Zygomaticomaxillary Suture Adaptations Incident to Anteriorly-Directed Forces in Rhesus Monkeys

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Histologic and radiographic studies of controlled force application to the maxillae of monkeys show varying rotational effects on the maxilla, dependent on the direction of force application.

KEY WORDS: Extraoral traction, Sutures

Although headgear has been used clinically since the early 1800's, our understanding of the biologic and biomechanical effects of extraoral force is still unclear. Perception of the influence of extraoral force has ranged from observation of only dental effects, to recognition of inhibitory effects on growth and more active stimuli at the craniofacial sutures.

The importance of sutures in craniofacial growth is well established. If the craniofacial skeleton was one bone, growth of that unit would involve a tremendous amount of remodeling. This effort is conserved to a considerable degree by the sutures, which allow for changes in the relative positions of the bones. The effect of therapeutic forces may be analogous to the growth process, if sutures are viewed as playing a passive role responding to the forces of other tissue growth and function (Moss and Salentijn 1968).

An understanding of the orthopedic effects of extraoral forces depends on achieving an understanding of the biologic response of the maxillofacial sutures to clearly defined force systems. Recently, the effects of extraoral forces on the sutures of facial bones have been investigated in both retraction of the maxilla (Droschl 1975) and in protraction (Kambara 1977, Nanda 1978, Jackson et al. 1979).

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Similarities have been described between sutures and the periodontal ligament, both in structure and in response to external force systems (NANDA 1978, HINRICHSEN 1968, MOFFETT 1969). The combination of rich vascularity with undifferentiated mesenchymal tissues that provide a source of osteoclasts and osteoblasts makes both tissues very responsive to the influence of applied forces.

However, maxillofacial sutures are much more complex in their gross and microscopic three-dimensional structure than the periodontal ligament. Thus, a histological study of a facial suture is meaningful only when a specific area of the suture is defined relative to the orientation of the applied force system.

This study relates histologic changes in various areas of the zygomaticomaxillary suture to the applied force systems, which are varied in their orientation relative to the occlusal plane.

— Materials and Methods —

This report is part of a larger research project investigating the effects of force system variables on the protraction of midfacial bones. The details of the methods have been previously published by NANDA (1978).

A total of eleven *Macaca mulatta* monkeys were used. Three animals served as controls, while the other eight were in the experimental group. All animals were between 32 and 48 months of age, classified as growing monkeys.

At least two metallic implants were placed on each side of each of the facial sutures (zygomaticomaxillary, frontomaxillary, zygomaticofrontal, and zygomaticotemporal sutures). Additionally, three implants were placed intraorally in the mandible and maxilla.

The monkeys were fitted with a maxillary splint cast of Vitallium. The splint included a bar extending out of the oral cavity, which was used for the application of the protraction force system. A halo headframe was constructed for each monkey to deliver the force. The frame was attached to the head with stainless steel pins which were placed through the periosteum of the cranial bones and the supraorbital part of the frontal bone. A vertical bar extended from the headframe at the midline to about 15mm anterior to the attachment bar of the intraoral splint.

The protraction force system was activated by a calibrated spring which connected the bar of the maxillary splint to the bar of the head frame. A force of 500 grams was applied for 81 to 115 days. The spring activation was adjusted every three weeks.

Cephalometric headfilms were taken prior to initiating the force delivery, and thereafter every three weeks. The serial headfilms were used to ascertain morphological changes, centers of rotation of midfacial bones, and the line of force application relative to the occlusal plane.

Four of the experimental animals were sacrificed at the end of the force application period, and the remaining four were observed for an additional six months following appliance removal.

All monkeys were perfused after sacrifice with normal saline solution, followed by 10% buffered formalin. Tissue blocks of the sutures were cut, embedded in paraffin, and 7μ serial sections were then cut and stained with hematoxylin and eosin.

In this report, a detailed analysis of the response of the zygomaticomaxillary suture to a protraction force system is presented.

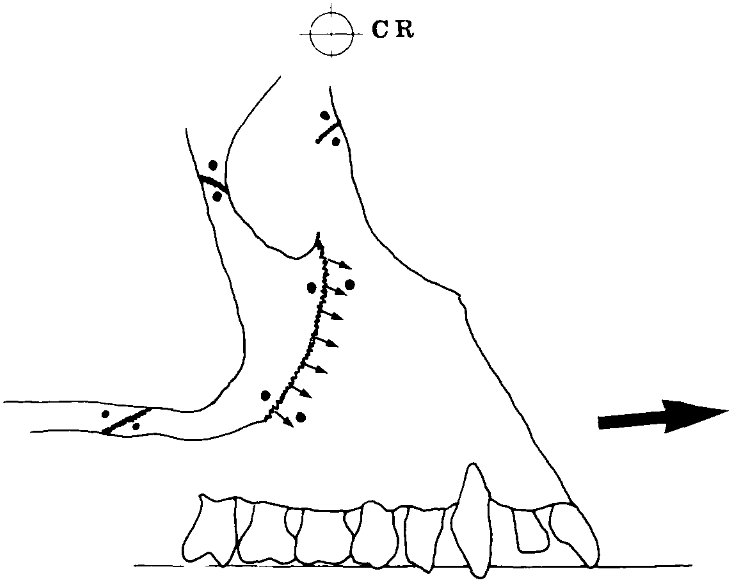

Fig. 1 The line of force application is indicated by the large arrow directed anteriorly from the maxilla. The direction of the force is parallel to the occlusal plane, and the center of rotation (CR) is high. The displacement of the zygomaticomaxillary suture is indicated by the small arrows, with the arrowheads representing the post-activation suture location.

— Results —

At the end of the activation period, 3mm to 6mm of anterior displacement was found at prosthion (the most anterior point of the maxilla) and at implants in the maxilla. These implants indicated a rotation of the maxilla as well as the anterior displacement. There was no relapse of the skeletal changes in the monkeys studied at the end of the six-month post-activation period. Cephalometric analysis of the control animals showed little growth during the experimental period.

The line of force delivery (measured relative to the occlusal plane) influenced the location of the center of rotation of the maxilla.

When the force direction included a substantial superior component relative to the occlusal plane, the center of rotation was lower (Figs. 1 and 2).

In the case of a force directed parallel to the occlusal plane as depicted in Fig. 1, the forces transmitted to various areas of the zygomaticomaxillary suture are nearly uniform, and the displacement of the suture is parallel to the facial surface. However, when the force is directed somewhat superiorly, as shown in Fig. 2, the superior aspect of the suture receives a compressive force and the suture area inferior to the center of rotation receives increasing tension.

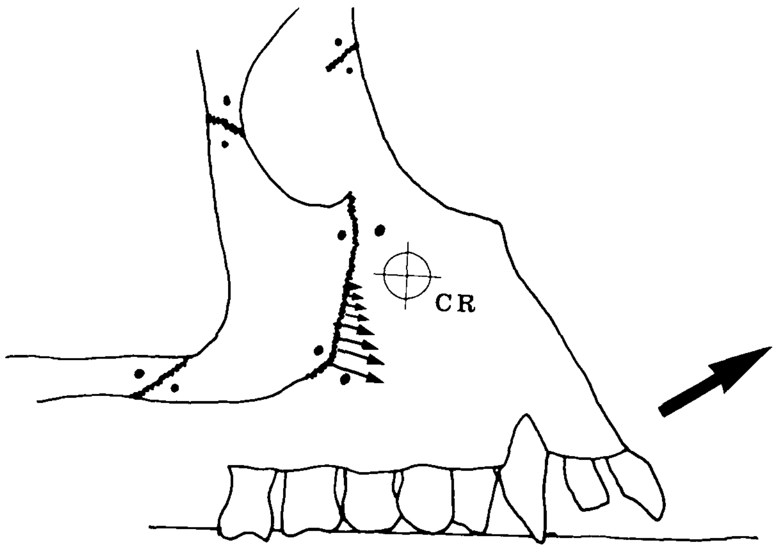

Fig. 2 Force is directed more superiorly than in Fig. 1, and the center of rotation is located more inferiorly.

Controls

Histologic examination of the zygomaticomaxillary suture of control monkeys demonstrated a capsular zone composed of dense connective tissue with fibroblasts and rich vascularity. No particular pattern of bone deposition or resorption was evident. The resting lines and areas of bone deposition were distributed on both sides of the suture (Fig. 3).

There also was no evident pattern of variation in the width of the suture in the controls; this variation is partly dependent on the orientation of the section to the suture, which changes from one area to another due to the complexity of this three-dimensional structure. As shown in Fig. 3, the course of the suture is very tortuous.

The control sutures demonstrated no particular pattern of stress or compression.

Experimental Subjects

In the experimental animals immediately after appliance removal, areas of both compression and tension were observed along the length of the suture. When the protraction force also had a superior component causing a "counterclockwise" rotation of the maxilla, the zygomaticomaxillary suture was stretched at its inferior third (Figs. 4, 5 and 6) whereas the orbital aspect was compressed (Figs. 7 and 8).

The response of the suture away from the facial surface was more complex. Areas of resorption and apposition were

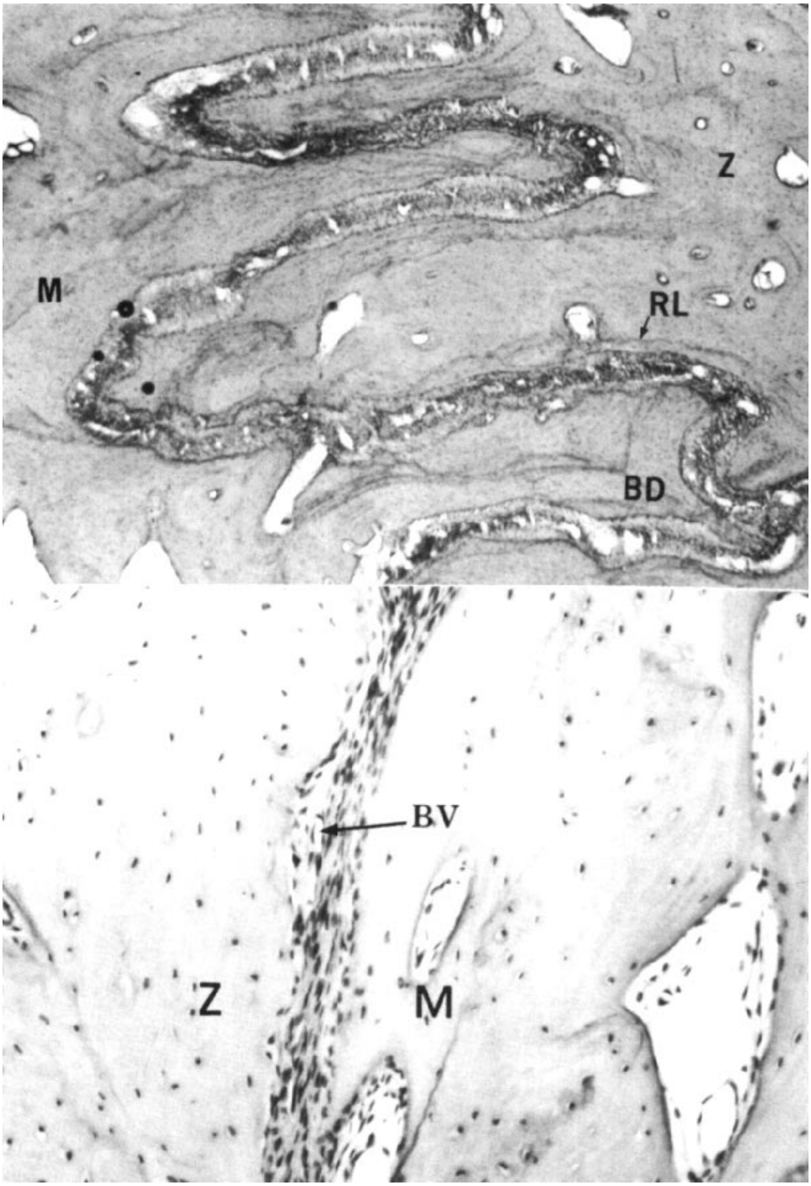

Fig. 3 Zygomaticomaxillary suture of control animals demonstrated a high level of vascularity and cellularity, with no particular pattern of bone deposition. Z, zygomatic bone; M, maxillary bone; RL, resting line; BD, bone disposition, BV blood vessels. (magnification top ×50, bottom × 125).

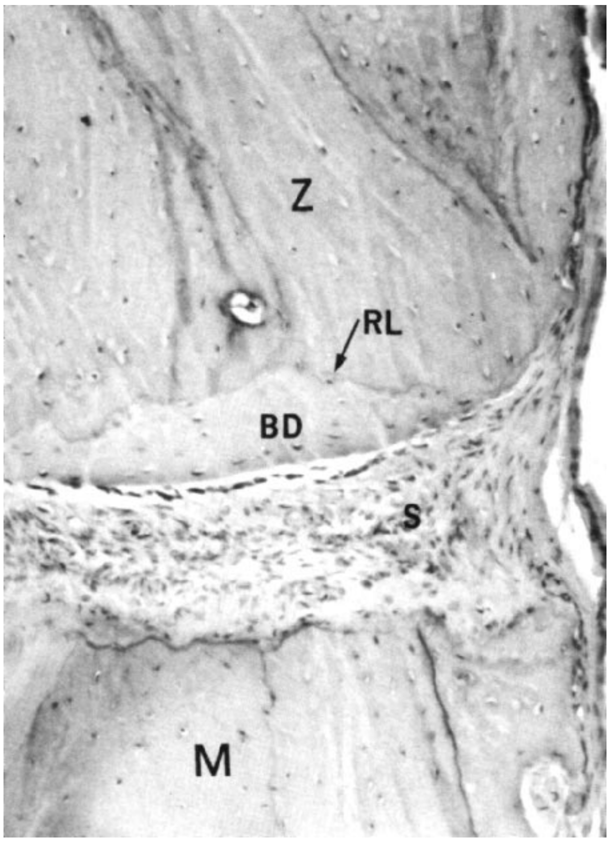

Fig. 5 The inferoposterior surface of the zygomaticomaxillary suture of an experimental animal, demonstrating stretched fibers (S), bone deposition (BD) and resting lines (RL). (magnification ×125).

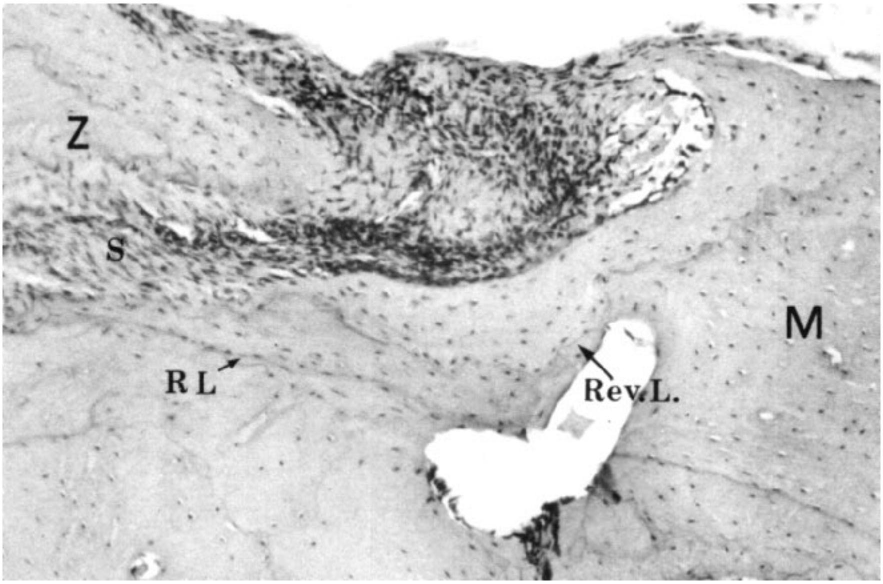

Fig. 4 Zygomaticomaxillary suture at the inferoposterior facial surface immediately after force application, showing stretched fibers (S) due to rotation of maxilla as depicted in Fig. 2. Note the reversal lines (Rev. L) and resting lines (RL). (magnification ×125).

found in close proximity, due to the complex anatomy of the bony interdigitations (Figs. 9 and 10). The suture fibers appeared stretched, relaxed or compressed, depending on their location relative to the direction of force and anatomy of the suture interdigitations.

Although sectioning causes artifactual variation in suture width as the three-dimensional complex is reduced to two dimensions for analysis, in general more areas of compression were noted in the superior third of the suture, and more areas of widening in the inferior third. This generalization is again qualified by the observation that stress and strain areas are seen throughout the course of the suture, often in close proximity due to the interdigitation of the suture.

After six months—

In the monkeys followed for six months after the removal of the force system, the zygomaticomaxillary suture was of normal width and the histologic findings resembled those in the controls (Fig. 11). However, numerous resting lines and reversal lines were present, indicating apposition and resorption activity due to the externally applied force as well as to normal remodelling.

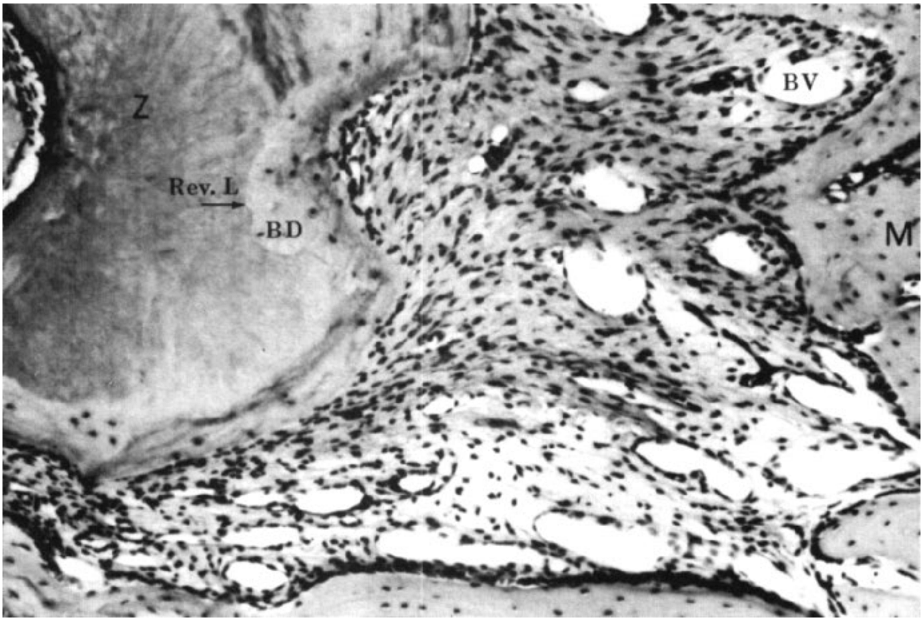

Fig. 6 An area of zygomaticomaxillary suture, near the inferoposterior surface, immediately after force removal. Stretched fibers and high vascularity are noted. Blood vessel (BV), reversal line (Rev. L), bone disposition (BD). (magnification ×150).

— Discussion —

As is the case for predicting tooth movement, an understanding of orthopedic effects requires definition and control of the variables of the force system. These include the magnitude, direction, point of application, duration and constancy of the force, as well as an understanding of the biologic response to these variables.

In many respects, the biologic response of sutures to force systems *is* similar to that of the periodontal ligament (Hinrichsen 1968, Moffett 1969). The histological appearance of fibrous cranial sutures, as well as their response to forces, resembles that seen in the periodontal ligament.

However, the suture remodels on both sides and is more complex in its three-dimensional macroscopic and microscopic morphology. As seen in this study, the tortuous path of the suture with its bony interdigitations makes it difficult to predict a suture's histologic response to an applied force system.

The suture is not only complex in its morphology; the response to a force system alters this morphology. A suture offers numerous resistance points along its complex surface. As some resistance areas are resorbed, others are formed. Likewise, as some areas resorb, this can lead to shifts in other areas from resorption to apposition. This explains the pres-

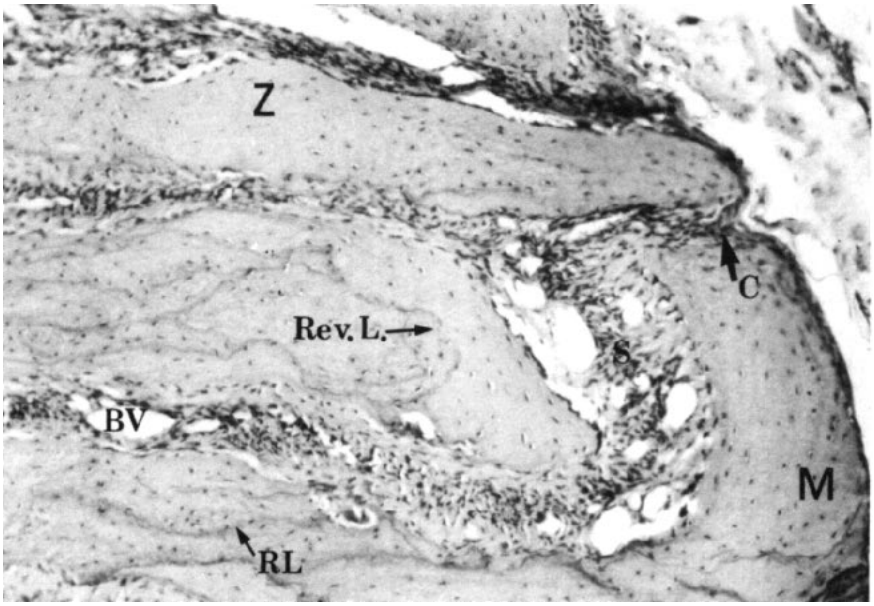

Fig. 7 Orbital surface of the suture shown in Fig. 4; this end lies above the center of rotation, demonstrating compression (Cd), yet areas of tension (stretching, S) are also ssen. Blood vessels (BV), resting lines (RL) and reversal lines (Rev. L). (×125).

ence of numerous reversal lines indicating a change from resorption to apposition.

An optimal force system to achieve an orthopedic effect can be described only when the response of the suture to the various parameters of the force system is understood. Predicting this response is complicated by the complex morphology of the sutures.

The many microscopic interdigitations provide resistance to forces applied to the suture. As an example, the zygomaticomaxillary suture might be expected to provide the least resistance to a protraction force applied to the maxilla when that force is directed through the center of resistance of the maxilla, since this would reduce rotation of the maxilla and thus decrease the shearing of the interdigitations of the suture and decrease the number of resistance points.

This study also demonstrates that protraction of midfacial bones was stable after the six-month observation period, suggesting that a clinically comparable appliance system can be successfully applied to correct midfacial retrusion with orthodontic/orthopedic forces (Delaire 1978, Nanda 1980).

Recent interest in functional orthodontics and use of orthodontic forces to attain orthopedic changes makes it imperative to understand the behavior, morphology and geometry of various facial sutures.

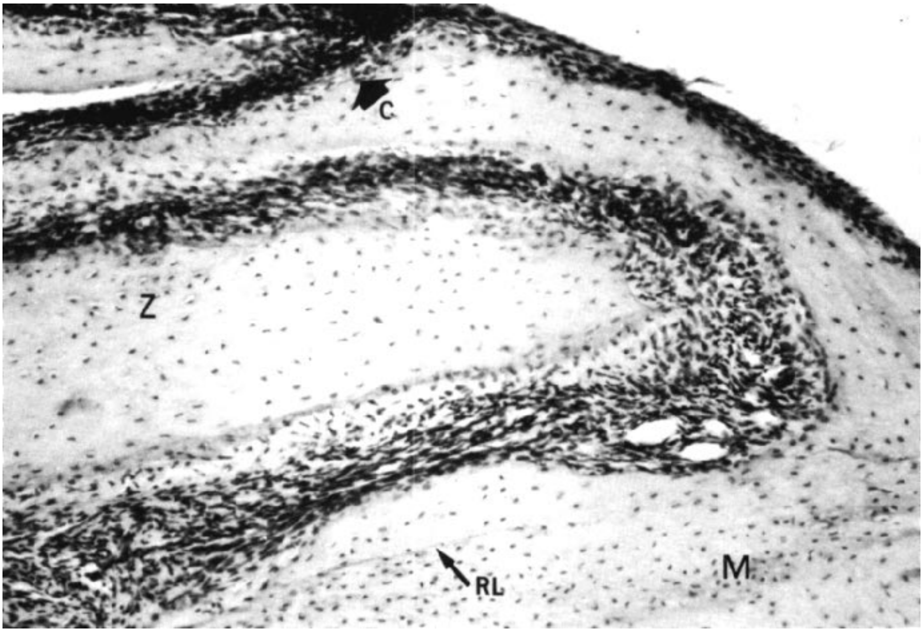

Fig. 8 Compression at the orbital surface of a suture. This one bone spicule shows both compression and tension, as well as increased cellularity (×150).

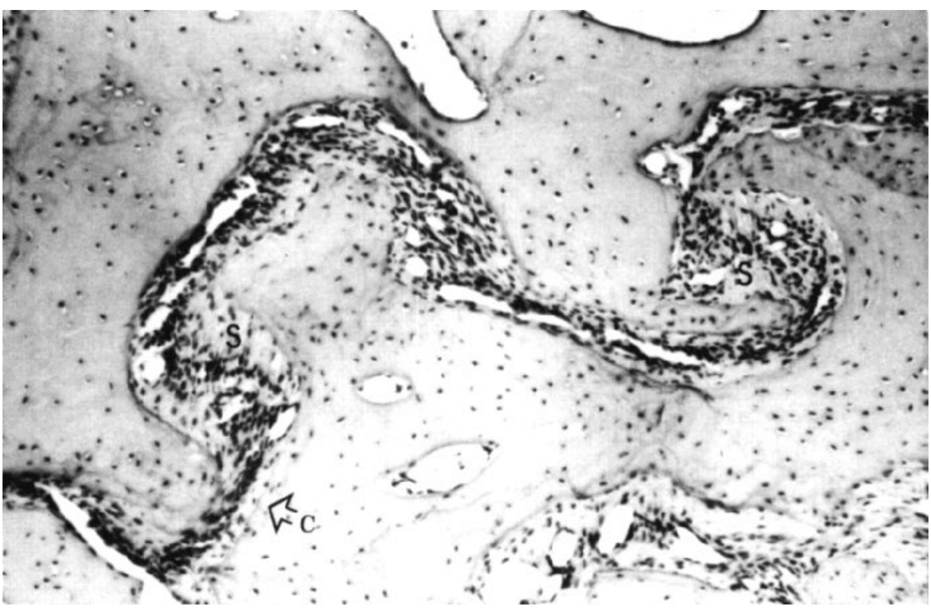

Fig. 9 Suture immediately after force removal, showing areas of compression (C) and stretching (S), often in close proximity (×150).

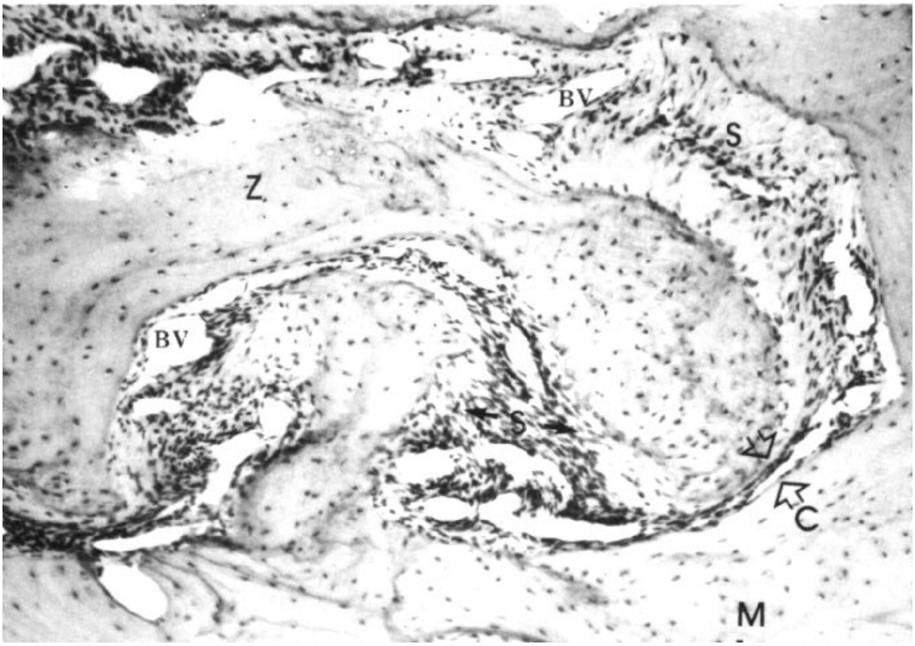

Fig. 10 The rotational effect and complicated anatomy are expressed by the compression (C) and tension (S) at this dovetailed maxillary spicule. (note the vascularity, BV). (×150).

This understanding will hopefully provide information of value in the application of accurately controlled forces to facial bones to achieve predictable results.

The complexity of the questions is demonstrated in this study.

— Summary —

To understand and ultimately predict the orthopedic effects of extraoral forces, the response of craniofacial sutures to the various parameters of an applied force system must be understood.

A protraction force system was applied to *Macaca mulatta* monkeys, keeping all force parameters constant except for variation in the angle of the anteriorly-directed force. Varying the direction of this force influenced the location of the center of rotation of the maxilla.

The histologic response of the zygomaticomaxillary suture is described as complex, varying in different areas of the suture, and closely related to the location of the center of rotation.

This study has been supported by Research Grant #DIO 3998-05 of the National Institute of Dental Research, National Institutes of Health, Bethesda, MD 20014

This paper was presented in part at the North Atlantic component of the Edward H. Angle Society of Orthodontists, 1980.

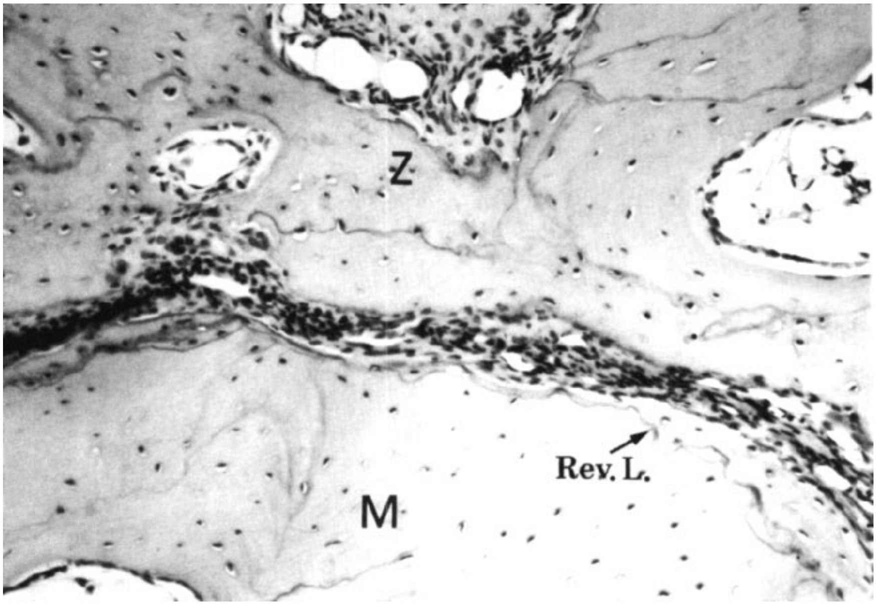

Fig. 11 Zygomaticomaxillary suture of a monkey 6 months after removal of the protraction force system. Note the reversal lines (Rev. L). Other aspects of the suture (width, cellularity, vascularity, etc.) are comparable to controls. (×200).

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