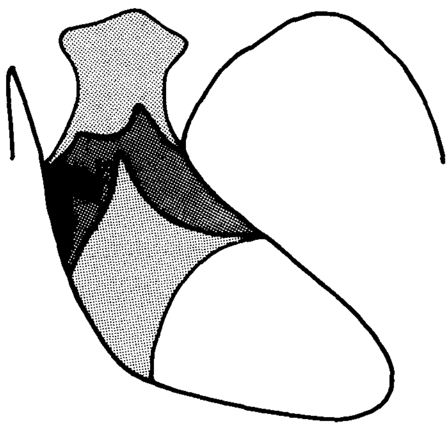

Fig. 4 Diagram of stresses within the lateral pterygoid plate. Highest stresses are at the simulated muscle insertion.

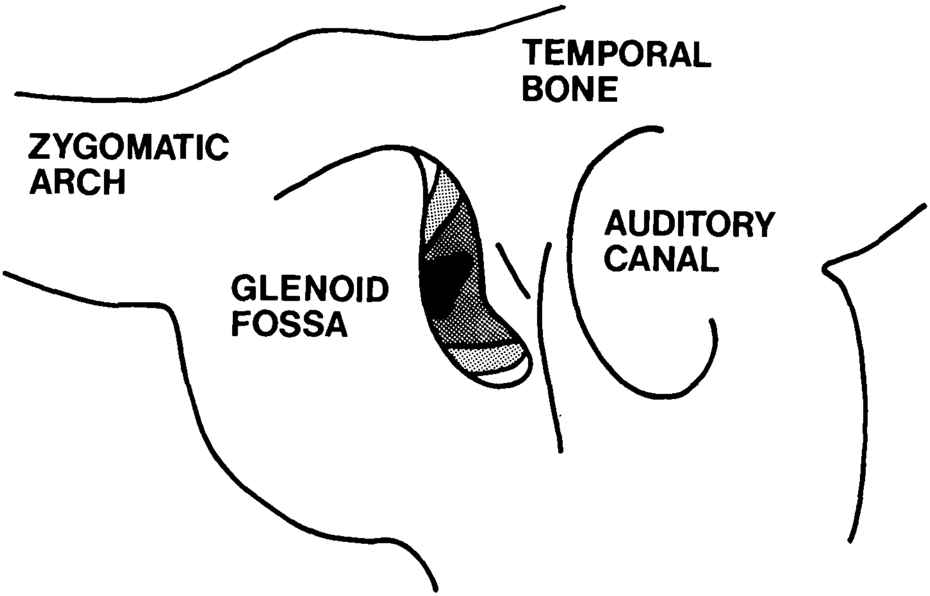

Fig. 5 Diagram of the stresses transmitted to the left glenoid fossa.

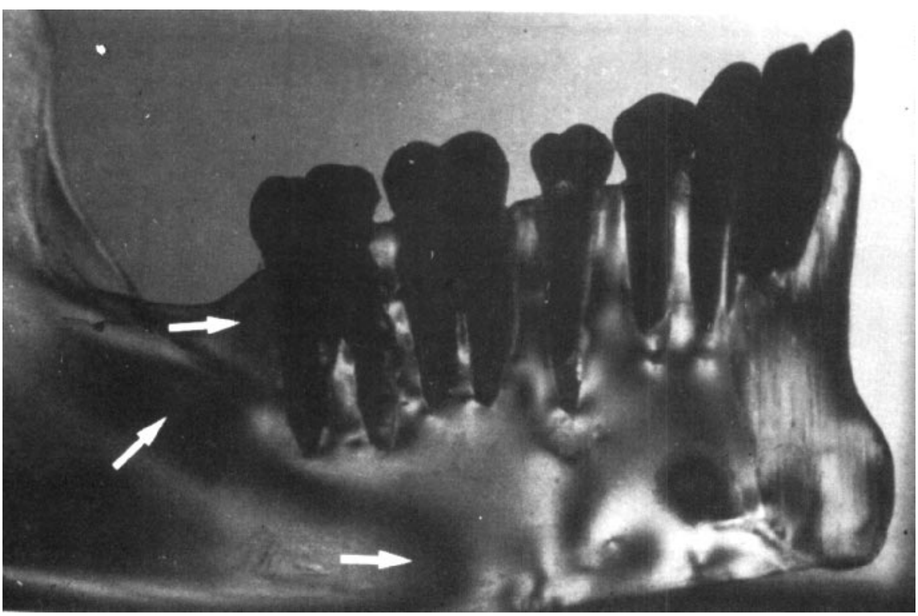

Fig. 6 Stress patterns in the occluded mandible under vertical chin cup traction.

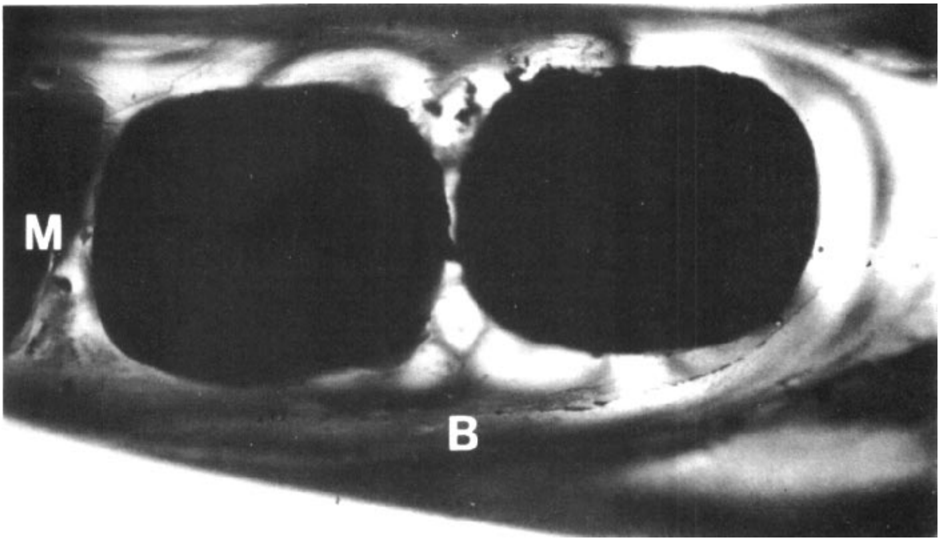

Fig. 7 Stress patterns around mandibular molars resulting from contact with the opposing maxillary teeth.

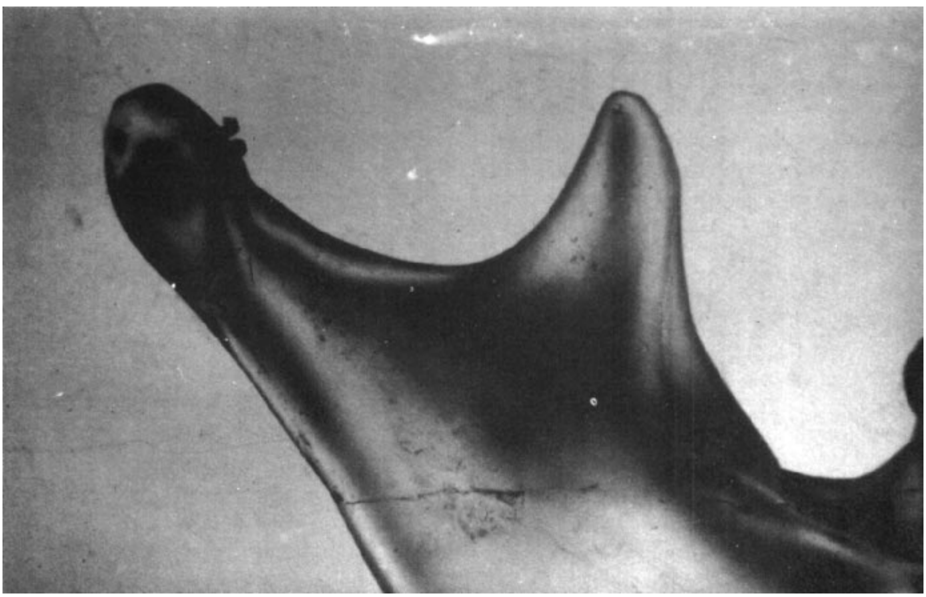

Fig. 8 Stress patterns in the ramus, showing concentrations in the sigmoid notch and the area of insertion of the simulated lateral pterygoid muscle on the condyle.

with the maxillary posterior teeth are, of course, the cause of these patterns.

The very heavy concentration of stress in the retromolar region is away from the teeth and apparently due to bending at this junction of the horizontal mandibular body and the ramus.

Continuing posteriorly, it was observed that the ramus is relatively stress-free below the region of the sigmoid notch. Here a significant crescent of stresses may be seen extending from the depth of the sigmoid notch superiorly to the area of insertion of the simulated lateral pterygoid on the anterior surface of the condylar head (Fig. 8).

Finally, a small concentration of stress was observed on the posterior aspect of the condyle head where it contacted the glenoid fossa.

The location and intensity of stresses within the mandible were further identified in the following sections.

a) A horizontal section through the head of the condyle showed stresses concentrated anteriorly, corresponding to the point of attachment of the simulated external pterygoid muscle.

b) A horizontal section through the neck of the condyle showed stresses localized at the buccal and lingual borders.

c) An oblique section through the area posterior and superior to the retromolar triangle and inferior to the neck of the condyle showed heavy stress superiorly, in the area corresponding to the sigmoid notch.

d) A vertical section through the area posterior and inferior to the retromolar triangle and angle of the mandible showed stresses concentrated superiorly in the retromolar triangle area and more diffusely in the area of the gonial angle (Fig. 9).

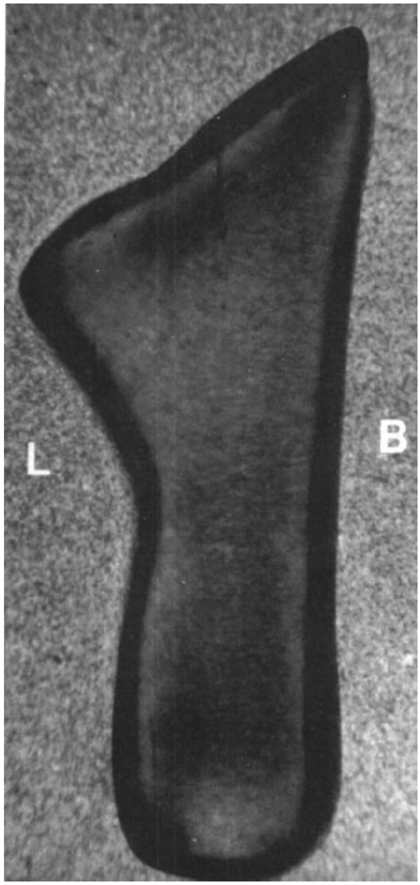

Fig. 9 Section through angle of mandible in the area of the retromolar triangle, showing stresses concentrated at the retromolar triangle and diffusely at the inferior border.

e) A horizontal section through the mandibular body at the level of the apices of the teeth showed some stress surrounding the apex of the cuspid and a greater concentration in the region from second bicuspid to second molar (Fig. 10). This correlates well with the findings on the intact hemimandible.

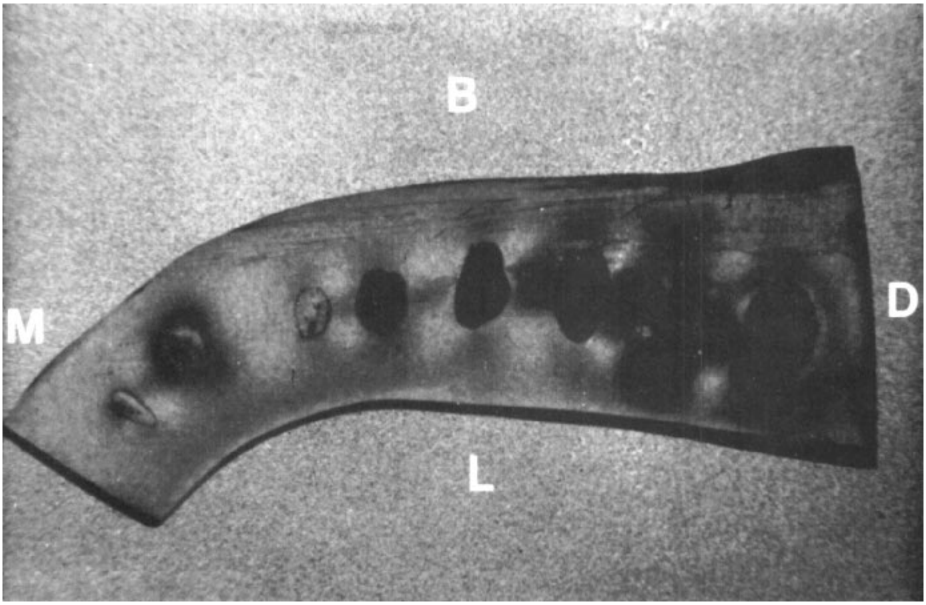

Fig. 10 Horizontal section at apices of teeth illustrating highest stress concentrations near posterior teeth.

Discussion

Stress patterns found in the maxillary and mandibular alveolar processes were reciprocal, a direct result of apically directed forces resulting from occlusal contact under the activation of the chin cup. Those stresses were more concentrated in the mandibular alveolar process.

A pair of reciprocal stress patterns were also found at the attachments of the tension coil spring simulating the lateral pterygoid muscle. The lateral pterygoid plate was stressed laterally, while the head and neck of the condyle were pulled in a medial direction.

A third pair of reciprocal stress patterns were observed at the interface between the head of the condyle and the posterior portion of the glenoid fossa. The stress was unexpectedly greater in the posterior part of the fossa than in the superior portion. Apparently the elevation of the chin rotated the mandible around a fulcrum at the posterior teeth, moving the condyle downward as it was pressed back.

A great deal of stress was noted in the posterior-superior half of the sigmoid notch, including the condylar process. Examination of sections from this area show a bending effect in the condylar process, apparently at least partially due to the medial pull generated by the lateral pterygoid coil.

From these observations it becomes clear that several factors are at work in a complex pattern. Each factor does seem to point toward the expected anterosuperior rotation of the mandible with a closing of the bite. The fulcrum of the rotation induced mechanically by the chin cup force is at the posterior teeth, which coincides with the center for the opposite condylar growth rotation reported by Schudy.[10]

The exact mechanisms by which the growth of the mandible might be redirected remain unknown. It is the intention of this study to give the clinician some insight into where and how orthopedic forces that might influence growth are distributed.

Summary and Conclusions

Birefringent materials were employed in the fabrication of a model of a human skull with distinct simulants for teeth, bone, and periodontal ligaments. The following observations were made subsequent to the application of force to this model with an extraoral high-pull chin cup:

1. Reciprocal stresses were observed in the posterior portion of the glenoid fossa and the contacting posterior part of the head of the condyle.
2. A tension coil spring representing the external pterygoid muscle applied reciprocal stresses at its insertions in the lateral pterygoid plate of the greater wing of the sphenoid and the anterior aspect of the head of the condyle.
3. Stresses were seen to radiate from the roots and apices of both the maxillary and mandibular posterior teeth.
4. A distinct concentration of stress was noted in the retromolar area of the mandible, away from the dentition, indicating a bending stress.
5. The posterior half of the sigmoid notch, below the anterior aspect of the head of the condyle, displayed a heavy band of stresses.
6. Selected sectioning of the mandible substantiated observations made from the intact hemimandible and also showed evidence of bending in the area corresponding to the head and neck of the condyle.

References

1. Lind, G.: The open-bite, its etiology and treatment, Internat. J. Orthod. 1:155-161, 1915.
2. Dewey and Anderson: Practical Orthodontia, C. V. Mosby Co., St. Louis, 1942.
3. Weinmann and Sicher, H.: Bones and Bones, ed. 2, C. V. Mosby Co., St. Louis, 1955.
4. Moss, M. L., and R. M. Rankow: The role of the functional matrix in mandibular growth. Angle Orthod. 38:95-103, 1968.
5. Moss, M. L., and L. Salentijn: Differences between the functional matrices in anterior open-bite and deep overbite. Am. J. Orthod., 60:264-280, 1971.
6. Moss, M. L., and L. Salentijn: The primary role of functional matrices in facial growth. Am. J. Orthod., 55:566-577, 1969.
7. Petrovic, A., and Stutzmann, J.: Le muscle pterygoidieu externe et la croissance due condyle mandibularie. Recherches experimentales chez le jeune rat, L'-Orthod. Franc. 43:271-285, 1972.
8. Petrovic, A. Oudet, C., and Gasson, M.: Effects des appareils de propulsion et de retrepulsion mandibulaire sur le nombre de sarcomeres en serie du muscle pterygoidieu externe et sur la croissance du cartilage condylien du jeune rat, L'-Franc. 44:191-210, 1973.
9. Odegaard, J.: Mandibular rotation studied with the aid of metal implants. Am. J. Orthod., 58:448-454, 1970.
10. Schudy, F. F.: The rotation of the mandible resulting from growth: its implications in orthodontic treatment. Angle Orthod., 35:36-50, 1965.
11. Alexander, R. G.: The effects on tooth position and maxillofacial vertical growth during treatment of scoliosis with the Milwaukee brace. Am. J. Orthod., 52:161-189, 1966.
12. Mahler, D. B., Peyton, F. A.: Photoelasticity as a research technique for analyzing stresses in dental structures. J. Dent. Res., 34:831-838, 1955.
13. Chaconas, S. J., Caputo, A. A., and Davis, J. C.: The effects of orthopedic forces on the craniofacial complex utilizing cervical and headgear appliances. Am. J. Orthod., 69:527-539, 1976.
14. de Alba, J. A., Chaconas, S. J. and Caputo, A. A.: Orthopedic effects of the extraoral chincup appliance on the mandible. Am. J. Orthod., 69:29-41, 1976.
15. de Alba, J. A., Caputo, A. A. and Chaconas, S. J.: Effects of Orthodontic Intermaxillary Class III mechanics on craniofacial structures (Part I) Angle Orthod., 49:21-28, 1979.
16. de Alba, J. A., Chaconas, S. J. and Caputo, A. A.: Effects of Orthodontic Intermaxillary Class III mechanics on Craniofacial structures (Part II). Angle Orthod., 49:29-36, 1979.