The Effect of Heavy Orthopedic Forces on the Sutures of the Facial Bones*

HELMUT DROSCHL, M.D.

A previous paper has discussed the marked retrusive effects of orthopedic force on the maxilla of the growing Saimiri Sciureus (squirrel) monkey.[1] The retardation, over periods ranging up to 90 days with continuous heavy force against the whole maxilla, produced a midface deficiency on the order of three premolar widths. Gold splints were cemented to the maxillary dental arch and forces of 100 gms on each side were exerted by an extraoral spring-loaded appliance attached to metal rings on each side of the commisure (Fig. 1). The posterior termini of bilateral pull-coil springs were fixed to a freely pivoting metal bar mounted on the restraining brace collar behind the monkey's head. The acrylic collar also served to prevent hand and arm manipulation of the appliances by the monkey.

Five growing male Saimiri Sciureus monkeys were used as experimental animals, all approximately 12-15 months of age. Their weight varied from 390 to 420 grams each. At the time of the experiment all monkeys were in the stage of upper second and third premolar eruption.[6]

All monkeys received metal implants in the significant areas of maxilla, mandible and cranial base.[7] A serial cephalometric radiographic study was made.[2,3,8]

Two monkeys served as controls. Three monkeys were fitted with appliances and restraining braces. The first (M-1) was sacrificed after 14 days; the second (M-2) after 30 days and the third monkey was sacrificed after 90 days.

Inasmuch as the response of the maxilla to heavy forces was the main objective of this study, the present report is limited to findings in this area. After two weeks the first monkey (M-1) showed no macroscopic changes. In both M-2, sacrificed after 30 days, and M-3, where cephalograms were made after thirty days, significant changes could be observed and recorded. There was a distinct posterior movement of the maxillary arch with the maxillary first molars moving distally, but not vertically (Fig. 2). The implant in the molar area showed an essentially backward positioning but no vertical change, matching the molar shift. The maxillary incisors moved bodily, distally and inferiorly into a retrusive or Class III relationship. It could be noted that the implants also moved posteriorly and inferiorly in the anterior portion of the maxilla. The infraorbital ridge implants followed the same pattern, shifting primarily downward.[17,18]

In M-3, after ninety days of continuous orthopedic force application, the same general changes were noted but of far greater magnitude (Fig. 3). The whole midface was "dished in." A severe maxillary retrusion and relative mandibular prognathism could be seen. When the teeth were occluded there was a discrepancy of three cusps. There was posterior and superior movement of the molars. The upward and backward implant movement, when superimposition was made on sella and anterior cranial base, implies the beginning of a maxillary rotation around a point anterior and superior to the molar area,

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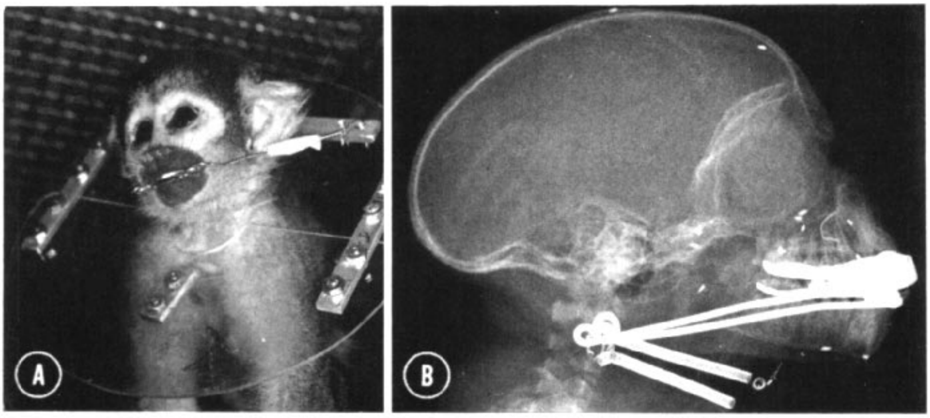


Fig. 1 Saimiri Sciureus (squirrel) monkey. Restraining collar and bilateral spring traction appliance in place. *A*, showing coil springs attached to pivoting posterior anchor bar. The monkey may turn his head, since the cervical pivoting bar moves freely and the collar does not impinge on the postcervical area. *B* is a lateral cephalogram taken with the springs detached from the pivoting bar, but illustrating the approximate angle of pull.

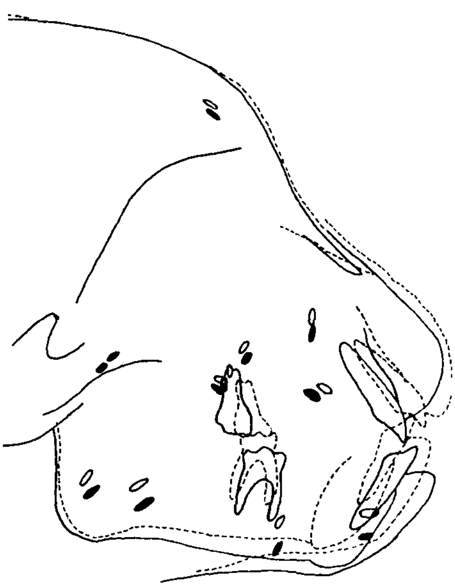


Fig. 2 Tracings of lateral cephalograms of M-2 taken before and after 30 days; superposed on the anterior cranial base. There is a developing Class III malocclusion with more vertical than distal movement. Mandible is being rocked open in anterior region, as maxilla descends.

apparently in the zygomatic arch. Thus, there appeared to be a rotation in the entire nasomaxillary complex in response to orthopedic force.

The control monkeys, by contrast, showed a steady downward and forward growth with the same relationship of the arches at the end as at the beginning.

The purpose of this paper is to investigate the histologic aspects of the effects of orthopedic force on the microstructure of facial sutures. As growth sites, they should be the main places to determine the response to change.

Oxytetracycline and Procion Red H-8 BS were used as *in vivo* bone markers in this experiment.[9,10] The monkeys received one injection of tetracycline (50 mg/kg body weight) intramuscularly at the beginning of the experiment, and at the end they were given tetracycline and Procion Red (100 mg/kg body weight) intraperitoneally two days before sacrifice. These markers served for the quantitative and interpretative histologic evaluation.[12,13,14]

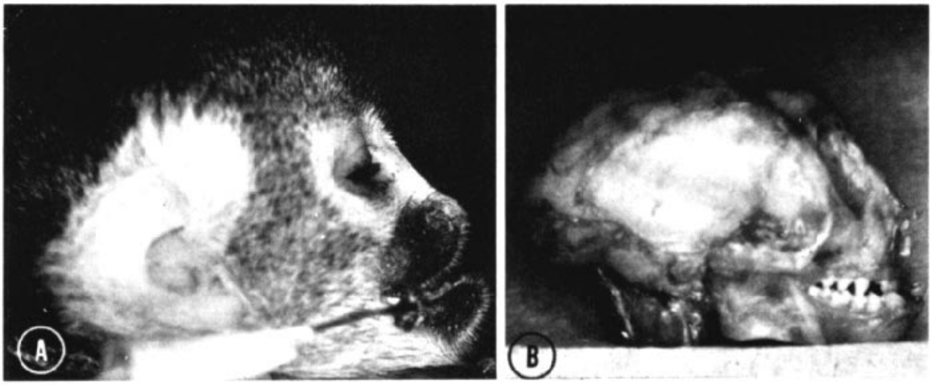


Fig. 3 Monkey M3 after 90 days of orthopedic traction. The significant midface deficiency is evident even before stripping away the skin. The maxillary dentition is posterior by the width of three premolar cusps.

Histologic Preparation

After sacrificing the monkeys at the end of the experience with an overdose of pentothal sodium, the heads were removed and the maxilla and surrounding tissues fixed in 10% buffered formalin. The left half of each maxilla was embedded in bioplastic (methyl methacrylate) for undecalcified sections. These were cut by a microtome to slice between 40 and 80 microns. The right half was decalcified, cut to regular histologic slices of 8 microns, and stained with hematoxylin-eosin. The following sutures have been studied: zygomaticofrontal, zygomaticomaxillary, frontomaxillary, and pterygopalatine.

Normally, in a growing suture three or four distinct layers can be distinguished (Figs. 4A, 5A). A capsular zone exists right in the middle of the suture. It is composed primarily of coarse bundles of mature, thick collagenous fibers. It is generally considered a dense and regular connective tissue with blood vessels. This layer is directly contiguous and continuous with the dense fibrous portion of the periosteum. The adjacent layer (intermediate zone) is much looser in texture and is more cellular. It is composed largely of immature, precollagenous fibrils. As these fibrils approach the suture bone surface, they thicken to become mature, coarse collagenous fibers (border zone).

Despite the controversy that exists on the primacy of sutural growth,[11] the bulk of evidence seems to indicate that sutural growth is a secondary response[14,15] reacting to other expansive growth forces that are responsible for the actual displacement of the bones involved. As the two bones become displaced away from each other, the fibers of the border zone become progressively embedded in the newly forming bone that has been added to each sutural bone surface. A new border zone is formed from the old intermediate zone as its fibrils lengthen in a direction away from the bone surfaces. They undergo differentiation into coarse, mature collagenous fibers. Thus, in physiologic and normal environment, the remodeling of the sutures and the displacement of the bones connected by the sutural tissue are in a state of equilibrium with the width of the suture remaining almost constant during the growing period.

The intermediate zone is the active part of the sutural growth site. When active growth and remodeling changes stop, the entire suture becomes essentially a single capsular zone.

Since heavy orthopedic forces are

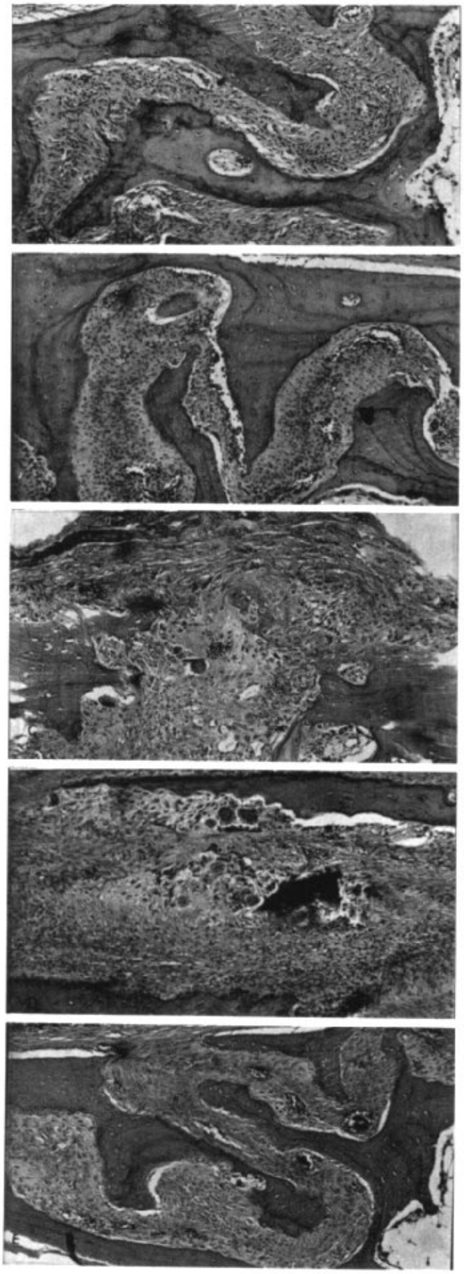


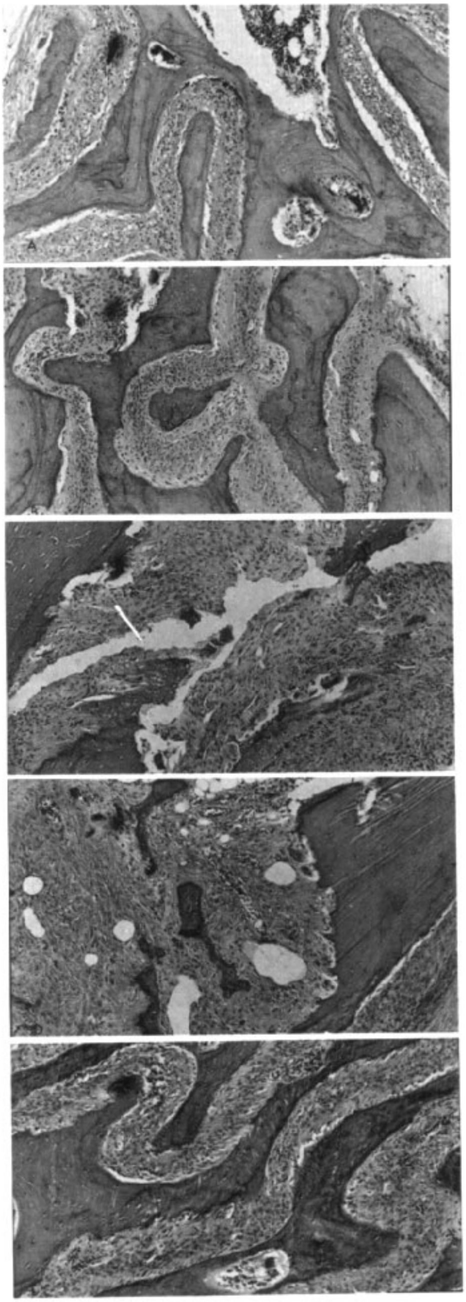
Fig. 4 Pterygopalatine suture (hematoxylin-eosion), × 65. *A*, Monkey M-4 (control monkey) vertical section through pterygopalatine suture. This untreated specimen shows a regular pattern. The capsular zone in the middle of the suture consists of dense, regular connective tissue and blood vessels. The adjacent intermediate zone is much looser in texture and more cellular. It is composed largely of immature precollagenous fibrils. As these fibrils approach the sutural surface of the bone, they thicken to become coarse collagenous fibers (border zone). *B*, Monkey M-1 (treated 14 days), which shows the same pattern in general, but with evidence of beginning osteoclastic activity in some areas. *C*, Monkey M-2 (treated 30 days) shows tremendous change in size and pattern. The suture is 2-3 times as wide as normal with signs of great activity. Cells and fibrils run in all directions with numerous osteoclasts at suture surface of bone. *D*, Monkey M-3 (treated 90 days), somewhat similar to *B*, with much less activity than seen after 30 days. The three zones seem to be forming again in some areas, reorganization has started and cellular activity is reduced. Many osteoclasts can be seen, but osteoblasts are lining up on the bone margin indicating new bone formation. *E*, Monkey M-5 (control monkey untreated for 90 days) showing similar appearance to *A*, above.

well beyond those normally involved, the question is asked, "How will the sutures react to this type of overload?"

Histologic Findings With Hematoxylin Eosin Stain

Monkey M-1, sacrificed after fourteen days, was compared with monkey M-4 or a control monkey sacrificed at the same time (Figs. 4B, 5B). In both monkeys the sutures had characteristics which exemplified the above description. It was easy to distinguish the relatively wide and dark fibrous capsular zone with blood vessels, as well as the lighter and looser intermediate zones, which were indicative of regular physiologic function. However, with a careful investigation of the sutures of M-1 who wore an appliance-delivering orthopedic force, it is possible to see in addition a significant number of osteoclasts, which indicates the beginning of cellular activity. In a few places all three zones begin to merge. In the sutures of M-4 very few osteoclasts are discernible.

M-2, sacrificed after one month of



orthopedic force, showed tremendous changes with signs of great activity (Figs. 4C, 5C). Significantly, the sutures are two to three times as wide as those of the control monkeys. The three zones have merged into one loose cellular texture, packed with irregular precollagenous fibrils. Fibers have no organization and seem to be running in all directions. On the bony periphery of the Howship's lacunae large numbers of osteoclasts may be observed. They are also seen at the margin of the neighboring bony marrow. The edges of the lacunae are serrated. Many more blood vessels can be observed in M-2 in all areas of the suture when compared with M-4.

M-3, sacrificed after three months of experiment, showed a similar appearance to M-2 (Figs. 4D, 5D). Nevertheless, the remodeling of the suture seems to have taken a rather steady course. There is more organization and the three zones have begun to form again. There is less cellular activity and fewer osteoclasts. Although the bony edges are also serrated, as with M-2, this may seem to be a bit less obvious; it is possible that there are less osteoclasts present. Osteoblasts are attached to the surface of the bony edges in a line indicating that there is new bone formation.

M-5, a control monkey, showed similar characterstics to M-4, which has already been reported (Figs. 4E, 5E). There was normal physiologic response. A wide capsular zone can be observed again; the intermediate zones and border zones seem normal. The serpentine shape of the sutures, with smooth edges restored again, is evident. Relatively few osteoclasts may be seen.

An attempt was made to compare

Fig. 5 Zygomaticomaxillary suture (hematoxylin-eosin), × 65. *A* through *E*, same monkeys as in Figure 4, same times of sacrifice, sections taken of a different suture. Findings are similar to those in Figure 4. The significant observation made is the change from a regular serpentine pattern to an irregular wide suture. This snake-like pattern returns in 5-E.

the four sutures within the same monkey to determine if there was a different type of activity elicited from one suture to the other. This was not possible, however, as all sutures showed essentially the same pattern of activity. In other words, if there was considerable activity in one suture, there would be the same in the remaining ones.

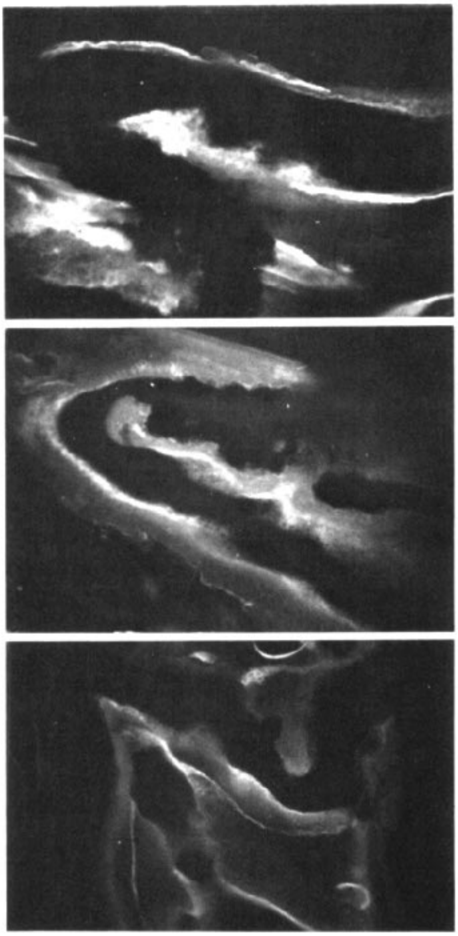


Fig. 6 Undecalcified ground sections, tetracycline and ultraviolet light × 63. Frontomaxillary suture. Above, Monkey M-2, orthopedic force for 30 days, heavy cellular activity causes intense and diffuse stain by the bone markers at the sutural surfaces. Areas of less stain uptake can be assumed to be areas of resorption. Middle, Monkey M-3, after 90 days of orthopedic force, a similar pattern is to be noted, but the diffuse areas are wider due to the longer treatment period. Below, Monkey M-5, control untreated monkey. Note that the staining is in single thin and sharp lines which demonstrate less activity and less growth velocity.

An attempt was also made to compare the periodontal ligament in the different monkeys. Again, no marked differences could be observed. However, the treated monkeys showed more resorption at the interdental septa. Where there is maximum resorption, the bony tissues appear isolated and surrounded by wide areas of connective tissue.

Histologic Sections With Ultraviolet Light

When a growing structure is injected with tetracycline, a bright yellow-gold fluorescence may be produced when the undecalcified section is viewed under ultraviolet light. Procion Red H-8 BS can be seen with considerably less brilliance, appearing as a brownish-red color and this is not confined to the tissues undergoing mineralization. The following observations are confined to monkeys M-2, M-3 and M-5 (Figs. 6 and 7).

Frontomaxillary Suture

M-2 and M-3 began to show significantly wider and more intensively stained areas on both sides of the sutures than the control monkey M-5. This would seem to indicate more appositional growth. M-3 has a wider stain zone than M-2 due to the longer treatment time (Fig. 6).

Pterygopalatine Suture

Although the sutures in M-2 and M-3 are very wide and irregular, staining with bone markers does disclose remodeling activity. When compared with the control monkey M-5, which shows a very regular and small stained area at the bones next to the sutures, M-2 shows a much more intensive and wider stained zone but this is irregular and frequently interrupted (Fig. 7).

Zygomaticomaxillary Suture

The pattern is very similar to the one for the frontomaxillary suture. However, the difference of the width of the stained zones between the treated and untreated monkeys seems to be smaller.

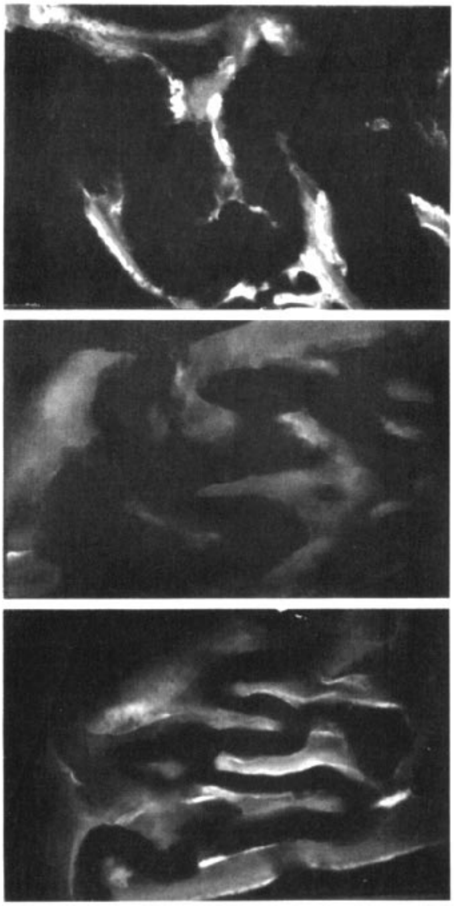


Fig. 7 Undecalcified ground sections, tetracycline and ultraviolet light × 63, pterygopalatine suture. Above, Monkey M-2, 30 day orthopedic force application. Wide, irregular suture, a few areas of intensive staining. The small bony areas between the serpentine arms of the suture are reduced in width by resorption. Middle, Monkey M-3, 90 day force application. Again, a wide, irregular suture with only a few stained areas. It seems that due to the rotation of the maxilla in this area, there appears to be a significant reduction of appositional growth with mainly resorbing activities to be seen. Below, Monkey M-5, control, untreated. The staining pattern seen here is illustrative of normal growth conditions. Again, a serpentine configuration and narrow width of the sutures are characteristic.

Zygomaticofrontal Suture

The stained zones of M-2 and M-3 again are significantly wider when compared with M-5. This finding coincides with the macroscopic findings in this experiment. Because of the rotational effect on the maxilla it seems logical that the highest degree of growth, over and above the normal growth, appears at the frontomaxillary and zygomaticofrontal sutures. Less growth seems to be seen in the zygomaticomaxillary suture and at the pterygopalatine suture. The remodeling and resorbing activity seems to be greater.

The appearance of the staining pattern (intensity, width, distribution) is clear and the growth activity at the different areas can be seen clearly. However, it should be mentioned that, depending on the part of the suture that is cut and because of the irregular growth and remodeling pattern, it is difficult to get exact measurements of the growth increments beyond what would normally be expected.

Discussion

Heavy orthopedic forces on the maxilla are used in orthodontic therapy, although with some techniques this is only intermittent force. In others, the force is continuous. In this experiment the heavy orthopedic forces produce significant change through continuous application.[18] Histologically, the sutures of the maxilla were heavily affected.[5] The orthopedic force produced a widening two to three times greater than normal, and there was evidence of intensive remodeling activity in the sutures. The regular pattern changed to a mixture of collagen fibrils and numerous active cells. The amount of growth could be observed with the use of the ultraviolet microscope along with the use of bone markers. There was significantly more growth to be observed in the treated bones. It is not possible, of course, to determine how much of the additional growth will remain on a permanent basis. The phenomenon of "catch-up growth" undoubtedly plays a role.[15] But it is certainly apparent that there is a tremendous effect on the sutures, a fact that may not be fully evident to many orthodontists.[4,16]

Summary

The effect of heavy continuous orthopedic forces was studied in three Saimiri Sciureus (squirrel) monkeys. Two additional monkeys served as controls. The maxillary sutures were investigated microscopically. In addition, the bone markers (tetracycline, Procion Red H-8 BS) served for quantitative evaluation under ultraviolet light.

After two weeks slight remodeling activity could be observed.

After one month a tremendous activity was found in the sutures. The width of the sutures was two to three times enlarged. The regular tissue pattern of the sutures had changed to a mixture of precollagen and collagen fibers running in all directions with plenty of active cells. In the ultraviolet light there is a take up of markers at the sutural margins.

After three months of treatment though, the sutures showed a similar pattern. The three zones of the sutures began to form again; osteoblasts were attached to the sutural margins and reorganization was relatively complete.

Universitätszahnklinik
Auenbruggerplatz 12
A-8010 Graz, Austria

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