THE UNIVERSITY OF MANITOBA

THE EARLY TISSUE RESPONSE TO RAPID MAXILLARY EXPANSION IN THE MIDPALATAL SUTURE OF THE RHESUS MONKEY

by

JOHN McGUIRE MURRAY

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Abstract

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Notwithstanding the amount of information accumulated on the effects of rapid maxillary expansion, the mechanism by which the midpalatal suture is opened has not been fully documented.

The present investigation was undertaken, therefore, in an effort to determine the very early response to rapid maxillary expansion which takes place in the bone and soft connective tissue of the midpalatal suture.

Six female Macaca Mulatta (Rhesus) monkeys were used; they comprised two control animals and four experimental animals. The four experimental animals were sacrificed following 24 hours, 4 days, 7 days, and 14 days of rapid maxillary expansion with a split acrylic jackscrew-type appliance which was held in place with orthodontic bands. All animals received one or more tetracycline injections at the beginning of their experimental periods, and the two control animals received a second injection on the day of their sacrifice. The second control and the 4 day animals

also received injections of H^3-proline four days prior to sacrifice.

Each animal had pre- and post-expansion study models of the maxillary and mandibular dental arches taken. Following sacrifice by perfusion fixation, the palates were removed with the teeth and alveolar processes intact, then occlusal radiographs were taken, and the palates were cut coronally into blocks. Alternate blocks were decalcified and routine histological sections of 5 microns in thickness were prepared. The undecalcified blocks were embedded in plastic and sectioned at 100 microns in thickness in order to be viewed with ultra-violet light. Soft x-ray spectroscopic plates were also made from representative hard sections. In addition, autoradiographic sections were prepared from the decalcified blocks of the second control and 4 day animals. All sections were then analyzed subjectively under the microscope. From the results obtained, the following conclusions were drawn:

1. As a result of the rapid expansion procedure, the midpalatal suture was opened. The point at which the suture split occurred between 4 and 7 days of expansion. The bony defect was greater at the palatal side than at the nasal side of the suture, indicating a probable rotation of the maxillary halves.

2. The actual mechanism of opening the suture involved a series of distinct stages: a) a period of connective tissue adaptation as a result of the external forces applied; b) connective tissue proliferation combined with relatively heavy bone resorption to "free" the processes; c) heavy bone deposition with probable continued proliferation of connective tissue. The rapid bone deposition appeared to be an attempt at maintaining sutural morphology.
3. The premaxillary-maxillary and maxillo-palatine sutures seemed to be adjustment sites which caused different rates of bone separation in the premaxilla and palatine bones as compared to the maxilla. The activation sequence over a given period of time may also influence the degree of suture opening.
4. Maxillary arch width at the molars increased as expansion progressed, but no significant change took place in the mandibular dental arch. The maxillary buccal dentition underwent a tipping movement during the first week of expansion but, by the fourteenth day, bodily tooth movement was occurring.
5. The undecalcified sections, marked with tetracycline, proved to be difficult to analyze precisely. In

order to accurately observe bone changes in the monkey by this method, longer intervals between injections and/or a multiple marking technique should be undertaken.

6. The soft x-ray spectroscopic plates were a useful adjunct to the histological findings. They indicated the relative size and location of the defect, as well as the relative degree of mineralization of the bone.

7. The injection of radioactive proline and the autoradiographic technique, as used in this investigation, proved to be a useful confirmation of the histological interpretation of connective tissue proliferation.

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CHAPTER I

INTRODUCTION

The Renaissance period of European culture represented the "rebirth" of art, architecture, music, literature, and thought. A similar type of re-awakening may be said to have occurred in North American thinking in regard to certain types of orthodontic procedures, particularly rapid maxillary expansion. With respect to the expansion technique, however, the renaissance has been more recent, having taken place in the last decade and a half.

Prior to the middle of the twentieth century, the effect of rapid maxillary expansion was somewhat dubious. The results of these expansive forces were thought by many to affect only the teeth and alveolar bone. Some early investigators did feel, however, that certain types of orthodontic movement could possibly have an effect on the surrounding bones of the face and palate.

Among the questions which arose during the many years of discussion were: 1) what type of appliance should be used; 2) what are the indications and contra-indications; 3) at what age should expansion be employed; 4) does the midpalatal suture open; 5) how does this opening take place, and 6) what are the results?

Within the last fifteen years, since the re-introduction of this technique into the armamentarium of the North American Orthodontist, human clinical studies and histological studies on animals have answered some of these questions. It has been demonstrated fairly conclusively that the mid-palatal suture does open in response to a rapid expansive force. Moreover, it has also been shown that, after a short period of time, this midline defect fills in with new bone, thus maintaining the expansion. The therapy was thus considered very useful in cases of constricted maxillae and/or nasal stenosis. Because it did produce the desired amount of expansion, the appliance of choice has been a midline jackscrew.

Further study showed that very little reaction took place in the alveolar bone, and tooth movement was very limited. The two halves of the maxilla were found to rotate laterally and superiorly, with consequent alterations taking place in the maxillo-facial sutures.

However, in spite of the rapid accumulation of information over the past decade and a half, this data was mainly concerned with the end of the expansion procedures. From the point of view of tissue reaction to these heavy expansive forces, very little has been written, particularly concerning the early stages of rapid maxillary expansion.

Therefore, the purpose of the present investigation was to determine the early reaction of the bone and soft connective tissue in the midpalatal suture region to a relatively rapid expansive force.

The main factors under consideration in this study were: 1) to determine the mechanism by which the midpalatal suture is opened; 2) from this, to approximate the time of opening; 3) to determine the concomitant reactions in the remaining palatal sutures and in the teeth and alveolar bone, and 4) to correlate these findings with those of previous investigations.

While it must be realized that there are a number of variables which affect the tissue reaction, an attempt was made in this study to keep the "time factor" as the only variable by which to study these tissue reactions.

To extrapolate information from the monkey to the human is perhaps somewhat easier than with other experimental animals. It was hoped, therefore, that this study might provide some basic information which would be applicable to the human clinical situation.

CHAPTER II

REVIEW OF THE LITERATURE

I. HISTORICAL REVIEW

The earliest reference to any type of rapid expansive force being exerted on the maxilla was that of E. H. Angell in 1860. He described a simple screw, attached to the bicuspids with "collars and clasps of gold." The patient turned the screw herself with a key, and "at the end of two weeks, the jaw was so much widened as to leave a space between the front incisors, ... showing conclusively that the maxillary bones had separated." The controversy began immediately.

McQuillen (1860), reviewing Angell's article, said that considering "the anatomical relations existing between the right and left superior maxilla ... such a result appears exceedingly doubtful. ... the separation of the maxilla ... could not take place without inducing serious disturbance in the surrounding hard and soft parts."

Farrar (1888) was also an opponent of the procedure. He contended that separation of the maxillae may result in a deformity. He described methods of binding the maxillae together while moving the teeth individually.

In 1893, Goddard described a rather successful spreading of the maxilla with a jackscrew. He stated that the space between the centrals, and the depression in the gum above this space, indicated that the two halves of the maxilla had separated in the median line.

G. V. Black (1893) also reported successful splitting of the midpalatal suture in his practise. He utilized split plates and jackscrews with which he opened the suture readily and widely. He indicated that it could then be held until it closed by a new formation of bone. However, seemingly doubtful of its effectiveness on older patients, he recommended its use on young patients.

At the same time, Case (1893) reported the use of a similar appliance, but made no mention of opening the suture. Rather, he felt that the expansion he achieved was due to the lateral bending of the alveolar processes.

Monson (1898) was the first to mention constricted nasal passages as an indication for palate splitting, thus rendering the patient a double service, allowing him freer nasal breathing and improving the dentition. He went on to describe his appliance, which was also a split appliance, but in combination with bands. The jackscrew was placed high in the vault, rather than the necks of the teeth, to obtain maximum widening of the vault.

Furthermore, Brown (1903), a physician and dentist, firmly believed that expansion opened the midpalatal suture; he strongly recommended the use of this type of treatment in the correction of constricted nares and of general underdevelopment of the middle third of the face. Reporting on one case, he appeared to have achieved six millimeters of expansion with a jackscrew appliance, and this expansion seemed to have caused a great improvement in the patients' general health.

In a paper which compares conventional methods of arch-spreading with expansion of the maxilla, Ottolengui (1904) described a wedge plate which opened the maxillary suture rather than just tipping the teeth. He stated that the suture had been opened, as indicated by the space between the centrals. In continuing, he mentioned that generally the suture was opened more in the anterior than in the posterior but, in the case he presented, the measurements indicated an equal widening along the whole suture. In the discussion following the paper, he was asked how he knew the suture had opened. He replied that he had "often been able to run [his] finger over the suture and feel the separate edges of the two bones. [He had] also passed needles through the suture."

During the same discussion of Ottolengui's paper, Angle (1904) stated that whether the suture had been opened or not was not the crucial question. Actually, he seemed more concerned with Ottolengui's position which was opposed to the conventional arch-spreading springs and ligatures.

On the other hand, Brady (1904), also discussing Ottolengui's paper, recognized a definite value in spreading the maxilla. He contended that within a few weeks a new deposit of bone would securely hold the maxillae. He went on to discuss two cases in which he inadvertently opened the midpalatal suture and to describe how easily and painlessly the splitting can be accomplished. He described a third case in which the maxillae were separated and the nasal passages widened, the latter being the intended result.

In 1905, Pfaff, a German Oral Surgeon, described an appliance with a palatal screw attached to bands, the bands being cemented to the teeth. This appliance was being used by Pfaff and his colleagues to correct prognathism and narrow nasal passages. For the latter purpose, he stressed that the maxilla must be expanded slowly. However, when he related that the patient only felt pressure on the forehead near the root of the nose, one would suspect a more rapid type of expansion. Also, he stated that he always found a lowering of the palate.

Most authors stressed the necessity for doing maxillary expansion in young patients, and Landsberger (1910) set a minimum limit of five years of age. He and other workers had discovered the difficulty of performing expansion in older patients: "The less the suture is ossified the less resistance the maxillary halves offer." However, the time they required varied from two weeks (Ottolengui) to three months (Landsberger).

Willis (1911) also used a screw appliance with bands cemented on the first molars and cuspids, but he claimed he could split the palate any time between the ages of eight and thirty. He called the separation of the incisors prima facie evidence of having separated the bones. He also observed separation on the roof of the mouth, widened nares with easier breathing, and other improvements in the patients' general health.

Wright (1911), a rhinologist, firmly believed that expansion would increase the size of the nasal cavities. Brown and Hartzell (1911), discussing Wright's paper, agreed, stating that maxillary expansion could be achieved. Dean (1911), another rhinologist, also showed increased nasal width as a result of maxillary expansion.

In 1912, Wright and Pullen, writing independently, both described the fibrous character of the suture in the maxilla which allowed the expansion to take place. Each indicated that this suture was a growth centre. Furthermore, each had been able to split the maxillary suture, and Wright reported increases of up to ten millimeters in interbicuspid width.

Contrary to this opinion, Ketcham (1912) claimed that all his attempts to open the midpalatal suture in living subjects or in a cadaver had failed, or at least he had not been able to prove that he had opened this suture. Neither had he been able to show radiographic evidence that the median maxillary suture had been opened, "except between the premaxillaries." Agreeing that it may be possible to do this in young children, he had been unable to secure proof that the median maxillary suture had ever been opened by rapid widening of the arch. Furthermore, he did not feel that there was any benefit derived from rapid widening of the maxilla since, the maxillary teeth would be placed outside the mandibular teeth, and this does not allow normal forces to be exerted, nor does it stimulate normal function.

Hawley (1912), fully aware of the discussion that had developed concerning maxillary expansion, presented both sides of the argument by reviewing the contemporary literature. He himself felt that the maxillary bones could be spread apart, but he disagreed with the use of jackscrews except in some difficult cases. Instead, he used bands and an expanded labial arch bar.

Also, on the basis of his radiographs, he came to a different conclusion concerning the spreading of the maxilla. His radiographs showed a dense suture area, but a thin area between the suture and the alveolar process was in evidence. Hence, he concluded that the thin plates of palatal bone, between the suture and alveolus, actually were stretched.

In addition, in his view, the lack of tipping of the teeth in the posterior segments was evidence that the maxillae were moving apart.

While reviewing the anatomy and physiology of the oronasal structures, Cryer (1913) agreed that widening the arch would help respiration but he also said that he had not observed any evidence of midpalatal suture splitting. Due to the fact that the maxilla was in articulation with so many other bones of the face, "it [had] always seemed to [him] to be impossible to open this suture by any force applied to the teeth."

Brown, in discussing Cryer's paper in 1913, and again in 1914, was convinced that the median palatine suture could be opened. He listed the main reasons for his belief, and these included: 1) the separation of the incisors was accomplished in 7 days to 2 weeks; 2) he performed it on a fresh skull in the presence of reliable witnesses; 3) he reported cases of trauma which had opened the suture; 4) he noticed visible or palpable depressions in the palatal midline; 5) patients reported easier breathing; 6) rhinologists reported increased nasal width, and 7) x-ray evidence showed palatal defect in the midline.

During the same discussion of Cryer's paper, several other men present, including Pullen, Hawley and Brady, confirmed Brown's statements by providing evidence of their own.

However, in spite of his being able to perform it, Brady seemed to disapprove of the operation.

The following year Kemple and Stanton (1914), often quoting Cryer's work, were opposed to a paper Brown (1914) had just presented. Stanton stated that he had tried to duplicate an experiment of Brown's on a fresh cadaver and that this had failed. Kemple questioned the radiographic evidence on the grounds that a diagnosis of an opened suture was too uncertain, and that he had radiographs showing open sutures where no appliances had ever been used.

Also aware of the controversy was Northcroft (1914), an Englishman. He reviewed the literature and reported on a case of his own in which he expanded the maxilla; he shows radiographic evidence. As well as the maxilla being expanded, he reported that the lower jaw had normally expanded, without aid, 2 mm. when released from the confining pressure of the embracing upper jaw.

It is interesting that about this time the first animal experiments were done by Dewey (1913). He was fully cognizant of the controversy over maxillary expansion and he was astute enough to realize one of the main reasons for this controversy when he said:

> With these different views in mind, I would say that all of the evidence that I have seen presented in favor of opening the median suture has been of a clinical character ... Clinical evidence is the

> principle evidence we have in favor of the opening of the suture, and I am one who believes that there is no class of evidence that is so faulty or open to so many grave errors.

His position on the question at this time would seem to be a "middle of the road" approach; he questioned whether or not the median suture could be opened, and also questioned the necessity of such a procedure.

Furthermore, in contradiction to Wright (1912) and Pullen (1912), he did not feel that the medial suture was a growth site. However, he did contend that this suture remained patent throughout life.

In his experiments on dogs, he could show no evidence of suture opening after eight-five days of maxillary expansion. In fact, he said the sutures were in closer approximation than in the non-expanded dogs. However, he described a generalized increase in bone formation (subperiosteal) as a result of the stress placed on the maxilla.

During the discussion of this excellent paper, Federspiel (1913) and Cryer (1913) congratulated and agreed with Dewey. Ottolengui (1913), who had previously designed a "wedge" appliance which he said opened the suture (1914), was now in doubt as to the truth of his prior claims. Barnes (1913), however, disagreed with Dewey, saying that the connective tissue was still present in the suture and was still capable of depositing bone when the suture was opened.

By the following year, Dewey (1914) had done some further experiments on dogs and now his conclusions were different from 1913. Showing anatomical and radiographic evidence, he illustrated that the median suture could be opened. Furthermore, he concluded that rapid bone growth, stimulated by the mechanical stress, filled in the suture very soon after it was opened. Barnes' statement (1913) had now been shown to be true. Dewey went on, however, to say that in spite of his findings, he could see no advantage in performing this type of operation.

In the discussion which followed, Ottolengui (1914), feeling that the median suture had not been proved opened simply by Dewey's radiographs, was now in disaccord with Dewey. Nevertheless, both were in agreement on the lack of advantages of the operation.

On the other hand, Hawley (1914), agreeing with Dewey that the suture could be opened, claimed that the operation was advantageous. He felt that it made treatment easier and shorter, and he stated that many of his cases were successful in these respects.

In regard to the suture opening, Federspiel (1914) also disagrees with Dewey. He said that many times, after arch expansion, he injected novocain, made an incision to determine if the palate was opened, and at no time did he see that the suture had been opened. But Dewey countered

Federspiel's argument with the fact that, very shortly after it had been opened, bone deposition filled in the suture.

It was about this time that the technique of maxillary expansion went out of vogue in North America. No doubt it was, as Haas (1965) says, due to the indifference of some of the most influential men in Orthodontics; men such as Angle, Case, Dewey, and others. They all seemed to prefer the more conventional methods of widening the dental arch.

However, the technique had become popular in European Orthodontic circles, where it has continued ever since. Babcock in 1911 described a split vulcanite expansion screw appliance. However, his activation sequence was rather slow; thus, one might doubt the suture opening effects. Lohman (1915) described another central screw expansion appliance designed by a Dr. Schroder-Benseler. This appliance was fixed to the teeth by means of gold caps. Lohman advocated the use of this appliance for treating children with narrow nasal passages or breathing problems.

Huet (1926), in France, described the splitting of the midpalatal suture with a split plate and jackscrew cemented to the teeth with bands. The screw was activated very rapidly until the suture opened, as determined by the decrease in resistance to turning the screw. This he said occurred in twelve to forty-eight hours. Following this he prescribed slower activation for four or five days, or until the molars were in correct articulation. He then said that at least six weeks retention was necessary to allow osseous union at the bones, during which time regular radiographic checks were to be made.

Again in France, Mesnard (1929), utilizing a midline screw, cemented the appliance to the first bicuspids and first molars. He, too, activated the appliance very rapidly until the decrease in resistance had indicated suture opening. Almost immediately, the child had more ease in breathing, and "[had] a definite sensation of traction in the nose." Activation continued until the correct intermolar distance was achieved; retention was from four to six weeks.

It is interesting to note that Lohman, Huet, and Mesnard all prescribed this appliance for use in nasal insufficiencies, but that none mentioned its use for dental correction of a contracted maxilla, unless it was implicated as a primary cause of narrow nasal passages.

Therefore, the technique of rapid maxillary expansion originated and disappeared in North America, was popularized in Europe, and was not to be reintroduced to this continent until many years later.

II. CONTEMPORARY REVIEW

Although the European workers were still using maxillary expansion, with success, as a regular part of treatment, with the advent of time and the improvement of research techniques, much more sophisticated types of studies have been done in the last fifteen to twenty years.

In 1953, Derichsweiler reported on one hundred and fifty cases on which he had done maxillary expansion with a screw-type appliance. He obtained his results from models, cephalometric headplates, palatal outlines and rhinological examinations. The patients reported no pain, and suture splitting, using three quarters of a turn of the screw per day, was complete in about three weeks.

His results showed: a three millimeter lowering of the palatal vault and nasal floor; a two millimeter increase in nasal cavity width with straightening of the septa and a change from mouth to nasal breathing; increases in arch width and arch length; an increase in arch width of more than nine millimeters in the bicuspid area and six millimeters in the first molar area; a diastema between the centrals which disappeared spontaneously; and spontaneous adjustments in the axial inclination of the mandibular teeth.

Generally speaking, in spite of his improved methods of data collection and better documentation, his finding do not differ a great deal from the findings of the workers forty years earlier.

Gerlach (1956), using stereograph tracings from models, showed that, over a long period of time, there was an increase in the basal bone width in the apical area of the maxilla. Thus he contended that maxillary expansion could stimulate a basal bone rebuilding process.

In the same year (1956), another study by Thorne also reported in his forty cases of rapid maxillary expansion, an increase in apical base width from one millimeter to six and a half millimeters. He also showed the other classical changes: intermolar width increases of almost seven millimeters, on the average; diastemas between the centrals; increased nasal cavity widths; and slight increases in mandibular intermolar widths. He activated his appliances reasonably rapidly (three one-quarter turns daily) and said some of his patients felt pressure on the bridge of their nose.

Several years later, reporting on these same cases in an American journal, Thorne (1960) claimed that after varying retention periods, a majority of these cases showed no changes, or else showed increases in apical base width and nasal cavity width. Only five out of twenty-eight cases showed decreases in gained widths. Although in his original

1956 paper, he recommended a minimum of three months of retention, these five cases had very little or no retention period.

In 1957, Derichsweiler reported on another study which utilized five young Rhesus monkeys. He used rapid expansion screw-type appliances cemented to place with six bands. It was his intention to study not only the effects of this procedure on the midpalatal suture but also the reaction at the fronto-nasal suture and at the pterygo-maxillary suture. One animal was utilized as a control and the remaining four had various activation sequences and retention periods. The rapidly activated animals showed transverse displacement of the bones and enlargement of the suture; the most rapid animal showed loss of the regular sutural morphology. Even with the strongest forces, Derichsweiler could see no tearing of tissues or haemorrhage; nor could he see bone resorption around the teeth or cementum or dentin lesions on the roots.

After the very rapid expansion, he also showed gross reactions at the fronto-nasal and pterygo-maxillary sutures. He recommended a six month retention period, for he stated that, following this, the suture had regained its normal morphology.

An interesting fact gained from this paper was his basis for a two-to-one ratio for man-to-monkey in respect to activations and amount of expansion gained. Thus, his recommendation for rapid expansion activating sequence in man was one or two one-quarter turns per day for the first three days, then one one-quarter turn per day until the desired amount of expansion was achieved.

Another type of study, using metallic implants, was done by Krebs (1958, 1959). He reported on only a single case in which he placed implants in the alveolar and basal bone of the maxilla. Following expansion, he measured the changes between the implants and in the dental arch. He observed that he got different increases in width of the various areas. Listed from greatest to least increase, they are: 1) intercanine width, 2) intermolar width, 3) alveolar arch (using implants), 4) basal bone of maxilla (using implants), and 5) nasal cavity width.

Furthermore, he reported that the maxilla rotated in the frontal and transverse planes, and that the two halves of the maxilla rotated to different degrees.

According to Haas (1965), it was about 1956 before the technique of rapid maxillary expansion was reintroduced into North America. This was apparently accomplished by Korkhaus while on a visit to the Orthodontic department at the University of Illinois. Interest in the procedure took hold and two years later, the next paper was published.

Debbane (1958) published a paper in which he described how he studied maxillary expansion utilizing the cat as an experimental subject. In all, he used nine cats which were divided into the following groups: three control animals; two animals to have continuous expansion; two animals to have intermittent expansion; and two animals to have intermittent contraction. The appliances were simple springs cemented to the cuspid teeth. He obtained his results from dental casts, cephalometric headplates, and histological sections. In the study, he states that he chose older cats so as to avoid normal growth of the suture from interfering with his results.

From his models, the cats subjected to expansion showed increases in intercanine width of between four and one-half and eight and one-half millimeters. On the other hand, the cats subjected to contraction showed decreases in intercanine width of two and three millimeters. His cephalometric films indicated that the premaxilla and the cuspid teeth moved downward and backward during expansion, and upward and forward with contraction.

Results from his histological preparations showed that expansion did open the midpalatal suture, more in the anterior or premaxilla than posteriorly in the maxilla. He observed bone deposition occurring along the sutural edges of the bone; this bone deposition, he contended, was due to Orthodontic force, and not growth. He stated that there was slightly more opening of the suture with the intermittent forces than with the continuous forces. However, he found less tooth movement with the intermittent expansive forces. Furthermore, he reported effects of the expansion on other sutures in the area, yet he stated that the palatal aspect of the premaxillary-maxillary suture was not affected.

The following year, Haas (1959) reported on the results of maxillary expansion in eight pigs. As his method of study, he used dental casts, vital staining, cephalometric headfilms, photography, and histology. His results could be listed briefly as follows: 1) the midpalatal suture opened with no pain and little resistance; 2) increases of up to fifteen millimeters were recorded, which indicates that this must be more than just tooth movement; 3) early opening was more scissor-like, while longer periods produced more parallel opening; 4) the suture opening was accompanied by very rapid formation of new bone; 5) accompanied by the lowering of the palatal vault, nasal width increased, as well as evidence of diastemas between the centrals.

Therefore, from the results of these two papers, it can be seen that any controversy would be over. Consequently, no papers against maxillary expansion have since been published. In Haas' words: "The general conclusion seems to be ... that the midpalatal suture can be opened to a degree sufficient to cause significant widening of the maxillary dental arch and at the same time increase intra-nasal capacity."

In 1961, Haas again reported the results of the experiments on the pigs, in addition to experiments on ten human cases. His sequence of activation for humans differed from that of Derichsweiler (1957); Haas suggested four one-quarter turns on the first day, and two one-quarter turns of the screw daily thereafter until the desired expansion was achieved.

The results he obtained from his human sample were similar to those in the experimental animals; that is, absence of pain; lowering of vault and nasal floor; increase in arch width and length; spreading and subsequent closing of maxillary incisors; and changes in the mandibular teeth. Within twelve to twenty-eight days of treatment, the intermolar widths in the humans increased from about one to five millimeters, or as he states, about one-half the amount that the screw was opened. Furthermore, he noted that the maxillae separated in a wedge-shaped movement; in other words, the sutural defect was larger at the palatal side than at the nasal side.

In 1964, Isaacson and Murphy applied rapid maxillary expansion to five cleft palate patients in whom they had placed metallic implants. Four of these patients were young and showed lateral expansion of basal and alveolar bone, as did Krebs' patient (1958). The older patient, however, did not show this lateral movement; Isaacson attributed this to the resistance of the remaining facial skeleton at the points of articulation with the maxilla.

In the same year, Isaacson, Wood and Ingram (1964) developed a dynamometer incorporated into a rapid expansion appliance to determine the forces involved during this procedure.

Isaacson and Ingram (1964) used this force measuring appliance on five patients, observing that each activation of the screw produced between three and ten pounds of force. Following each activation, there was a slight decrease in the pressure being exerted but at no time during treatment did they notice a significant change in force values. They thus concluded that the major resistance to expansion was in the maxillo-facial sutures other than the midpalatal suture.

This then would contradict Huet (1926) and Mesnard (1929), both of whom claimed they noticed a decreased resistance in the screw while activating it. Huet even reported that the resistance was reduced enough that the patients could turn the screw with their fingers.

Zimring and Isaacson (1965), again using the pressure recording appliance, performed expansion on four patients with the same basic results as previously mentioned. They also found that, in older patients, the residual loads built up in the appliance at a faster rate. Hence, they concluded that the activation sequence should vary with the patient according to his age.

These residual loads were also found to dissipate almost completely within five to seven weeks; thus retention with the expansion appliance itself was recommended for this minimum time. Premature removal of the appliance in one patient produced an extremely rapid relapse of one and one-half millimeters in nineteen hours.

Haas (1965), with the aid of three cases, reviewed his findings on the subject of maxillary expansion and merely expanded on the results of his earlier work (Haas 1959, 1961). He achieved expansion in a period of one to three weeks and contended that there was little likelihood of much tooth movement in so short a period of time.

An interesting investigation was carried out by Cleall, Bayne, Posen and Subtelny, (1965) using six Rhesus monkeys. Two animals served as controls and the remaining four were subjected to various periods of expansion, expansion and retention, and expansion retention and post-retention. No mention was made of the activation sequence, although mention was made of the amount of expansion achieved; that is, four millimeters after two weeks of expansion, and six millimeters after three months of expansion. The retention period and post-retention period were each three months in duration. Their main methods of investigation were histologic and radiographic.

They found that after two weeks of expansion, the suture had indeed been opened, producing a relatively large midline defect. At this point, they found that "the cellular reaction noted after two weeks of expansion was both reparatory as well as osteoclastic." After three months of expansion, as evidenced by the radiographs, they again had produced a very large defect in the midpalatal suture region. At this point, the cellular reaction was found to be predominantly osteoblastic, and the suggestion was made that resorption had taken place at some time earlier than the three months stage.

In the animal which had been expanded for three months and retained for three months, a more or less normal suture presented. Osteoblastic and osteoclastic activity suggested to them that "remodelling of the newly repaired suture was taking place."

The final experimental animal, subjected to expansion, retention and post-retention, presented a histologically and radiographically normal appearance. They found no evidence of breakdown in the suture area after removal of the appliance and during the post-retention period. This indicated that the repaired suture was stable.

In 1966 Starnbach, Bayne, Cleall and Subtelny did a continuation of the study begun by Cleall et al (1965). Using one control monkey and the same four experimental monkeys, they investigated the buccal movement of the teeth and the rotational movement of the palate, as well as the adjustment in various facial sutures. The histological examination of the periodontal structures around the teeth indicated a bodily movement of the teeth in a buccal direction. Bone resorption was seen on the buccal plate of bone throughout the length of the roots at the end of the expansion phase. As retention and post-retention periods passed, progressive repair of the alveolar bone was seen.

Measurements of the angle between the long axes of the teeth and the palatal plane remained basically unchanged during the experimental procedures. This also indicated that the teeth had not tipped during expansion. Furthermore, their measurements indicated a significant rotation of the two halves of the maxilla in an upward and lateral direction relative to the central sutural area. They also showed that as a result of the expansion of the maxilla, the facial sutures made adjustments, then, following the retention period, returned to normal. The most adjustment occurred in the fronto-nasal region; the least occurred in the zygomatico-temporal region.

Until this point in the literature, many authors have suggested the use of maxillary expansion primarily as a treatment for nasal stenosis. Wertz (1968) recognized this fact and so, using an air-flow recording mechanism, he measured air flow in thirteen patients before and after rapid maxillary expansion. He recorded the successful splitting of the suture in all cases, with the widest part of the defect in the anterior. Furthermore, he mentioned that he achieved the expected lateral rotation of the maxillary halves. However, he reported only limited success in being able to show increased nasal air volume following expansion. He concluded that: "On the basis of this [his] work, the opening of the midpalatal suture for the sole purpose of increasing nasal permeability cannot be justified unless the obstruction is ... accompanied by a bilateral maxillary arch width deficiency."

Timms (1969), discussing maxillary expansion, gave a reasonable summary of its effects. He said, however, that very little space was gained in the dental arch as a result of expansion. Haas (1961) stated, on the other hand, that we do get an increase in arch length.

Again, on the clinical level, Davis and Kronman (1969) have indicated the anatomical changes which we could expect as a result of treatment with maxillary expansion. Some of their findings corroborate the work of Haas (1965).

Their general findings from twenty-six treated children may be listed as follows: 1) the anterior of the maxilla moved forward and downward; 2) the angle between the cranial base and the palatal plane increased; 3) the mandibular plane angle increased and is clinically evidenced as bite opening; 4) maxillary intermolar width increased more than intercanine width; 5) the mandibular intermolar width also increased; 6) the palatal vault did not lower, but remained at the same height; and 7) the P.A. radiographs showed no significant changes in the orbital, condylar, or zygomatic areas.

Their findings on the palatal vault are in contradiction to the majority of the authors. Their technique of tracing the vault from sectioned casts had not been previously reported upon. From this, they found only one case which showed a lowering of the vault.

Wertz (1970) produced an extensive investigation on sixty patients from his practise, supplemented with expansion done on two dried skulls. He reported successful suture opening. However, the older patients demonstrated more limited orthopedic changes. His skeletal changes generally are in agreement with those of Haas (1965) and Davis and Kronman (1969), which include: downward displacement of the maxilla and mandible; lateral rotation of the maxillary halves; and non-parallel opening of the suture. Unlike Haas, he found that any arch length gained during expansion was lost in the stabilizing period. Furthermore, contrary to Davis and Kronman (1969), Wertz found that the majority of his cases failed to show any increase in mandibular intermolar width.

Thus, a great deal of information had been gathered on the subject of rapidly expanding the maxilla; the first one hundred years was slow, but the past decade has increased our knowledge tremendously.

To quote Davis and Kronman (1969):

> It is doubtful that midpalatal suture expansion will again fall into disuse, as it did in the earlier part of this century. As this procedure becomes more popular, it is imperative that further studies of the surrounding structures be undertaken.

From the literature, we know the results of maxillary expansion. Therefore, it was anticipated that this study might answer some questions regarding the early stages of expansion, namely: 1) what is the mechanism of midpalatal suture opening; 2) when does this suture open, and 3) what are the reactions in the remaining palatal sutures, teeth and alveolar bone? Furthermore, it was hoped that these findings could be related to previous investigations.

CHAPTER III

MATERIALS AND METHODS

I. SAMPLE

The sample in this study consisted of six female Macaca Mulatta (Rhesus) monkeys. Monkeys were chosen for this investigation because of their reasonable similarity in skeletal and dental patterns to those of the human being. However, distinct differences do exist and these differences are primarily in the skeletal morphology.

One of the main differences in the palatal area of the monkey is the presence of a separate premaxilla (Figure 1.). This premaxilla articulates with the horizontal plates, or palatal processes of the maxillary bone, at the premaxillary-maxillary suture. It is also divided into left and right halves by the short inter-premaxillary suture running anteriorly from the large incisive foramen.

From the point of view of maxillary expansion, the premaxillary-maxillary suture is important in that it presents a resistance to lateral movement of the maxilla. This resistance is not present in the human palate.

With regard to the number and arrangement of both the deciduous and permanent dentitions, the dental pattern of the Rhesus monkey is similar to that of the human.

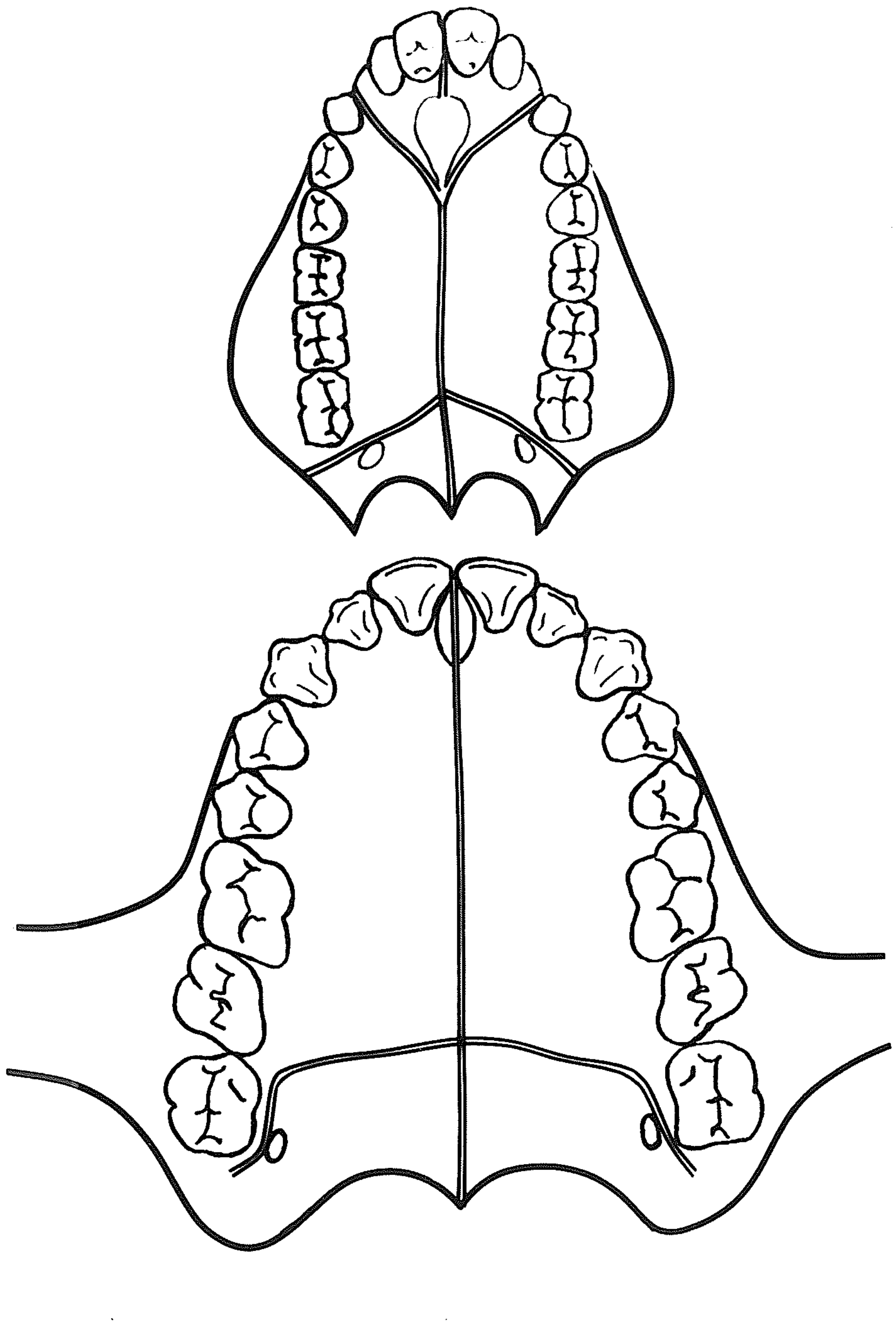

Figure 1. Diagram showing the differences in palatal morphology between the monkey (top) and human (below). Note the presence of a separate premaxilla in the monkey and the persistence of primate spaces.

Differences are present only in the morphology of the individual teeth and in the persistence of "primate spaces" into the permanent dentition of the monkey. Since the human lacks these primate spaces in the permanent dentition, a crowded condition is more common, and so is the necessity for maxillary expansion. Also, since crowding and maxillary contraction are rarely seen in the Rhesus monkey, maxillary expansion therapy is moving the maxillary dentition from a normal physiologic position to an abnormal buccal crossbite.

In spite of the obvious differences, it was felt that the Rhesus monkey would provide suitable material, the results of which could be interpreted and possibly applied to the human being. Furthermore, as this investigation was intended to be a continuation of work done by Cleall *et al* (1965), it was deemed advisable to utilize a similar sample.

All six animals were caught wild and then imported via a domestic supplier.[1] As the animals had been stabilized by the supplier, experimental procedures were begun as soon as the animals arrived at this laboratory. While in our laboratory, the animals were maintained on a commercial chow,[2] and water, *ad libitum*, with daily supplements of fresh fruit, usually bananas.

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[1]Primate Imports Corporation, Port Washington, Long Island, N.Y.

[2]Ralston Purina Company, St. Louis, Missouri

The six animals used in this investigation were utilized as four experimental animals and two control animals. These animals all weighed between eight and nine pounds; that is, about four kilograms. Their age, as determined from the dental formula, was approximated at forty months (Hurme, 1960).

All the animals were required to have a specific maxillary dental pattern. This consisted of the presence of the following teeth: 1) maxillary permanent central incisors, 2) maxillary permanent lateral incisors, 3) maxillary deciduous cuspids, 4) maxillary deciduous first molars, 5) maxillary deciduous second molars, and 6) maxillary permanent first molars. Thus, all six monkeys corresponded in age approximately to a seven to nine year old human child.

All procedures were carried out under general anaesthesia. A 5% solution of sodium pentobarbital[3] was used, the dosage being about 37 milligrams per kilogram of body weight, administered intraperitoneally. This was sufficient to produce general anaesthesia for a minimum of two hours.

Each of the animals was fitted with a cone-shaped plastic collar.[4] These collars prevented the monkeys from

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[3]Abbott Laboratories Ltd., Montreal, Canada.

[4]Moss Corporation, Chicago, Illinois.

removing their appliances from their mouths, and also facilitated the catching and handling of the animals. (Figure 2.). The collars produced no irritation to the monkeys' necks, and they managed to eat and drink very well without the use of their hands.

II. EXPERIMENTAL PROCEDURES

Study models were made of the maxillary and mandibular dental arches at the beginning of each of the six animals' experimental periods. Using a standard Broadbent-Bolton cephalometer (Broadbent, 1931), lateral and postero-anterior cephalometric roentgenograms were also taken.

The four experimental monkeys had slice preparations made on the maxillary first deciduous molars and on the maxillary first permanent molars (Tylman and Tylman, 1960). Bands, using .125 x .004 inch band material,[5] were pinched to fit all four prepared teeth in each animal. Impressions were taken with the bands seated on the teeth, and working stone models were poured with the bands reseated into the impression. Buccal and lingual wires were soldered to the bands to provide added rigidity, and split acrylic appliances were fabricated, each with an expansion screw embedded in

[5] Rocky Mountain Dental Company, Toronto, Canada.

Figure 2. Photograph showing the plastic collar worn by the monkeys in this study.

the midline of the appliance (Figure 3.). It was found that each appliance opened approximately 1 millimeter after four one-quarter turns of the screw.

On the second day, following the preparation of the teeth, the appliances were cemented into place in the mouth. About one hour after cementation, activation of the expansion screw was begun. This initial activation consisted of three one-quarter turns of the screw; that is, 0.75 millimeters. The screw was then given one one-quarter turn, or 0.25 millimeters of activation, every 24 hours thereafter for the duration of the experimental period in each animal.

The four experimental animals were sacrificed at periods of 24 hours, 4 days, 7 days and 14 days following the initial activation.

During the periods in which the appliances were in place in the four experimental animals, these animals' chow was softened in water to prevent dislodging of the appliances due to heavy mastication.

All the appliances stayed in place for the duration of each experimental animal, except for the 14 day experimental animal, which lost its appliance sometime between the last activation and the day of sacrifice. Thus, a maximum of 24 hours of relapse may have occurred in this animal.

Each animal received an intraperitoneal injection of tetracyline at the beginning of its experimental period,

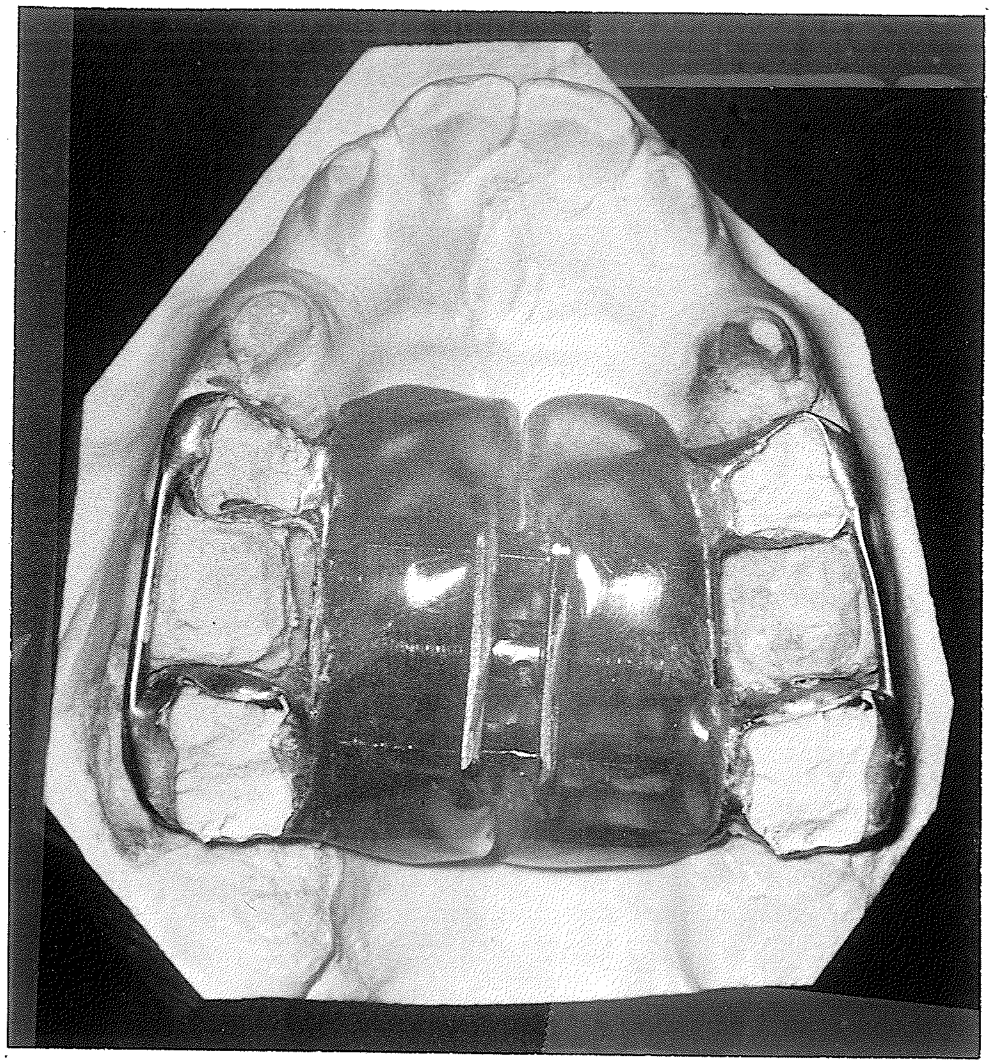

Figure 3. Photograph of the completed appliance, on the working stone model, used in this study.

and the two control animals received a second injection on their day of sacrifice. The tetracycline localized in areas of bone formation, giving a visible marker under ultra-violet light. As suggested by Turpin (1968), the dosage of tetracycline used was 50 milligrams per kilogram of body weight.

Four days prior to their sacrifice, the second control animal and the 4 day experimental animal also received intra-peritoneal injections of 1.5 millilitres of H^3-proline.[6] The radioactive proline was incorporated into developing collagen and gave a visible marker of its location when autoradiographs were prepared.

Table I shows the injection, and appliance activation sequences for each of the six monkeys used in this study.

On the day of sacrifice, the four experimental animals had another set of study models, and lateral and postero-anterior cephalometric radiographs taken for purposes of comparison with the pre-expansion records. These records showed the gross changes in the maxillary and mandibular dental arches, and in the skeletal pattern.

Sacrifice of all the animals was performed by means of perfusion fixation with 1000 cc. of warmed isotonic 2.5%

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[6]New England Nuclear Corporation, Boston, Massachusetts.

gluteraldehyde via the left ventricle. The perfusion time was about thirty minutes. The animals were decapitated and the heads stored in 2.5% gluteraldehyde under refrigeration (Warshawsky and Moore, 1967).

TABLE I

INJECTION AND APPLIANCE ACTIVATION SEQUENCES
FOR THE SIX ANIMALS USED IN THIS STUDY

KEY:

T = Tetracycline Injection
A = Appliance Cemented
P = H3-Proline Injection
S = Sacrifice
3 = Three one-quarter turns
1 = One one-quarter turn

DAY / ANIMAL	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Control 1	T						T S											
Control 2	T									P				T S				
24 Hours	T													T A 3	S			
4 Days	T													T A P 3	1	1	1	S
7 Days	T						T A 3	1	1	1	1	1	1	S				
14 Days	T A 3	1	1	1	1	1	1	1	1	1	1	1	1	1	S			

III. PREPARATION OF SECTIONS

The palatal portions of the maxillae were removed with bone burrs from the skulls with the teeth and alveolar processes intact. The appliances were removed and a supero-inferior occlusal radiograph was taken of each palate. This was intended to permit gross radiographic evaluation of the midpalatal suture area.

Each palate was then cut coronally into blocks approximately 2.5 millimeters in thickness (Figure 4.) using a Gillings Hamco rotary diamond cutting machine (Figure 5.). A total of fourteen blocks was obtained from each palate.

Those blocks represented in figure 4 by capital letters (A, B, C, etc.) were embedded in Bio-plastic.[7] Undecalcified sections were cut at approximately 100 microns in thickness. These sections were viewed through a microscope[8] with an HBO 200 W4 super-pressure mercury lamp, barrier filter 53, and an ultra-violet light exciting filter U.G.1. The fluorescent tetracycline markers provided an appraisal of the direction of bone changes relative to the markers.

Representative sections of equal thickness from each of the undecalcified blocks were used to make soft x-ray

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[7]Wards Natural Science Establishment Inc., Rochester, N.Y.

[8]Carl Zeiss

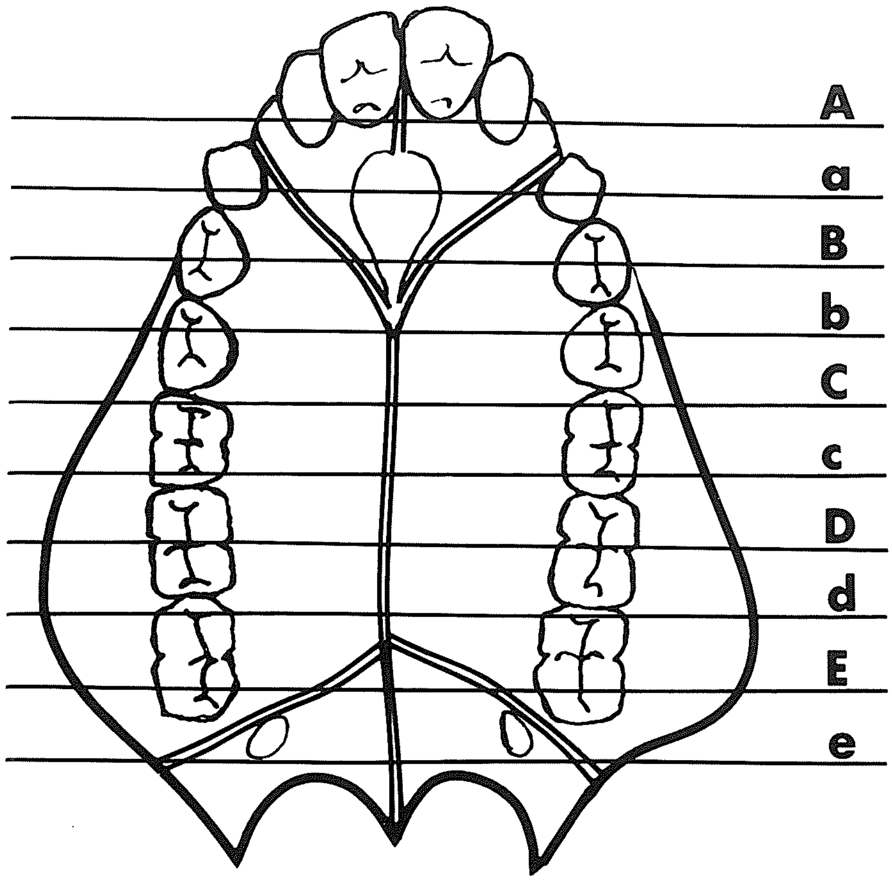

Figure 4. Diagram illustrating the coronal cutting of the palates into blocks. Blocks with capital letters (A, B, C, etc.) were left undecalcified, and blocks with small letters (a, b, c, etc.) were decalcified.

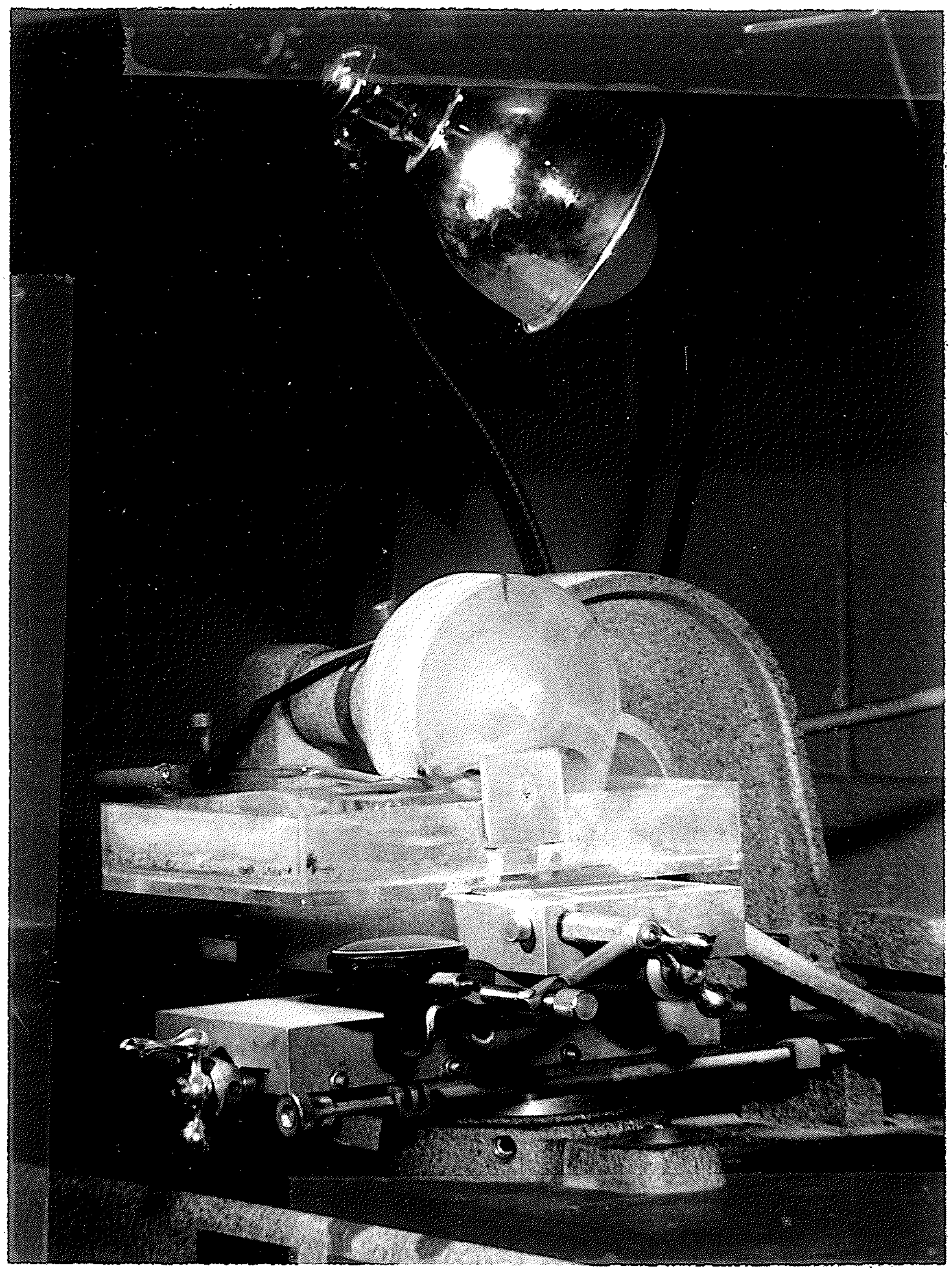

Figure 5. Photograph of the Gillings-Hamco rotary diamond cutting machine, used for cutting the palate into blocks, and for sectioning the undecalcified blocks.

radiographs. These were made on Kodak type 649-0 spectroscopic plates using a Philips soft x-ray machine with a copper Machlett anode (Figure 6.). The sections were centered directly on the plates, which were placed in a casette holder 25 centimeters from the x-ray source. The machine was set at 33 kilivolts and 15 milliamperes, and the sections were exposed for 20 minutes. The plates were developed for 4½ minutes in Kodak D19 developer, fixed in Kodak F-5 fixer for 8 minutes, and washed in running water for 15 minutes. These soft x-ray radiographs allowed for a gross evaluation of the relative degree of mineralization of the bone of the midpalatal suture region.

Alternate blocks (Figure 4:a, b, c, etc.) were decalcified in isotonic 4.13% E.D.T.A. (disodium ethylenediamine tetraacetate) solution, embedded in parafin, sectioned to 5 microns in thickness, and stained with haematoxylin and eosin. In addition to their providing the basis for a histological evaluation of the bone and soft connective tissue reactions, which occurred during the experimental period in the region of the midpalatal suture, these sections also allowed for an evaluation of the changes which took place in the periodontal ligament and the alveolar bone surrounding the teeth.

Several sections from each of the decalcified blocks of the second control animal and the 4 day experimental

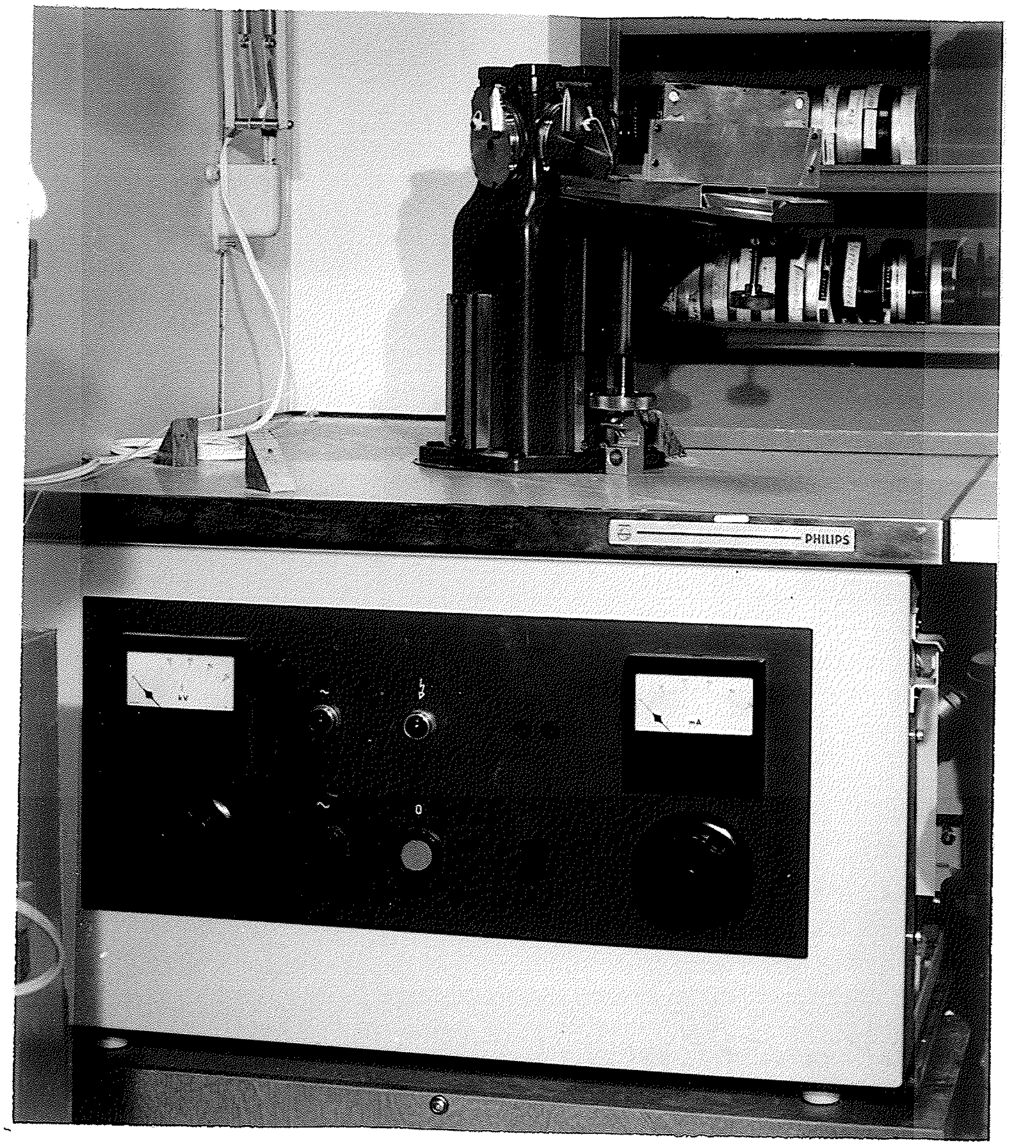

Figure 6. Photograph of the Philips soft x-ray machine used for making the soft x-ray radiographs.

animal were used to prepare autoradiographs. The sections were coated with Kodak NTB3 emulsion, exposed for 21 days, developed and fixed as previously described, and then stained routinely with haematoxylin and eosin.

Upon subjective analysis under the microscope, it was anticipated that the basic histological material would reveal, through observation of the bone and connective tissue reactions, the mechanism of midpalatal suture opening and the reactions in the remaining palatal sutures and the teeth and alveolar bone. The occlusal radiographs, with the support of the histological data, would show when the suture opened. Similarly the soft x-ray radiographs would indicate when the suture had opened as well as showing relative changes in the degree of mineralization of the bone. The fluorescent tetracycline markers would support the histological data by showing the relative direction of the bone changes. Also, the autoradiographs would reveal the relative amount of collagen formation and thus corroborate the histologic interpretation of the connective tissue reactions involved in opening the suture. Furthermore, it was anticipated that some of this data could be correlated with previous histological investigations.

No quantitative analyses were attempted in this study, due to the nature of the specimens, and the small sample size.

CHAPTER IV

RESULTS

I. ANALYSIS OF THE CONTROL ANIMALS

The data obtained from the two control animals was used as a frame of reference with which to compare the gross morphological changes and the histological changes with those which occurred following expansion in the four experimental animals.

A preliminary examination of the postero-anterior and lateral cephalometric headfilms, taken during this study, revealed that serial tracings of these films could not be accurately superimposed. This was due to the fact that the monkeys could not be easily placed in a reproduceable position in the cephalometer. Consequently, no attempt was made to analyze any cephalometric changes which may have occurred.

The study models of the two control animals showed that no changes had occurred during the experimental period in the intermolar widths between the maxillary first permanent molars (Table II).

From the occlusal radiographs, both control animals were observed to have normal palatal sutures. These sutures were very narrow and well-delineated (Figure 7).

TABLE II

MAXILLARY AND MANDIBULAR INTERMOLAR WIDTHS BEFORE AND AFTER EXPANSION

ANIMAL	INTERMOLAR WIDTHS BEFORE EXPANSION	INTERMOLAR WIDTHS AFTER EXPANSION
Control 1	Max: 29 mm / Mand: 28 mm	
Control 2	Max: 29 mm / Mand: 25 mm	
24 Hours	Max: 28 mm / Mand: 25.5 mm	Max: 28 mm / Mand: 25 mm
4 Days	Max: 28.5 mm / Mand: 24.5 mm	Max: 30 mm / Mand: 25 mm
7 Days	Max: 29.5 mm / Mand: 25 mm	Max: 31.5 mm / Mand: 25.5 mm
14 Days	Max: 30 mm / Mand: 26 mm	Max: 33 mm / Mand: 26 mm

(All measurements were made at the tips of the mesio-buccal cusps.)

Both of the control animals presented similar histological findings. The palatal sutures consisted of interdigitating processes of bone, separated by relatively narrow bands of fibrous connective tissue (Figure 8.). The general morphology of the intermaxillary or midpalatal suture varied; it was more convoluted or complex in some areas than in others (Figure 9.).

Figure 7. Occlusal radiograph of the second control animal showing normal gross sutural morphology. (X3)

Figure 8. Photomicrograph showing general morphology of the midpalatal or intermaxillary suture of the first control animal. (X60)

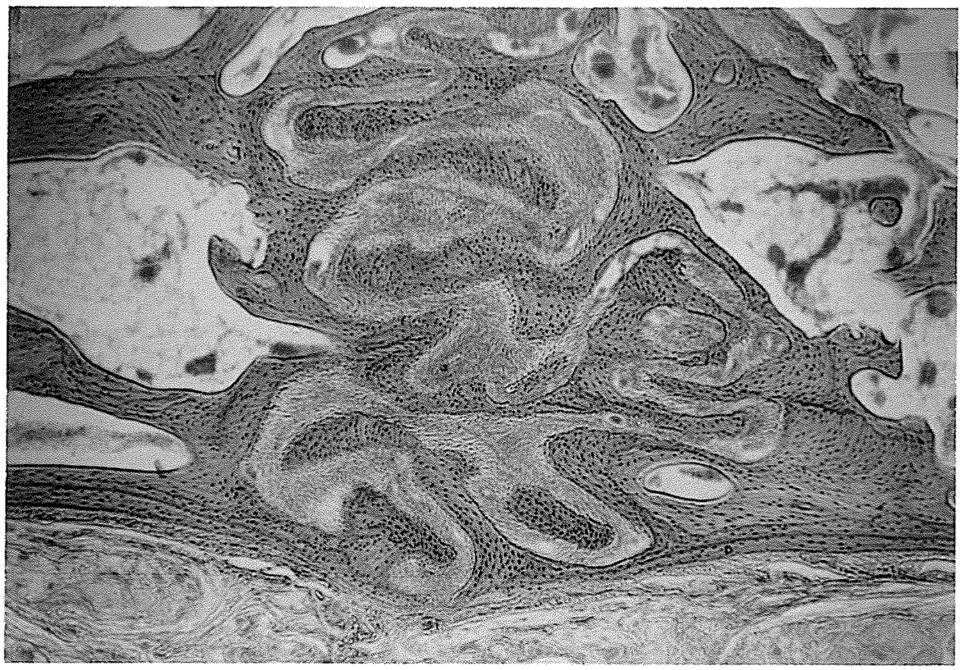

Figure 9. Photomicrograph showing variance in the general morphology of the midpalatal suture. Compare with Figure 8. (X60)

The sutural connective tissue appeared well-organized, with a regular fibre arrangement. The central portion of the connective tissue contained large numbers of nuclei, while the outer portions had much fewer nuclei (Figure 10.). There were not large numbers of blood vessels present in the connective tissue, nor were these vessels engorged.

At this stage, the normal bone reaction appeared to be of a remodelling nature. Bone deposition, bone resorption and resting bone were observed to be randomly located along the bony edges of the suture (Figure 10.). Osteoclasts could be seen in some areas where resorption was occurring, but they were not always present. In areas of deposition, osteoblasts, lined in rows along the edge of the bone (Figure 11.), were observed.

The interpremaxillary, premaxillary-maxillary, maxillo-palatine and interpalatine sutures all presented the same normal remodelling process, but the general morphology of the sutures differed from that of the midpalatal suture. The interpremaxillary suture showed few or no processes and generally presented relatively flat surfaces (Figure 12.).

As a result of the plane of section, the premaxillary-maxillary and the maxillo-palatine sutures presented a variety of morphologies from very simple to very complex (Figure 13.). The interpalatine suture generally presented a less complex arrangement of bony processes (Figure 14.).

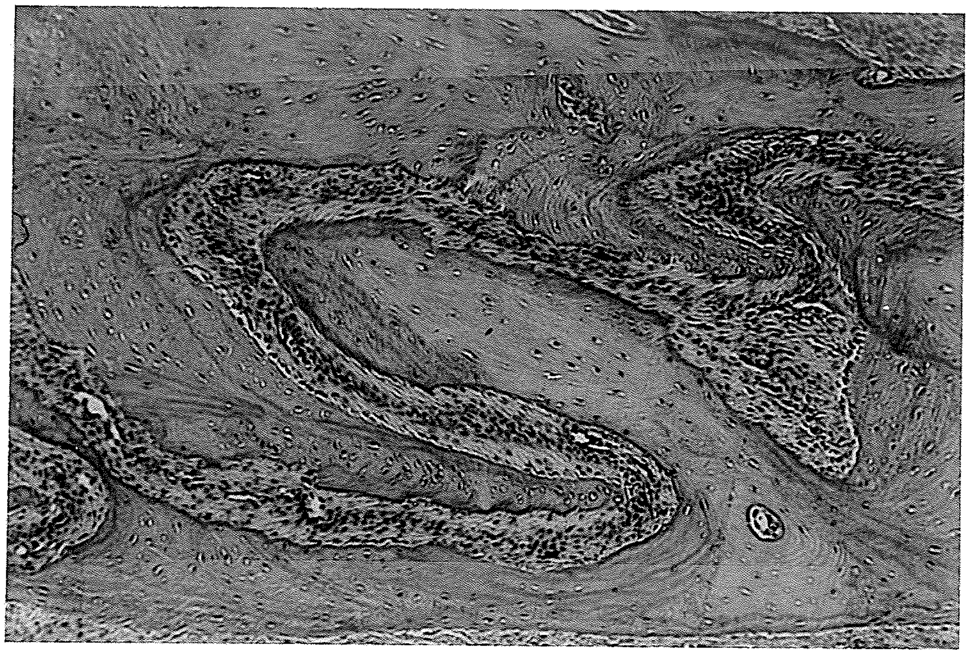

Figure 10. Photomicrograph showing normal sutural connective tissue. Note the central nucleus-filled zone, and also the arrangement of the fibres. (X150)

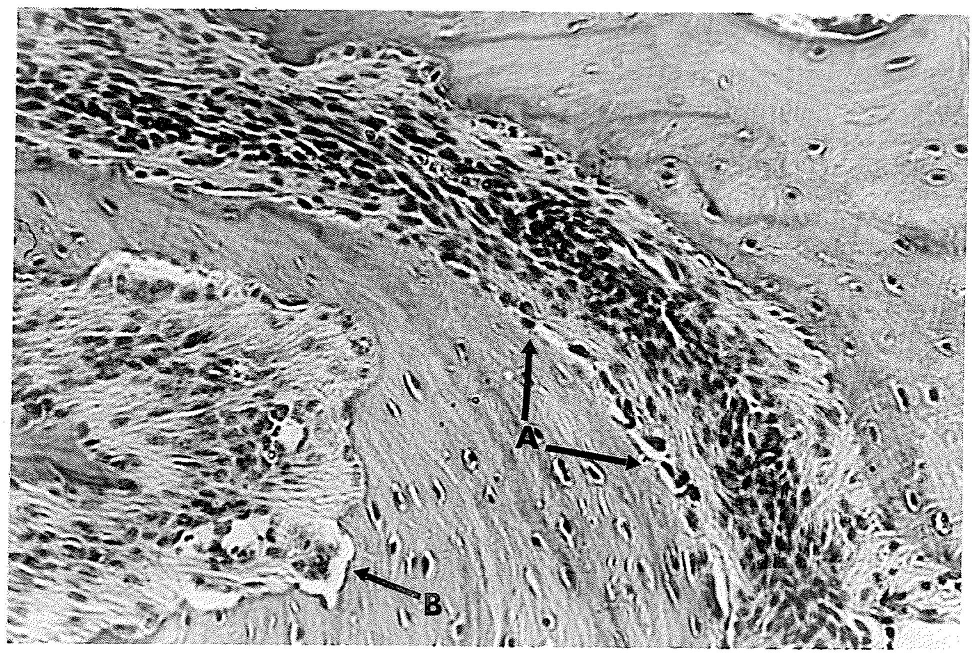

Figure 11. High power photomicrograph showing rows of osteoblasts in areas of deposition (A). Also note osteoclasts present in some areas of resorption (B). (X400)

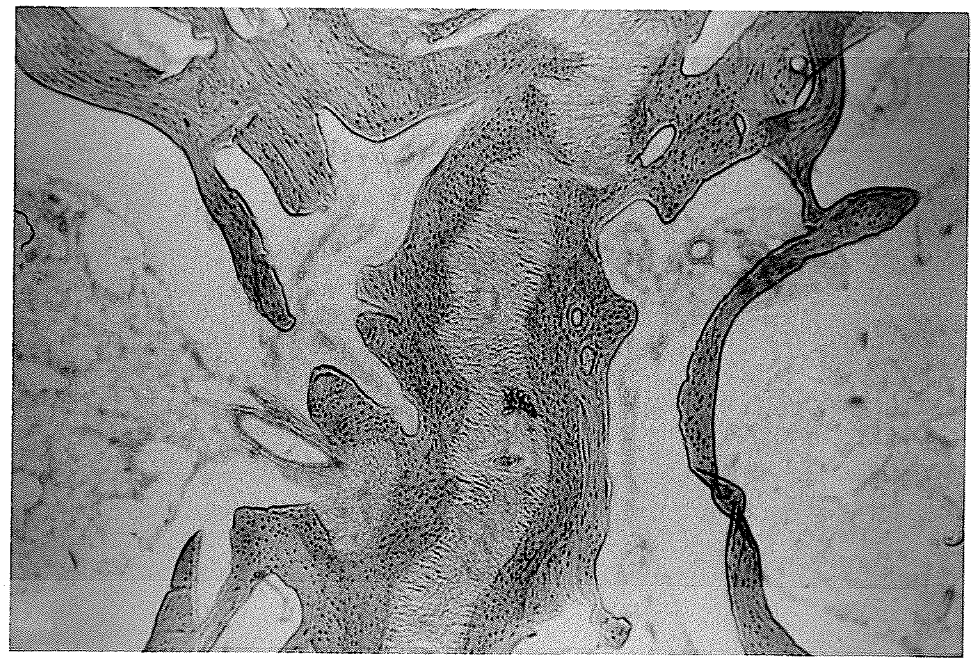

Figure 12. Photomicrograph demonstrating simple morphology of interpremaxillary suture. (X60)

Figure 13. Photomicrograph showing morphology of maxillo-palatine suture. The premaxillary-maxillary suture presented a similar morphological appearance. (X60)

Figure 14. Photomicrograph demonstrating the general morphology of the interpalatine suture. (X60)

Examination of the periodontal structures showed both control animals to have normal supporting tissues. The periodontal ligament was of uniform width around the root and the fibres of the ligament generally ran in the directions best suited for support during normal function (Figure 15.).

The periodontium showed the normal amounts of fibrocytes, cementoblasts, and osteoblasts (Figure 16.). Occasionally osteoclasts could be seen, indicating that some mild remodelling was in progress in the alveolar bone.

When the undecalcified sections were viewed with ultra-violet light, in order to determine the location of the tetracycline bone markings, the histological findings were confirmed. The fact that only scattered areas of the bone, along the edges of the suture, picked up the tetracycline marker confirmed that bone deposition was occurring in dispersed regions (Figure 17.). In most areas, bone growth was not occurring rapidly, as shown by the fact that the double label could not be easily discerned even in the second of the two control animals, into which the tetracycline was injected at a fourteen day interval (Table I).

Both control animals showed the same results when the soft x-ray radiographs were examined. Each animal showed the suture to be a relatively narrow radiolucent band,

Figure 15. Photomicrograph showing the appearance of the periodontal ligament. Note the regular width of the ligament and the absence of stretching or compression. (X60)

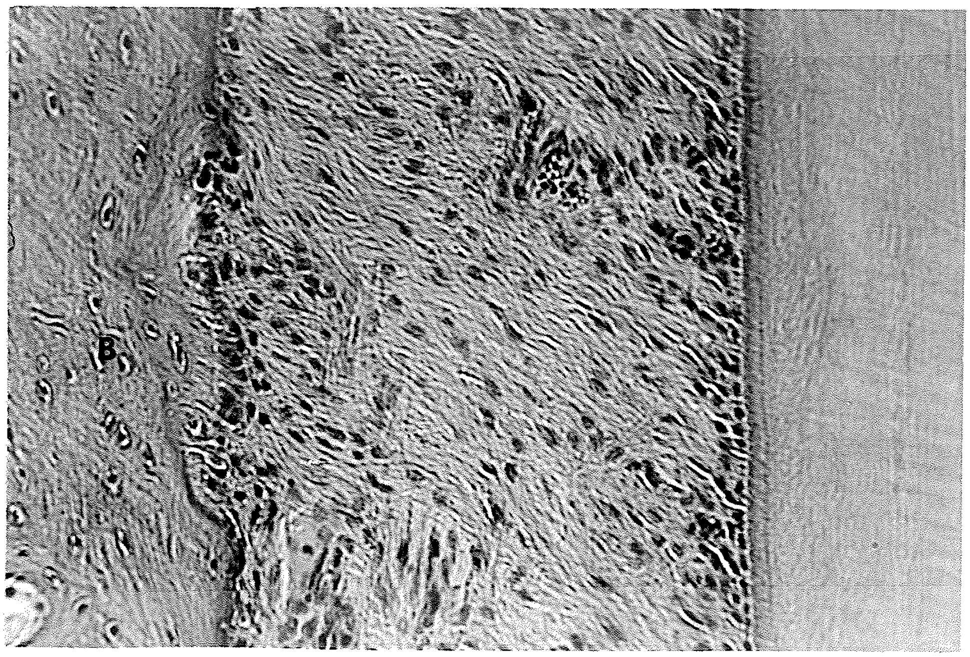

Figure 16. High power photomicrograph showing the cellular elements in the periodontal ligament. Observe the remodelling of the alveolar bone (B). (X400)

Figure 17. Photomicrograph of an undecalcified section viewed with ultra-violet light. Note the irregular marking of bone with the fluorescent tetracycline. (X150)

bordered by well-defined, well-mineralized bony processes (Figure 18.). Some areas of less well-mineralized new bone and scalloped areas of bone resorption could be detected along the edges of the bony processes (Figure 19.). This corroborated the histological findings.

The second control animal was one of two animals which received an injection of H^3-proline four days before sacrifice (Table I). Any collagen being formed at the time incorporated the radioactive proline into its structure and this radioactive proline was manifested as silver grains when the sections were processed as described previously.

At this stage, a fine field of silver grains was seen to be distributed over the sutural connective tissue. The distribution of the grains was fairly even over all the connective tissue, with perhaps a slightly larger number of grains located close to the edges of the bone. Very few grains could be seen over the bone itself, which indicates that the collagen fibres had not yet been incorporated into the developing bone (Figure 20.). This same general distribution was observed over the connective tissue of all the palatal sutures.

Areas of resorption generally showed less collagen formation than did areas of deposition (Figure 21.).

The autoradiographic findings would thus corroborate the analyses of the undecalcified and routine histological sections.

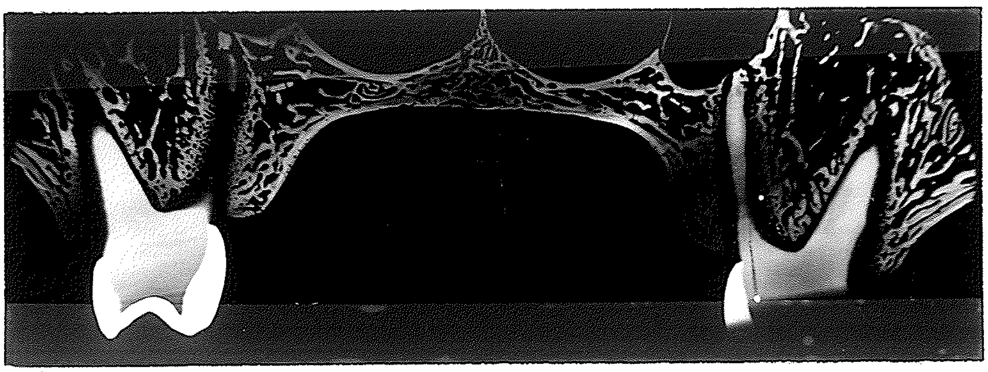

Figure 18. Soft x-ray radiograph of the midpalatal suture region, showing the normal sutural morphology. (X4)

Figure 19. Photomicrograph of a soft x-ray radiograph of the midpalatal suture. (X60)

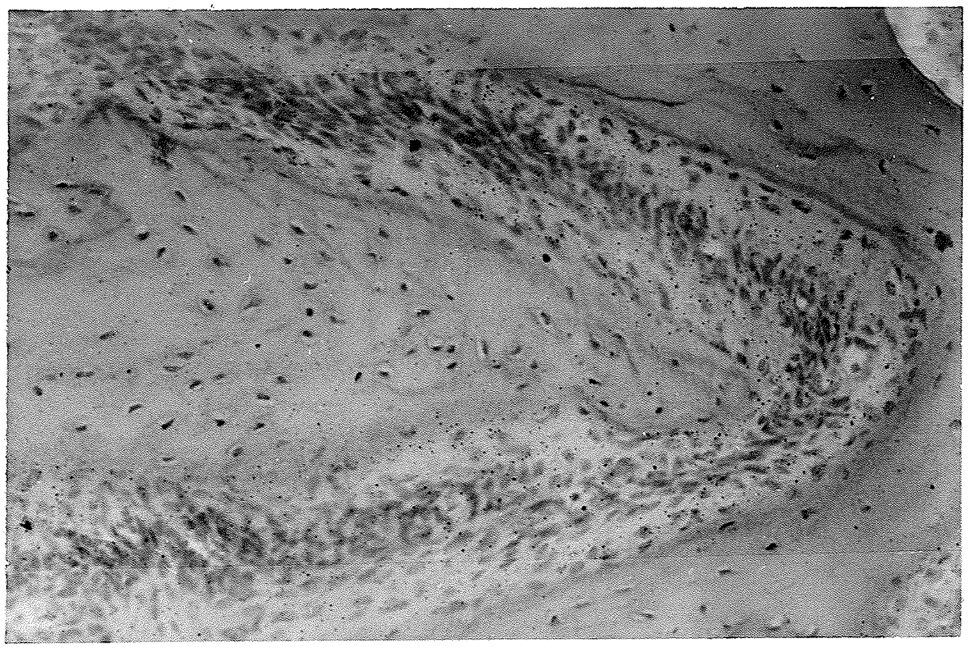

Figure 20. High power photomicrograph showing dispersion of silver grains over the sutural connective tissue. Observe the relatively larger number of silver grains over the edges of the connective tissue, as compared to the central zone. (X400)

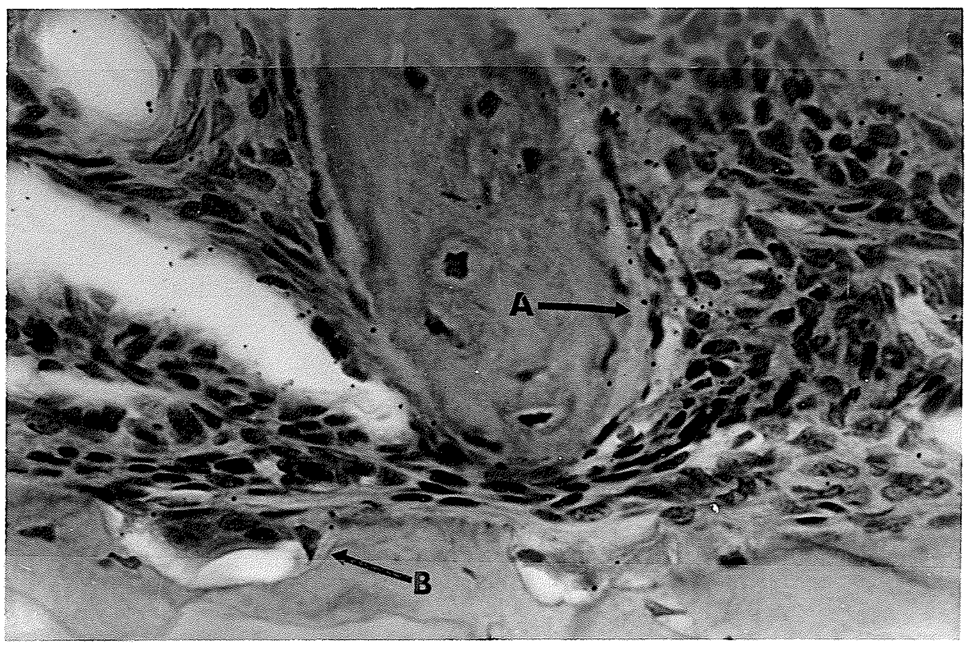

Figure 21. Very high power photomicrograph showing greater number of silver grains over areas of deposition (A), as compared with areas of resorption (B). (X960)

II. ANALYSIS OF THE 24-HOUR EXPERIMENTAL ANIMAL

The first experimental animal was sacrificed following 24 hours of maxillary expansion (Table I). This animal showed no gross changes when compared with the control animals.

Examination of the pre-expansion and post-expansion study models revealed that there had been no measurable change in the intermolar width between the maxillary first permanent molars. Furthermore, there had been no significant change in the mandibular intermolar width (Table II). Similarly, the occlusal radiographs indicated no gross changes when compared with the control animals. The sutures in the palatal area were generally narrow and well defined, with only a mild indication of some disruption having taken place in the intermaxillary suture (Figure 22.).

The histological findings differed slightly from the control animals, but the differences were not marked. At this stage, there appeared to be no increase in the vascular response. Some slight movement of the bones had taken place as the mild stretching of the sutural connective tissue fibres, which alternated with areas of compression of the connective tissue indicated (Figure 23.). However, the sutural connective tissue had become relatively disorganized (Figure 24.), having lost the definite fibre orientation seen in the control animals.

Figure 22. Occlusal radiograph of palatal area. This appears basically the same as the palatal area of the control animal (Figure 7.), with perhaps some slight disruption in the intermaxillary suture. (X3)

Figure 23. Photomicrograph showing midpalatal suture after 24 hours of expansion. Note the areas of connective tissue compression. (X60)

Figure 24. Photomicrograph of the midpalatal suture showing the disorganized appearance of the sutural connective tissue. (X150)

The bone tissue reaction had not changed from the picture seen in the control animals. Remodelling of bone was occurring and areas of deposition, resorption, and resting bone were observed in random formation along the edges of the bony processes (Figure 25.).

When compared with the controls, no vascular changes were seen in the interpremaxillary suture. In some areas, the connective tissue appeared as though it may have been slightly compressed, and it also appeared somewhat disorganized. As in the control animals, the bone reaction was one of remodelling, with random areas of osteoblastic and osteoclastic activity in evidence (Figure 26.).

In the premaxillary-maxillary and maxillo-palatine sutures, the same disorganized connective tissue and lack of vascular response was observed. A unique picture was seen in that perfectly alternating rows of compressed and stretched connective tissue presented, indicating that the maxilla was being moved laterally against the resistance of the premaxilla and palatine bones (Figure 27.). The bony processes are vertical rather than horizontal, in these sutures, as the premaxilla and palatine bones lie superiorly to the maxilla in the regions of articulation.

Again, the reaction in the bone tissue was a remodelling process. Even in the compressed areas, the short time of expansion was not enough to allow much osteoclastic activity to

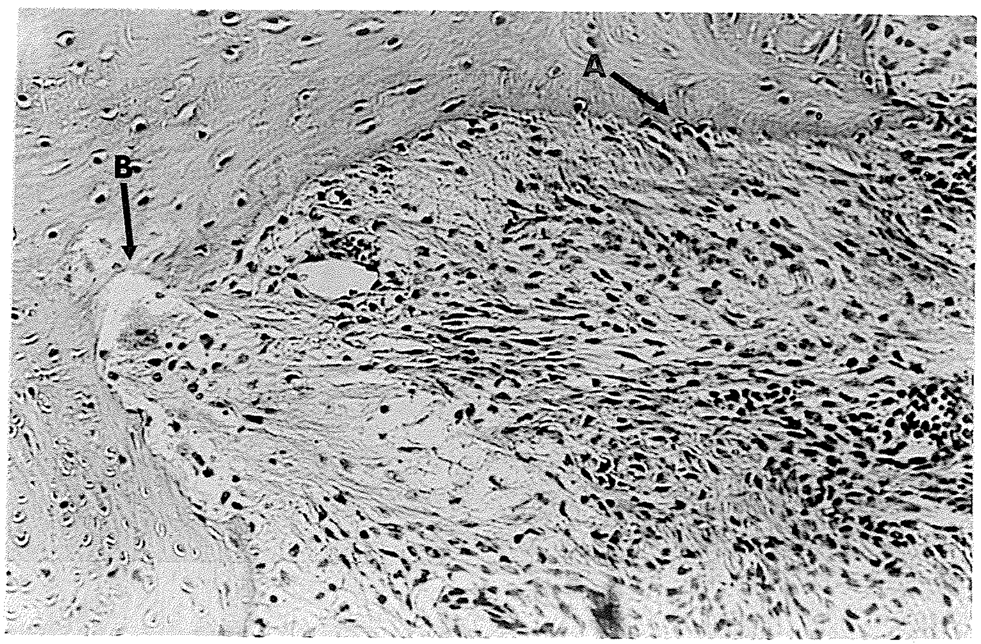

Figure 25. High power photomicrograph showing areas of bone deposition (A), and resorption (B). Again note the disorganized appearance of the connective tissue. (X400)

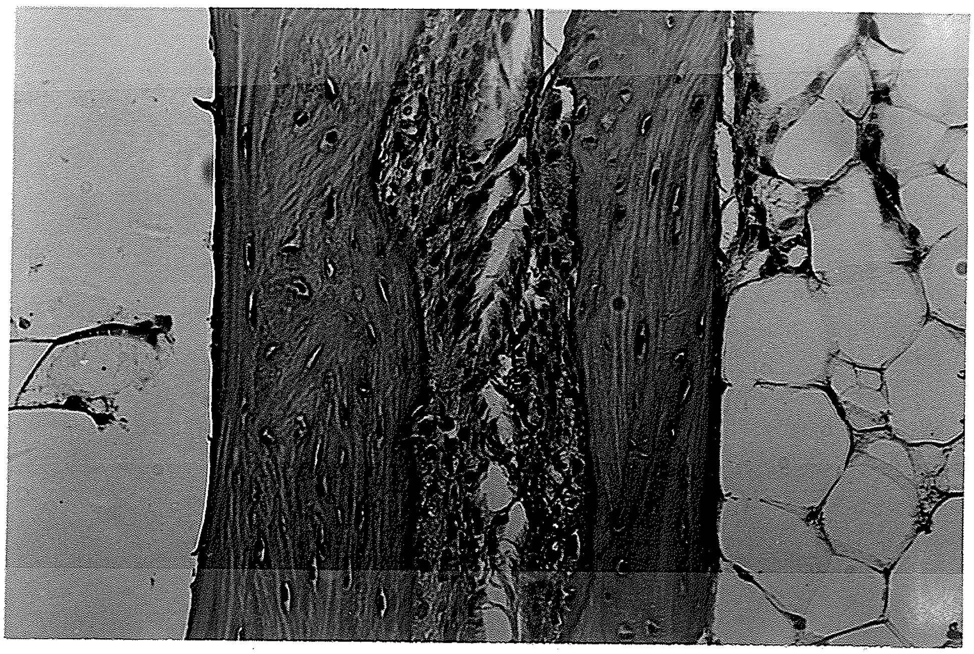

Figure 26. High power photomicrograph of the interpremaxillary suture. Observe the disorganized connective tissue, and generalized bone remodelling. (X400)

Figure 27. Photomicrograph of the premaxillary-maxillary suture showing alternate rows of connective tissue compression and stretching. The maxillary bone (to the inferior) is moving laterally in the direction of the arrow. (X60)

begin (Figure 28.).

The interpalatine suture showed no gross separation of the bones, and little or no compression or stretching of the connective tissue. Nor was there any change in the vascular supply (Figure 29.). However, on closer examination, the connective tissue was found to be disorganized, as observed in the more anterior sutures. As seen in the control animals, the bony processes showed areas of deposition, resorption, and resting bone (Figure 30.).

An examination of the teeth and alveolar areas showed the periodontal structures to be normal. There was no stretching or compression of the periodontal ligament (Figure 31.). The fibres of the periodontal ligament appeared normally oriented, and the cellular elements present reflected the picture seen in the control animals. The alveolar bone was undergoing normal remodelling, with perhaps a slight preponderance of deposition (Figure 32.).

The undecalcified sections, under ultra-violet light, gave a picture again similar to the control animals. The double tetracycline label (Table I) could not be discerned except in isolated areas. Along the bony margins of the suture, the fluorescent marker was picked up only in scattered areas which confirmed the histological picture of remodelling (Figure 33.).

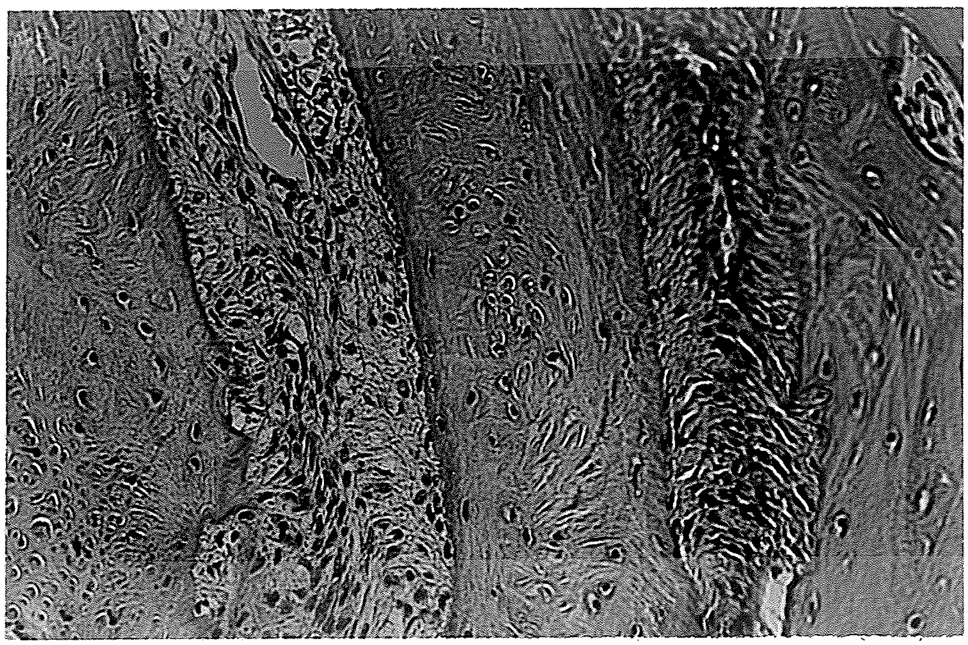

Figure 28. High power photomicrograph of the premaxillary-maxillary suture demonstrating resorption and deposition in regions of compression and stretching. (X400)

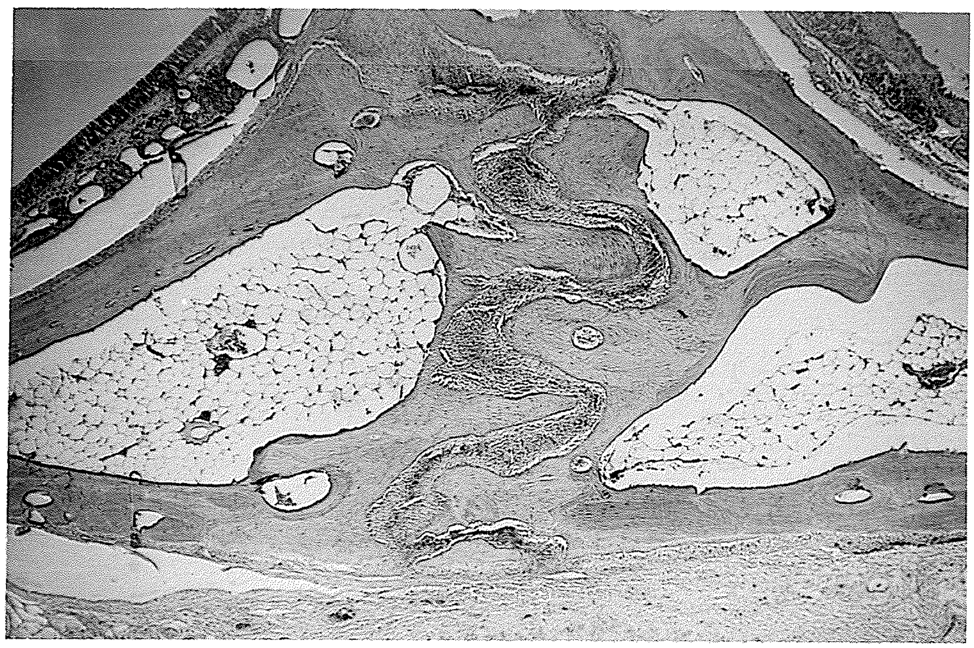

Figure 29. Photomicrograph demonstrating very mild stretching and compression of connective tissue in the interpalatine suture. (X60)

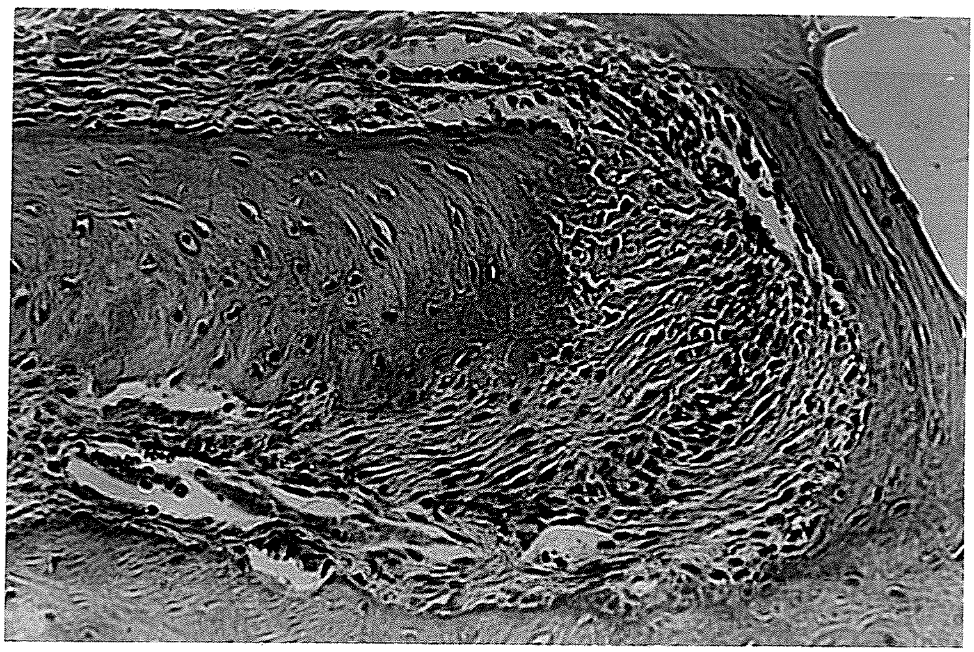

Figure 30. High power photomicrograph to show disorganized connective tissue and remodelling bone in the interpalatine suture. (X400)

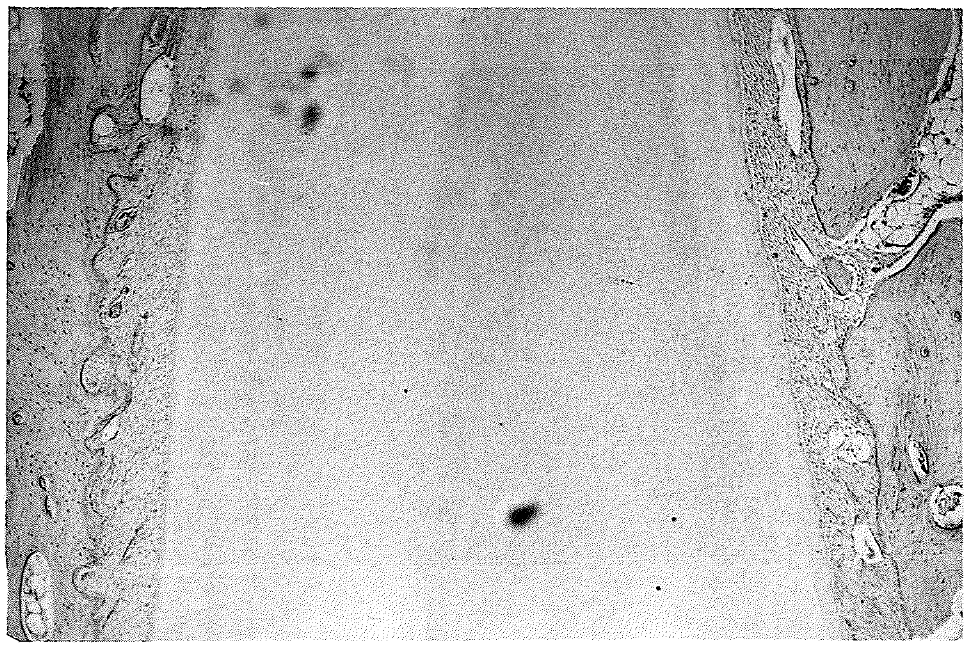

Figure 31. Photomicrograph showing part of the periodontal structures of the maxillary first permanent molar. Observe the absence of stretching or compression of the periodontal ligament. (X60)

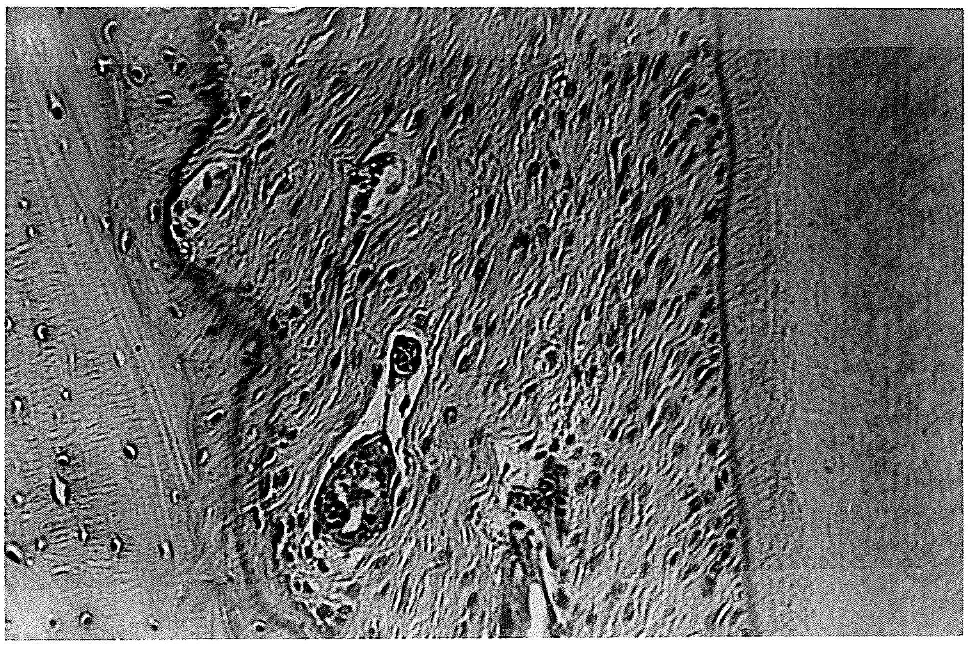

Figure 32. High power photomicrograph showing a normal fibre arrangement, and cellularity of the periodontal ligament. (X400)

Figure 33. Photomicrograph showing appearance of the midpalatal suture of the 24 hour experimental animal, as seen in the undecalcified sections with ultra-violet light. (X150)

Furthermore, a normal result was seen when the soft x-ray radiographs were examined. The suture was observed as a narrow radiolucent line. The bony processes appeared to be well-mineralized (Figure 34.). Areas of less well-mineralized new bone and scalloped areas of bone resorption confirmed that remodelling of the bone was taking place (Figure 35.).

This animal did not receive an injection of H^3-proline so autoradiographs were not prepared (Table I).

In summary, the first experimental animal, sacrificed following 24 hours of maxillary expansion, showed only slight differences when compared with the control animals. Grossly, no alteration of the palatal sutures could be seen from the occlusal radiographs, nor was any separation of the maxillae noted from the study models. Histological evidence indicated no changes in the vascular supply, but the sutural connective tissue had lost its normal fibre orientation and generally appeared to be very disorganized. It could be concluded that slight changes in the position of the maxillae had occurred, since some areas of the midpalatal sutural connective tissue were compressed, as were areas of the connective tissue in the premaxillary-maxillary, and maxillo-palatine sutures. However, no changes could be observed in the periodontal ligament or in the alveolar bone. The histological evidence was substantiated by findings from the undecalcified sections and from the soft x-ray radiographs.

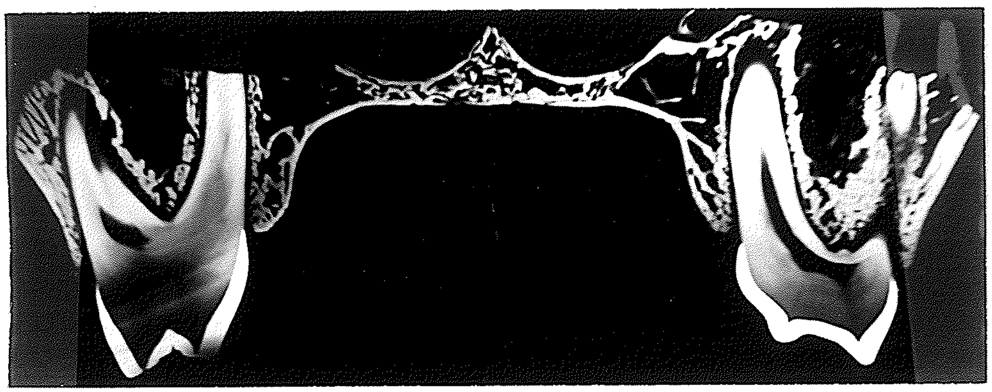

Figure 34. Soft x-ray radiograph of the midpalatal suture of the 24 hour experimental animal. (X4)

Figure 35. Photomicrograph from a soft x-ray radiograph of the midpalatal suture region of the 24 hour experimental animal. (X60)

III. ANALYSIS OF THE 4-DAY EXPERIMENTAL ANIMAL

The second experimental animal was sacrificed following 4 days of rapid maxillary expansion (Table I). Examination of the models taken before and after expansion showed a 1.5 millimeter increase in the intermolar width between the maxillary first permanent molars. However no significant change could be found in the mandibular intermolar width (Table II).

The occlusal radiographs indicated some disruption of the intermaxillary or midpalatal suture. This suture did not appear narrow and well-defined, as in the control animals. However, the remaining palatal sutures presented a well delineated normal appearance (Figure 36.).

The histological sections presented a different picture in comparison to the control animals and to the 24-hour experimental animal. The connective tissue of the suture was much wider and somewhat stretched in many areas which indicated that separation of the bones was taking place. In many other areas of the suture, however, the connective tissue appeared very compressed as a result of the inferior and lateral rotation of the bony processes. The vascularity of the connective tissue had changed, there now being numerous large blood vessels present (Figure 37.). Only occasionally a fractured process was found. There appeared to be slight

Figure 36. Occlusal radiograph showing palatal area of the 4 day experimental animal. Note the disrupted appearance of the midpalatal suture (arrows). (X3)

Figure 37. Photomicrograph of midpalatal suture region. Note separation of the bones, and the increased number of blood vessels. (X60)

haemorrhage, but there was no inflammatory response present. The less convoluted areas of the midpalatal suture presented about the same amount of bone separation and connective tissue stretching, but less compression of the connective tissue was seen (Figure 38.). In the areas where the connective tissue was not compressed, it appeared much more dense, and more cellular than in the control animals. Generally, it appeared much more organized than in the 24-hour experimental animal, having now regained some of its fibre orientation (Figure 39.).

The reaction in the bone tissue was predominantly resorption in most areas of the midpalatal suture, yet some deposition was occurring. Large numbers of osteoclasts were present along the edges of bone (Figure 39.). Osteoclastic activity was occurring in all areas of compression, and osteoclasts were also seen in areas of connective tissue stretching (Figure 40.).

There did not appear to be much separation of the bones in the interpremaxillary suture area. However, the sutural connective tissue seemed to be slightly stretched, and possibly more dense. There also seemed to be an increase in the vascularity. The bone tissue presented areas of resorption and deposition, with a predominance of the latter (Figure 41.).

The premaxillary-maxillary and maxillo-palatine sutures presented a more advanced stage of what was observed in the 24-hour animal. Lateral movement of the maxilla against the

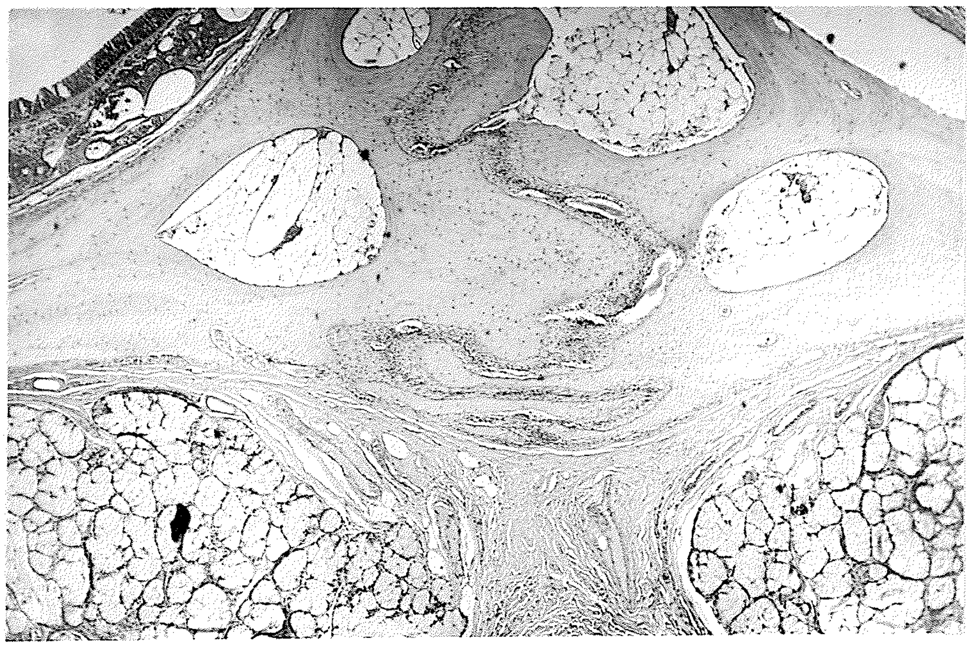

Figure 38. Photomicrograph illustrating a less convoluted area of the midpalatal suture. (X60)

Figure 39. Higher power photomicrograph of the midpalatal suture. Observe the increased density and cellularity of the connective tissue. Also, note the amount of osteoclastic activity. (X150)

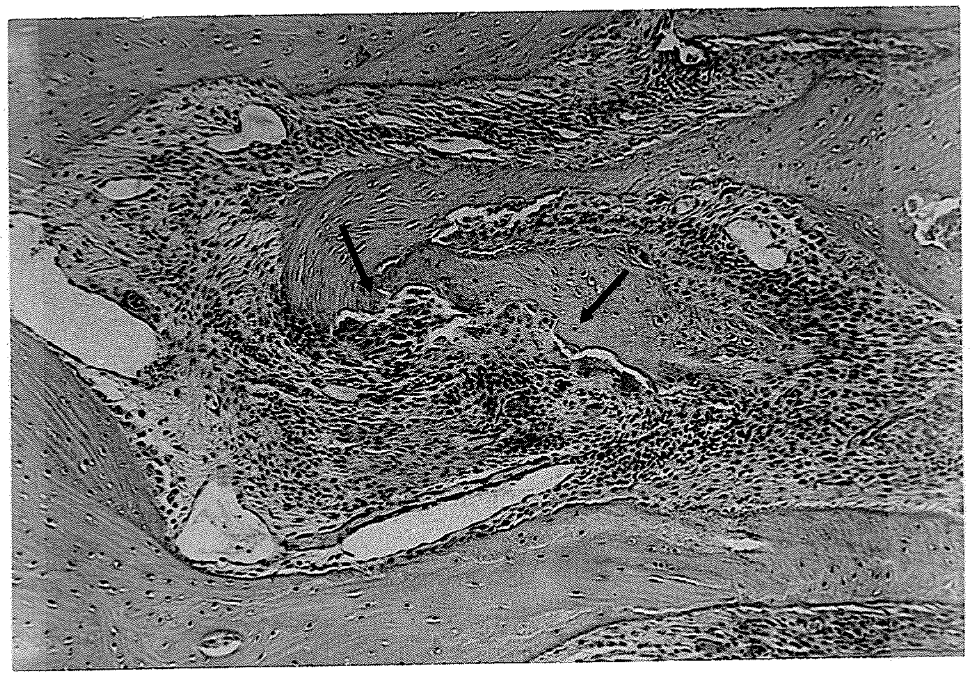

Figure 40. Photomicrograph demonstrating the presence of osteoclastic activity, in the absence of connective tissue compression (arrows). (X150)

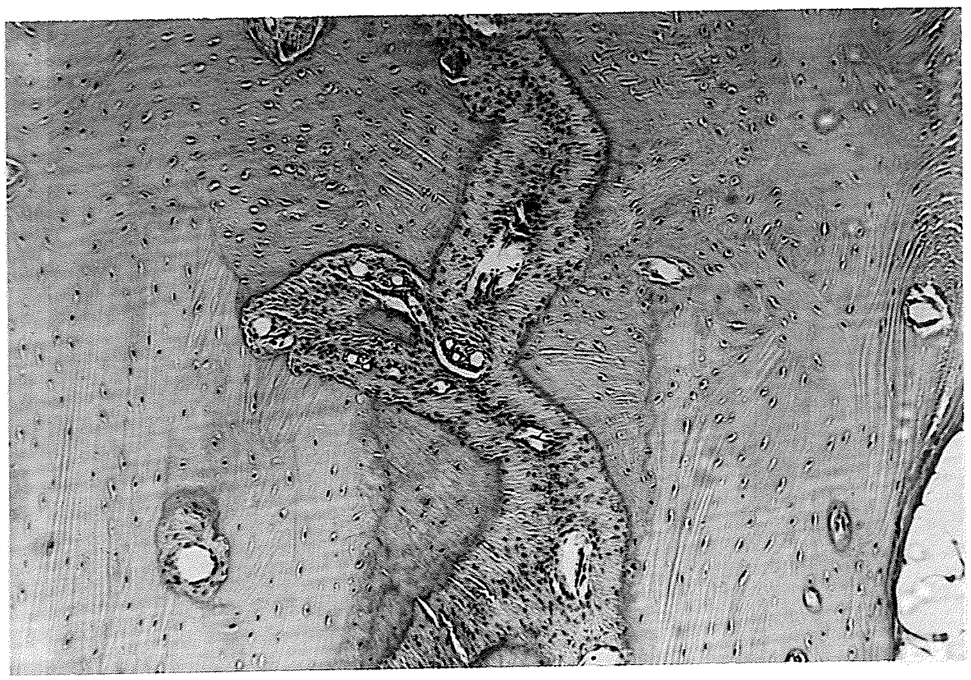

Figure 41. Photomicrograph of interpremaxillary suture. Note that the connective tissue may be slightly stretched. Also seen is the predominance of osteoblastic activity. (X150)

premaxilla and palatine bones had produced areas of severely compressed connective tissue, alternating with areas of stretched connective tissue. These sutures also showed an increased vascular response (Figure 42.).

As in the midpalatal suture, the connective tissue in these sutures appeared more dense and more cellular than in the control animals. The bone reaction showed areas of heavy resorption, alternating with areas of deposition. Numerous osteoclasts and osteoblasts were present in their respective areas (Figure 43.).

A less convoluted interpalatine suture presented, so areas of compressed connective tissue were less numerous than in some of the other sutures in this animal. The connective tissue appeared more fibrous, and there had been a large increase in the vascularity (Figure 44.).

Resorption could be seen in areas of connective tissue compression, but the predominant bone reaction was one of deposition (Figure 45.). This same type of reaction was noted in the interpremaxillary suture.

From an examination of the teeth and periodontal structures, it was evident that some buccal movement of the teeth was taking place. Compression of the periodontal ligament had occurred on the buccal side of the root, accompanied by resorption of the alveolar bone. On the lingual side of the roots, stretching of the periodontal ligament and bone

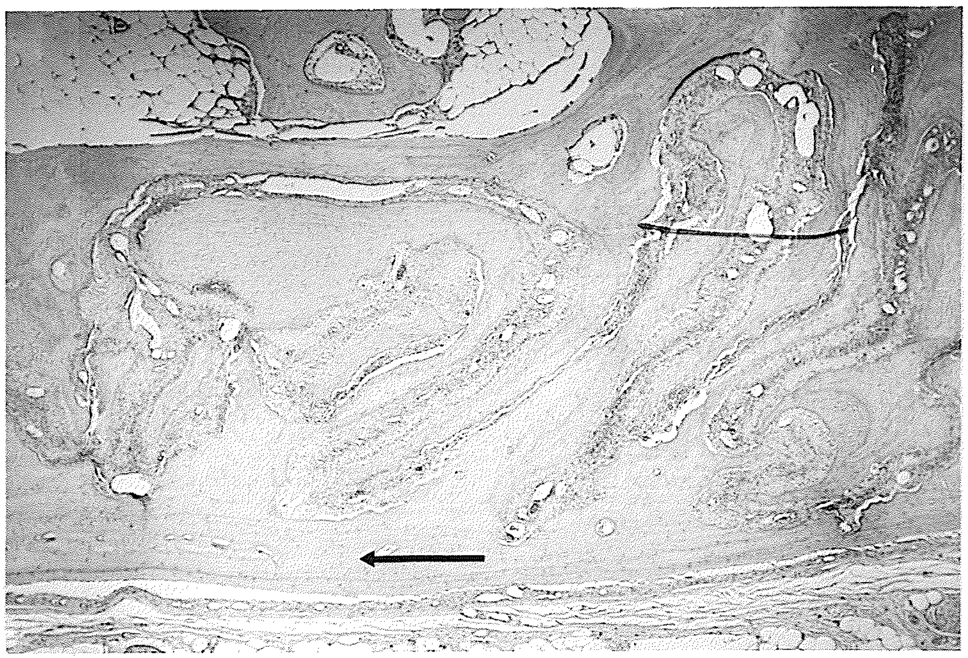

Figure 42. Photomicrograph of premaxillary-maxillary suture showing the alternate compression and stretching. The maxilla is moving in the direction of the arrow. (X60)

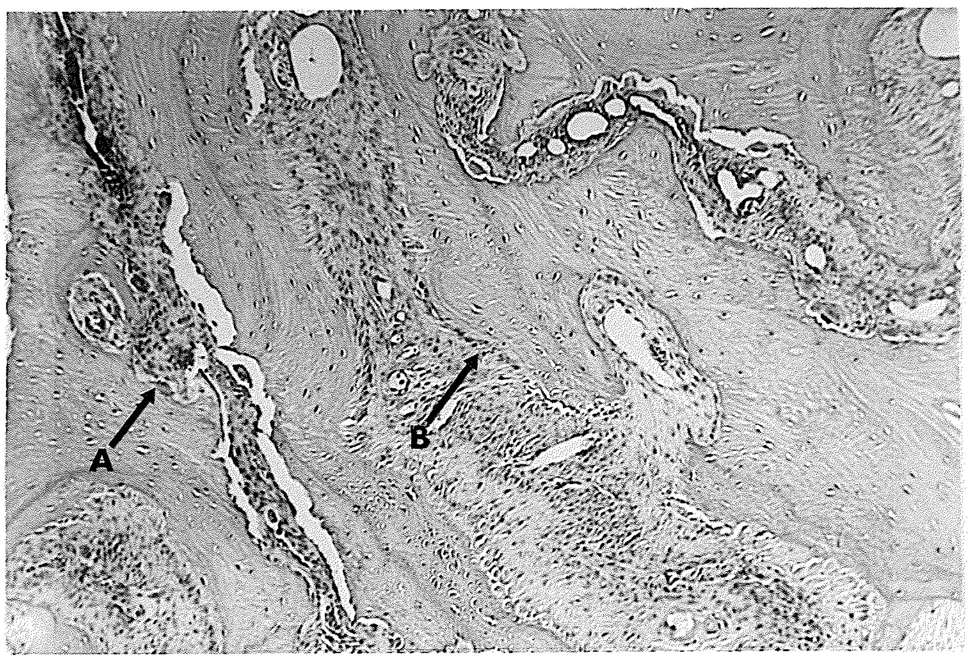

Figure 43. High power photomicrograph showing areas of heavy resorption (A) and heavy deposition (B) in the premaxillary-maxillary suture. (X150)

Figure 44. Photomicrograph of interpalatine suture. Observe the resting lines, (arrows) and the increased number of blood vessels in the suture. (X60)

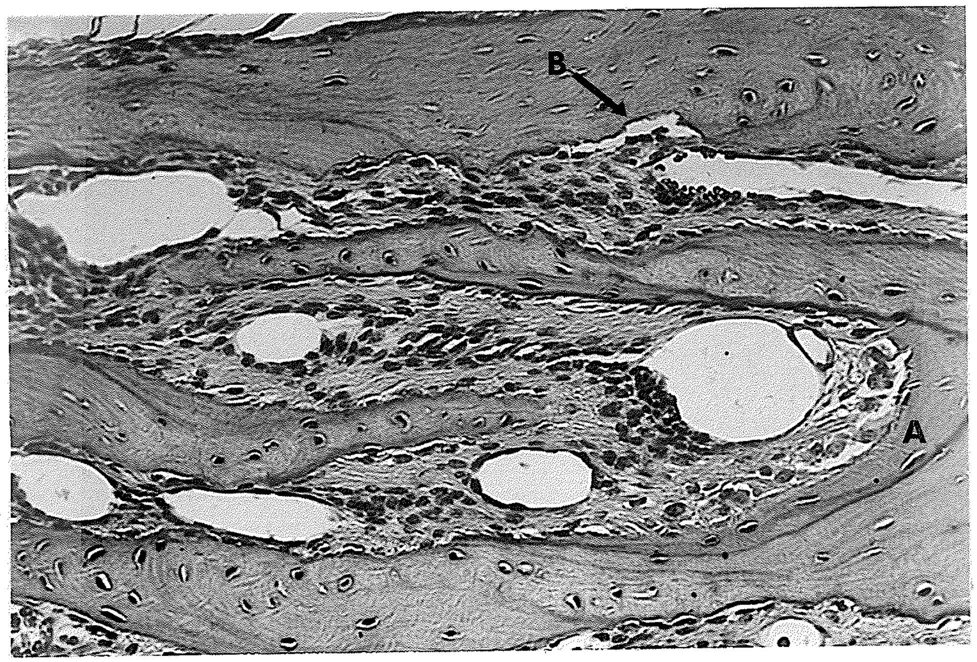

Figure 45. High power photomicrograph to show the predominance of bone deposition (A) in the interpalatine suture. Some areas of resorption were seen (B). (X400)

deposition could be seen (Figure 46.). There may have been some slight tipping of the teeth, since these reactions were not as severe near the apical ends of the roots as they were at the cervical portion.

Further corroboration of the histological analysis was seen in the undecalcified sections. In the very convoluted areas of the suture, much of the tetracycline marker was missing from the bone. This indicated that the resorption which was taking place had removed a good portion of the bone which had been deposited in the two week period prior to expansion (Figure 47.).

Examination of the soft x-ray radiographs also confirmed the above findings. Compared with the control animals, the radiolucent suture area seemed wider and was bordered by bone that was less well-mineralized (Figure 48.). Indicative of the resorption that was taking place, the edges of the bony processes were very scalloped in appearance. Smooth areas of less well-mineralized new bone could also be seen where bone deposition was occurring (Figure 49.).

The 4-day experimental animal was the second of two animals to receive an injection of H^3-proline (Table I). The autoradiographic preparations from this animal showed the silver grains in the sutural connective tissue to be relatively more numerous than in the second control animal (Figure 50.). This would indicate a more rapid proliferation

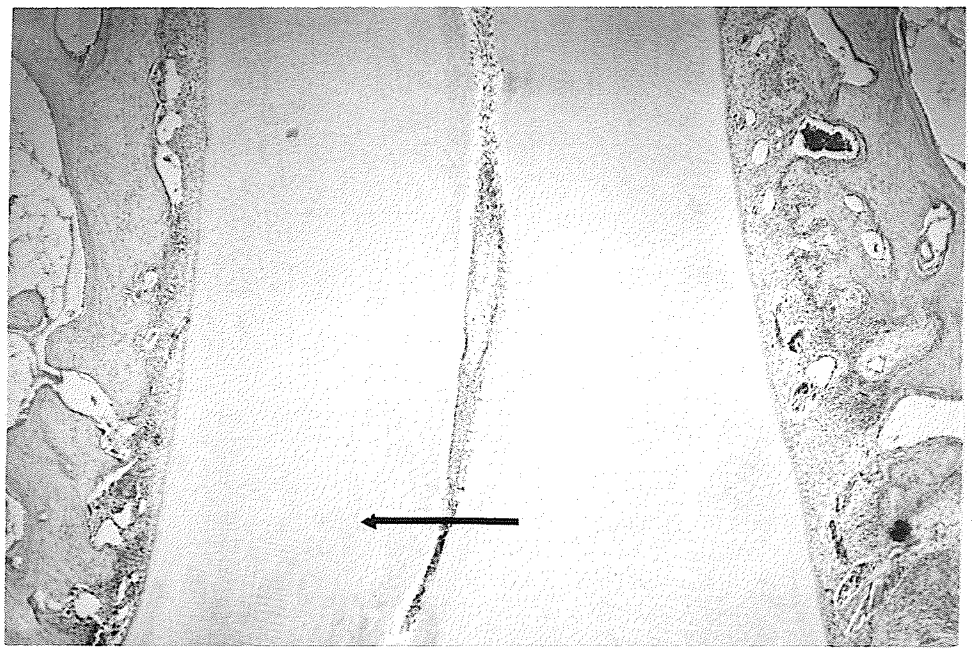

Figure 46. Photomicrograph of the first permanent molar showing compression of buccal periodontal ligament, and stretching of lingual periodontal ligament. Tooth is moving buccally, in the direction of the arrow. (X60)

Figure 47. Photomicrograph of undecalcified section of midpalatal suture region, as seen with ultra-violet light. Note the absence of the tetracycline marker in the suture due to the heavy resorption. (X150)

Figure 48. Soft x-ray radiograph of midpalatal suture region. (X4)

Figure 49. Photomicrograph of soft x-ray radiograph. Note the scalloped edges of the bony processes indicating osteoclastic activity. (X60)

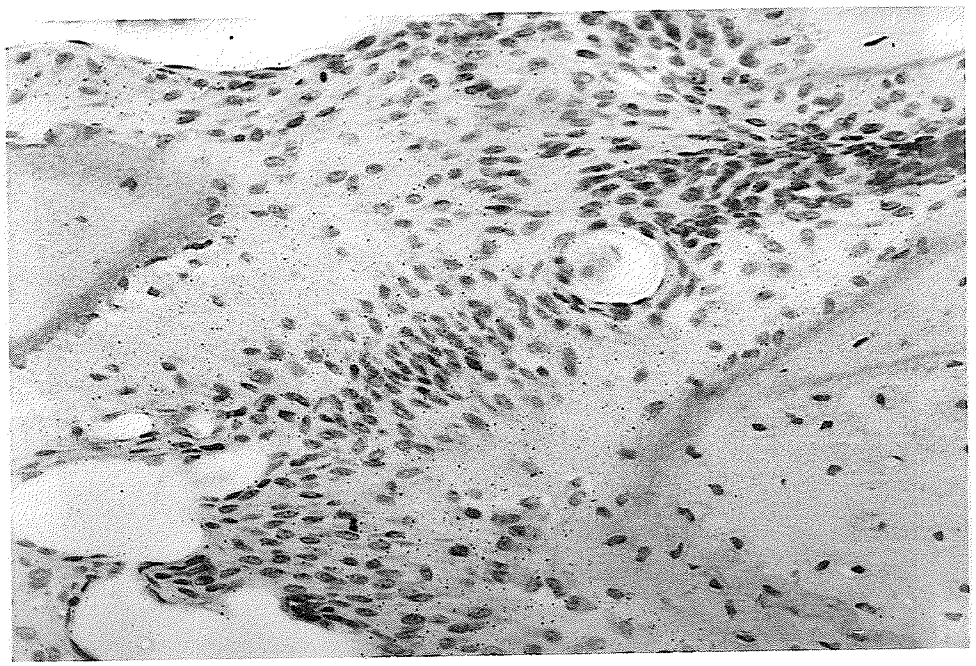

Figure 50. High power photomicrograph showing an increase in the relative number of silver grains over the connective tissue, as compared with the control animal (Figure 20.). Also note the fairly even distribution of silver grains. (X400)

of collagen. As also noted in the control animal, there were fewer silver grains in areas of resorption, as compared with areas of deposition (Figure 51.).

Another interesting finding, as compared with the control animal, was the greater number of grains found in areas of bone (Figure 51.). This would illustrate that, in areas where bone deposition was taking place, it was being formed at a faster rate than in the control animal. All the sutures of the palatal area showed this same distribution of silver grains.

In summary, the second experimental animal, sacrificed after 4 days of maxillary expansion, showed a number of changes when compared with the control animals. On a gross level, the maxillary arch width at the molars had increased approximately 1 millimeter. The occlusal radiographs showed a disruption in the intermaxillary suture, but indicated no changes in the remaining palatal sutures. The histological findings showed a more cellular sutural connective tissue, an increase in the vascularity, and slight separation of the bones. The bone tissue reaction in the intermaxillary, premaxillary-maxillary and maxillo-palatine sutures seemed to be predominantly resorption; however, a certain amount of deposition was occurring. The remaining sutures showed some resorption, but osteoblastic activity was more prevalent. The periodontium indicated a possible buccal tipping of the teeth.

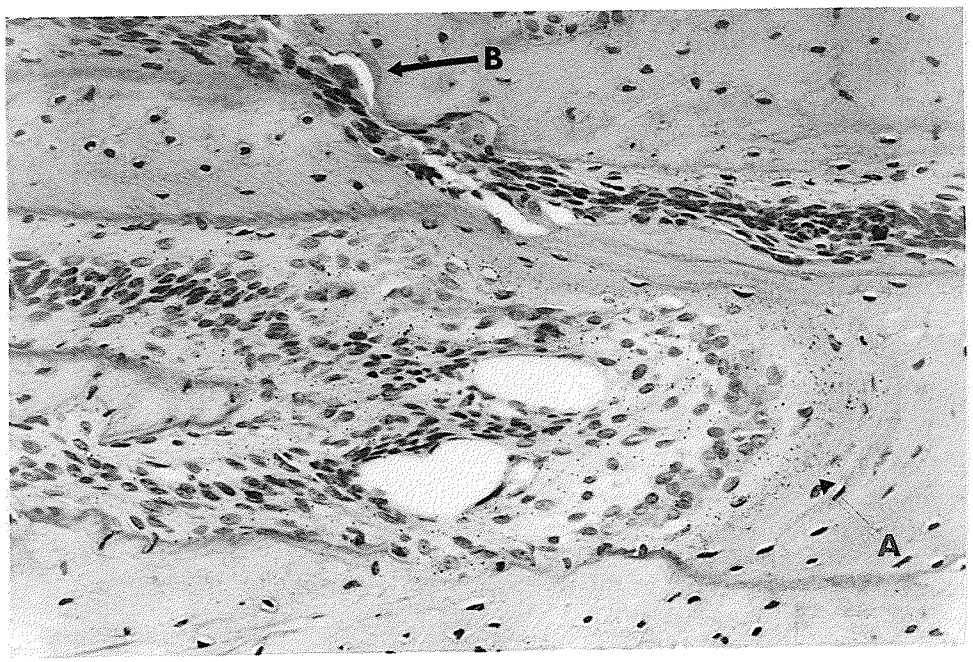

Figure 51. High power photomicrograph showing larger number of silver grains located over new bone tissue (A), as compared to the control animal (Figures 20, 21.). Also note the lack of silver grains in areas of resorption (B). (X400)

The histological analyses were supported by evidence from the undecalcified sections and the soft x-ray radiographs. In addition, the autoradiographs showed increased collagen formation, and an increase in the rate of bone deposition.

IV. ANALYSIS OF THE 7-DAY EXPERIMENTAL ANIMAL

The third experimental animal was sacrificed following 7 days of maxillary expansion (Table I). A number of gross changes could be seen at this stage. From the study models, taken before and after expansion therapy, it was observed that there had been an approximate 2 millimeter increase in the intermolar width between the maxillary first permanent molars. There had been, however, no significant change in the intermolar width in the mandible (Table II).

Examination of the occlusal radiographs showed that separation of the maxillae had occurred at the intermaxillary or midpalatal suture; a defect between the two bones could be seen. The interpremaxillary suture also showed some mild separation at its posterior end. No changes were observed in the other sutures of the palate when compared with the control animals (Figure 52.).

The histological findings indicated that a substantial separation of the bones had taken place in the main part of the midpalatal suture. There were a number of blood vessels present in the suture, but the vascular response, in general,

Figure 52. Occlusal radiograph showing opening in the mid-palatal suture, and the posterior end of the interpremaxillary suture (arrows). (X3)

was not as marked as in the 4-day experimental animal. The sutural connective tissue appeared much less dense than in the previous animals and presented a very stretched appearance. In some areas, however, there was compression of the sutural connective tissue (Figure 53.). Generally, the separation was more marked at the palatal side of the suture than at the nasal side (Figure 54.).

More posteriorly in the intermaxillary suture, the bones showed some separation, but not to the extent of the more anterior areas. However, the sutural connective tissue indicated the same extreme stretching of the fibres with some areas of compression present (Figure 55.). Fractured processes were often observed (Figures 53, 54, 55.); also, there appeared to be a mild inflammation and exudate present in the sutural connective tissue.

Under higher power, the connective tissue fibres proved to be very stretched and to be almost always stretched in a lateral direction. It was difficult to determine subjectively whether or not there had been an increase in the number of cells, but this was considered very likely (Figure 56.).

The bone tissue reaction was almost complete deposition. Osteoblasts were seen lining the edges of all the bony processes. In particular, the ends of the processes and the recessed areas, showed very large amounts of bone deposition (Figure 57.). Osteoclastic activity was noted, but only in

Figure 53. Photomicrograph of midpalatal suture showing the degree of separation of the maxillary bones. (X60)

Figure 54. Photmocrograph of nasal side of suture, of the same section as figure 53. Note the less marked separation of the bones. (X60)

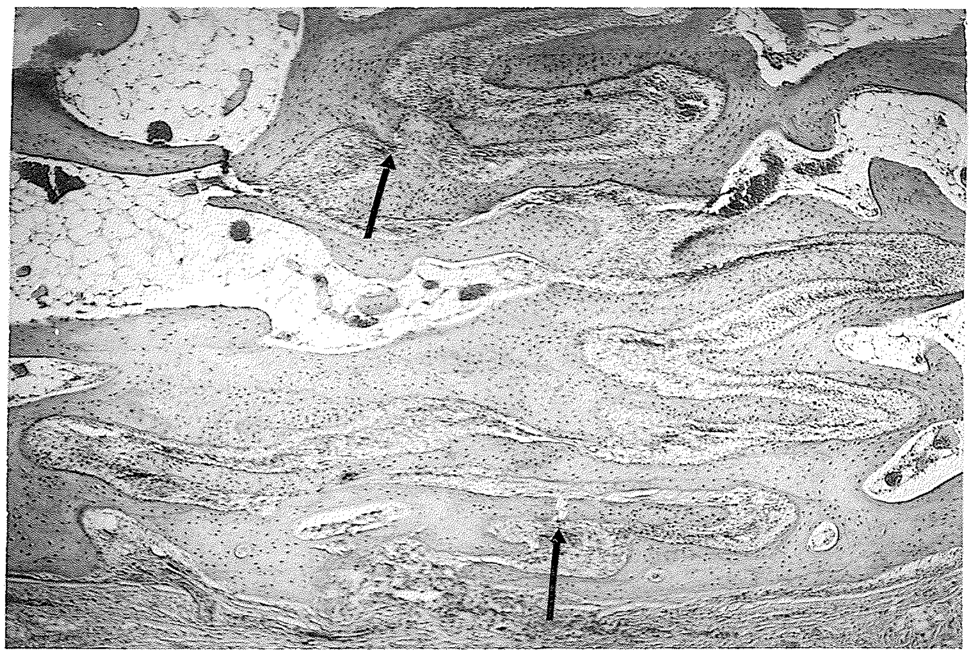

Figure 55. Photomicrograph showing more convoluted area of midpalatal suture, with somewhat less separation of the bones. Also note the fractured processes (arrows). (X60)

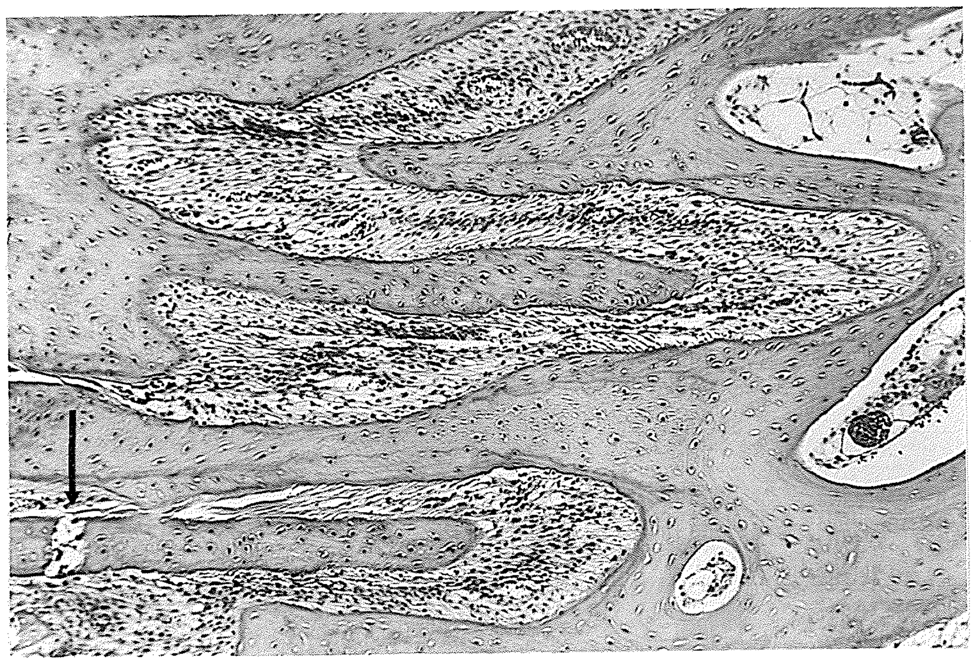

Figure 56. Photomicrograph of midpalatal suture to demonstrate the stretching of the connective tissue and the large number of connective tissue cells. Also observe the fractured process (arrow). (X150)

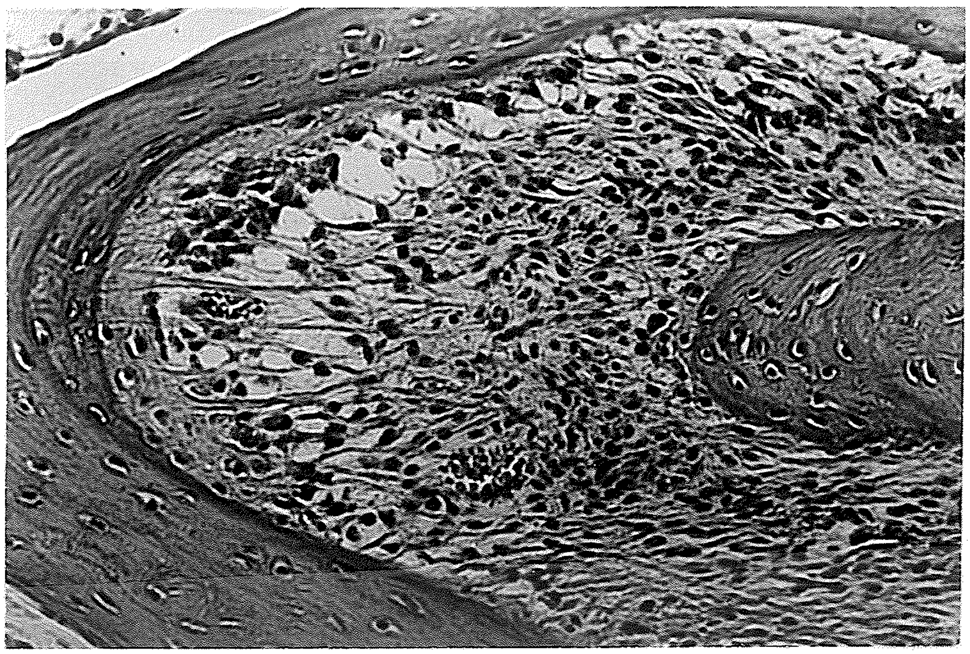

Figure 57. High power photomicrograph showing the large amount of bone deposition taking place in this animal. (X400)

a few isolated areas where connective tissue compression had occurred (Figure 58.).

A similar, but less severe result, was seen in the interpremaxillary suture. The sutural connective tissue appeared somewhat stretched, but not to the extent seen in the midpalatal suture. Some blood vessels were evident, but the vascularity was not marked. Bone deposition was the predominant activity, with numerous osteoblasts lining the bone (Figure 59.).

The premaxillary-maxillary and maxillo-palatine sutures appeared much as they did in the 24 hour and 4 day experimental animals. The laterally moving maxilla produced alternate rows of stretched and compressed connective tissue in the sutures with concomitant osteoblastic and osteoclastic activity. However, there was a large increase in the vascularity in these sutures, particularly in the maxillo-palatine suture (Figure 60.).

Separation of the bones had occurred at the interpalatine suture as well, but not to the extent of the midpalatal suture. Although the sutural connective tissue was quite stretched in many areas, there did not appear to be any marked vascular response (Figure 61.). Bone deposition was the dominant reaction along the bony processes. Only a few isolated areas of osteoclastic activity could be seen (Figure 62.).

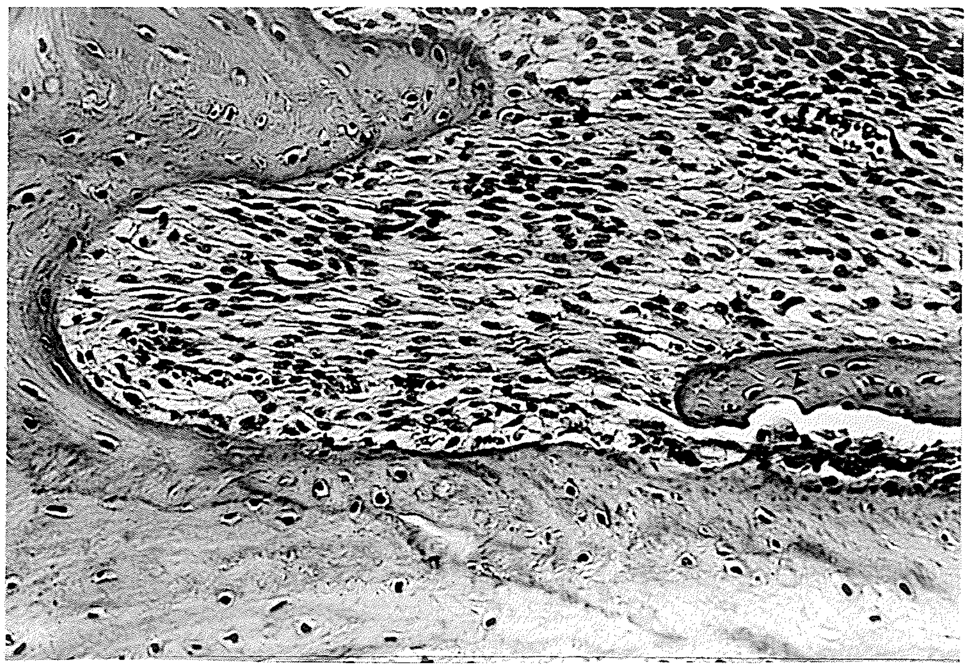

Figure 58. High power photomicrograph illustrating an isolated area of osteoclasis (arrow). Again note the heavy bone deposition. (X400)

Figure 59. Photomicrograph of interpremaxillary suture. Observe the mild stretching of the connective tissue, and the predominance of osteoblastic activity. (X150)

Figure 60. Photomicrograph of the maxillo-palatine suture. The alternating regions of stretching and compression are evident. Maxilla is moving in the direction of the arrow. (X150)

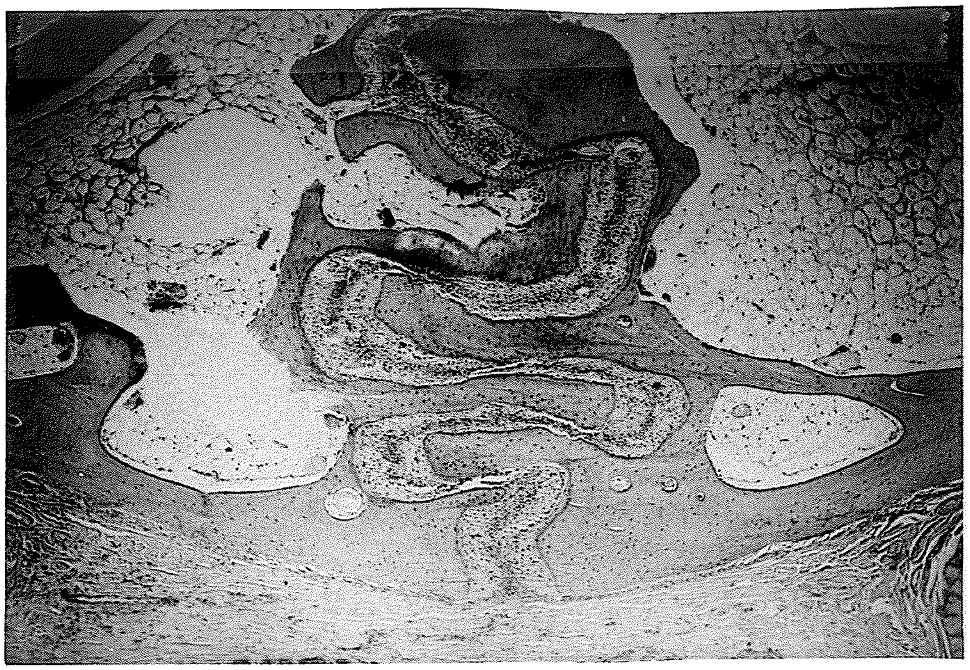

Figure 61. Photomicrograph showing the degree of separation of the bones in the interpalatine suture. (X60)

Figure 62. High power photomicrograph of the interpalatine suture. Note the stretched connective tissue, and the predominance of osteoblastic activity. (X400)

Examination of the teeth and periodontium indicated that buccal tooth movement was occurring. However, the pattern of resorption and deposition seen on the alveolar bone, and the concomitant stretching and compression of the periodontal ligament, suggested that the movement was a tipping movement. On the buccal side of the roots, compression of the periodontal ligament and alveolar resorption were seen near the alveolar crest; and periodontal ligament stretching with bone deposition were seen toward the root apex. The reverse picture was seen on the lingual or palatal side of the roots (Figure 63.). No cementum or dentin lesions could be seen.

Further substantiation of the histological findings was given by the undecalcified sections. The degree of separation of the bones was easily observed on these sections. They showed that the suture had opened more at the palatal side than at the nasal side. The tetracycline labels were not seen clearly in some areas, probably due to resorption at an earlier stage of expansion (Figure 64.).

The soft x-ray radiographs gave additional corroboration to the histological evidence. A relatively large midline radiolucent defect was seen toward the palatal side of the suture. Again, less separation of the bones had taken place toward the nasal side of the suture (Figure 65.). Along the bony edges of the suture, the bone appeared less well

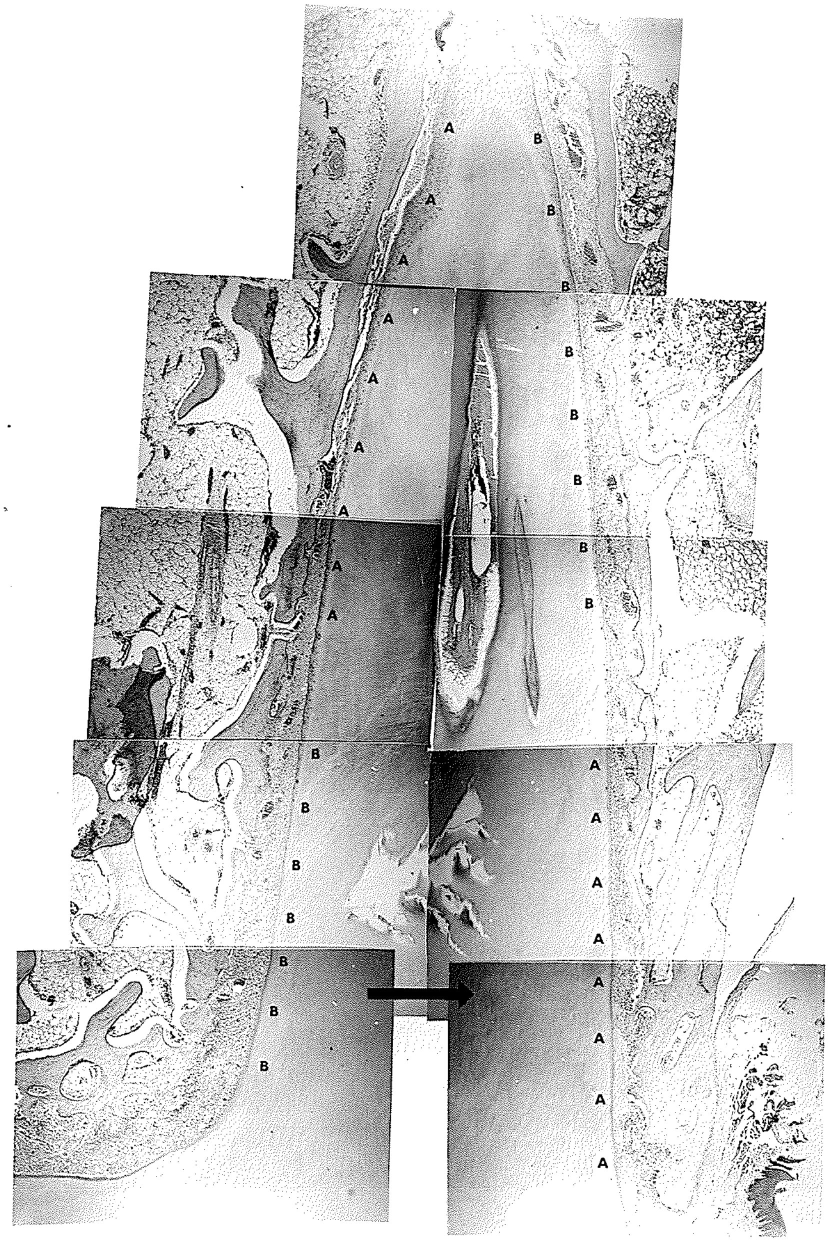

Figure 63. Composite of low power photomicrographs of the entire root of a tooth. Areas of periodontal ligament compression and bone resorption (A), with stretching of the ligament and bone deposition (B) indicate the tooth is tipping. Arrow represents the direction of force. (X60)

Figure 64. Photomicrograph of an undecalcified section of the midpalatal suture of the 7 day experimental animal, as seen with ultra-violet light. Observe the degree of opening of the suture. (X150)

Figure 65. Soft x-ray radiograph of the midpalatal suture of the 7 day experimental animal. Observe that the bony defect is greater at the palatal side than at the nasal side. (X4)

mineralized than in the earlier experimental animals, which indicated that new bone was being deposited (Figure 66.). Even areas of the suture where the bones had not been separated to as great an extent, large amounts of less well-mineralized new bone could be distinguished (Figure 67.).

This animal did not receive an injection of H^3-proline, thus autoradiographs were not prepared.

In summary, the third experimental animal, sacrificed 7 days after the commencement of maxillary expansion, showed very different findings when compared to the control animals and to the earlier experimental animals. On a gross level, widening of the maxillary arch at the molar area was demonstrated from the study models. Furthermore, the occlusal radiographs showed opening of the intermaxillary suture, and the posterior portion of the interpremaxillary suture.

Histologically, the main portion of the intermaxillary suture showed a relatively large separation of the bones; the more posterior portion of that suture was not opened to the same extent. The vascular response was greater than in the control animals, but had subsided somewhat in comparison to the 4 day experimental animal. The sutural connective tissue appeared very cellular, but less dense, in that it was extremely stretched in many areas. Osteoblastic activity was most predominant on the bony edges of the suture. However, small isolated areas of resorption were seen. An exudate

Figure 66. Photomicrograph of soft x-ray radiograph. Note the less well mineralized spicules of new bone in the area of greatest cellular activity. (X60)

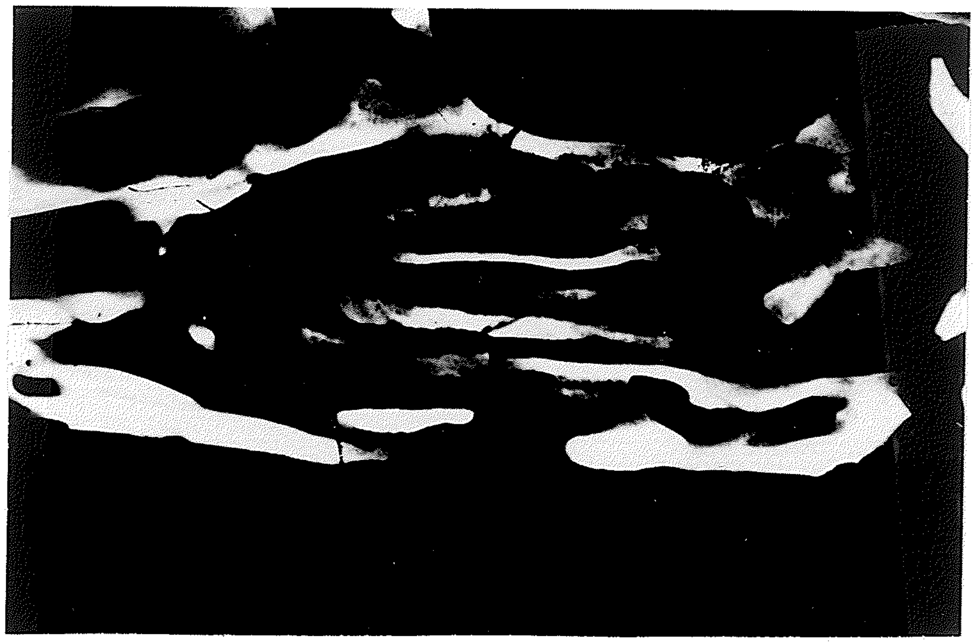

Figure 67. Photomicrograph of soft x-ray radiograph. Observe that although the bony defect is not as large as in figure 66, there are still numerous areas of less well mineralized new bone. (X60)

and some minor inflammation could be seen in the region of the sutures.

At the interpremaxillary and interpalatine sutures, separation of the bones and bone deposition were observed, but not to the extent of that in the intermaxillary suture.

The premaxillary-maxillary and maxillo-palatine sutures showed the combination of resorption and deposition seen in the earlier experimental animals.

Findings from the undecalcified sections and from the soft x-ray radiographs served to corroborate the histological observations.

V. ANALYSIS OF THE 14-DAY EXPERIMENTAL ANIMAL

The fourth experimental animal was sacrificed 14 days after the beginning of maxillary expansion (Table I). Again, gross changes were observed when compared with the control animals.

When the pre-expansion and post-expansion study models were examined, it was seen that there had been approximately a 3 millimeter increase in intermolar width at the level of the maxillary first permanent molars. However, there had still been no increase in the mandibular intermolar width (Table II).

The occlusal radiographs indicated a disruption and separation in the intermaxillary suture. However, the defect was not as great as in the 7 day experimental animal. This animal showed separation of the bones through the entire length of the interpremaxillary suture, and some slight separation was noted in the interpalatine suture. No gross changes could be seen in the remaining palatal sutures (Figure 68.).

In the histological sections, it was observed that in the main part of the intermaxillary or midpalatal suture, there was a relatively moderate separation of the bones. This opening was larger than in the first and second experimental animals, but was no larger than in the 7 day experimental animal. There did not appear to be any increase in vascularity when compared with the control animals. The sutural connective tissue seemed to be extremely cellular, and areas of compression or hyalinization of the connective tissue were rare. As in the 7 day experimental animal, the sutural defect was greater toward the palatal side than the nasal side (Figure 69.).

Toward the posterior end of the midpalatal suture, the general morphology of the suture was more complex or more convoluted. The amount of separation of the bones did not seem to be as great as that in the more anterior sections. However, the sutural connective tissue was still very cellular, and areas of compression or hyalinization were not generally present. Blood vessels were present, as before,

Figure 68. Occlusal radiograph showing disruption and opening of the intermaxillary, interpremaxillary and part of the interpalatine sutures (arrows). (X3)

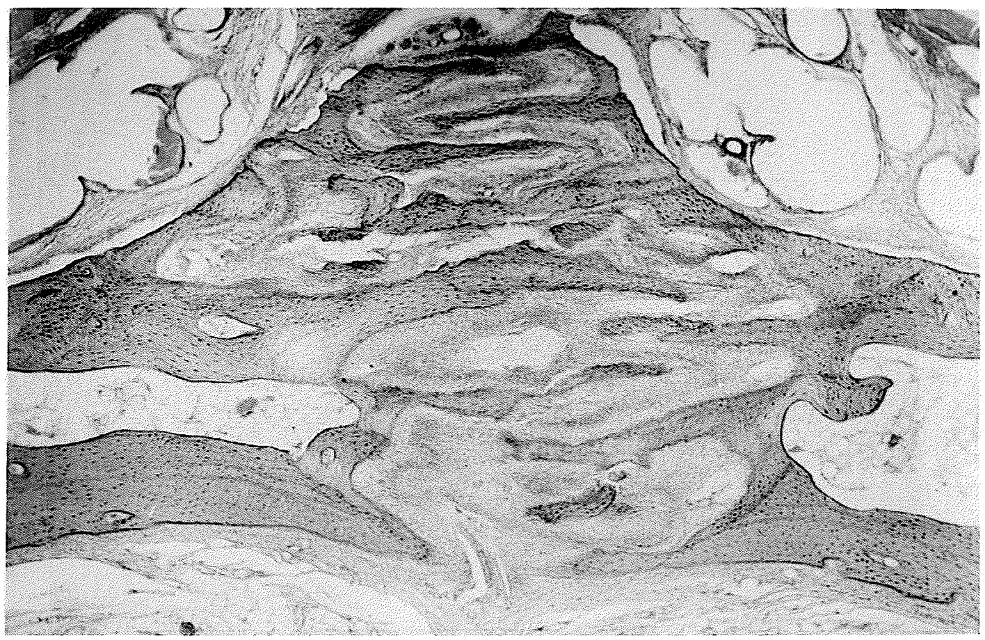

Figure 69. Photomicrograph showing the degree of bone separation in the midpalatal suture. Note that the defect is greater toward the palatal side than at the nasal side. (X60)

but the response was not marked (Figure 70.). Generally, there were no fractured processes observed, nor was there any haemorrhage or inflammation observed in the suture region.

Although it appeared stretched in many areas, on closer examination the sutural connective tissue proved to be generally quite disorganized. Also, it seemed as if there had been an increase in the number of connective tissue cells in the suture (Figure 71.).

Judging by the irregularity of the bony processes (Figure 69, 70, 71.), the amount of osteoid and the number of resting lines (Figure 72.), and the predominance of osteoblasts lined up along the edges of the bone (Figure 73.), it appeared that very heavy bone deposition was taking place at this stage.

Some isolated areas of osteoclastic activity were noted. These areas were not seen frequently, but there were perhaps more seen in this animal than in the 7 day experimental animal (Figure 74.).

From the histological sections, the interpremaxillary suture did not show a large amount of separation of the bones. Nor was there any marked vascular response. However, the sutural connective tissue appeared very cellular and, in most areas, quite stretched. As in the intermaxillary suture, the number of resting lines and the number of osteoblasts along

Figure 70. Photomicrograph of the more posterior portion of the midpalatal suture. Observe that the defect is not as great as in the more anterior region. (Compare with figure 69.) (X60)

Figure 71. Photomicrograph showing the highly cellular, disorganized connective tissue. Note the extent of bone deposition. (X150)

Figure 72. Photomicrograph of midpalatal suture. Note the new osteoid tissue (A), and the resting lines in the bone, where two new processes have been deposited (B). (X150)

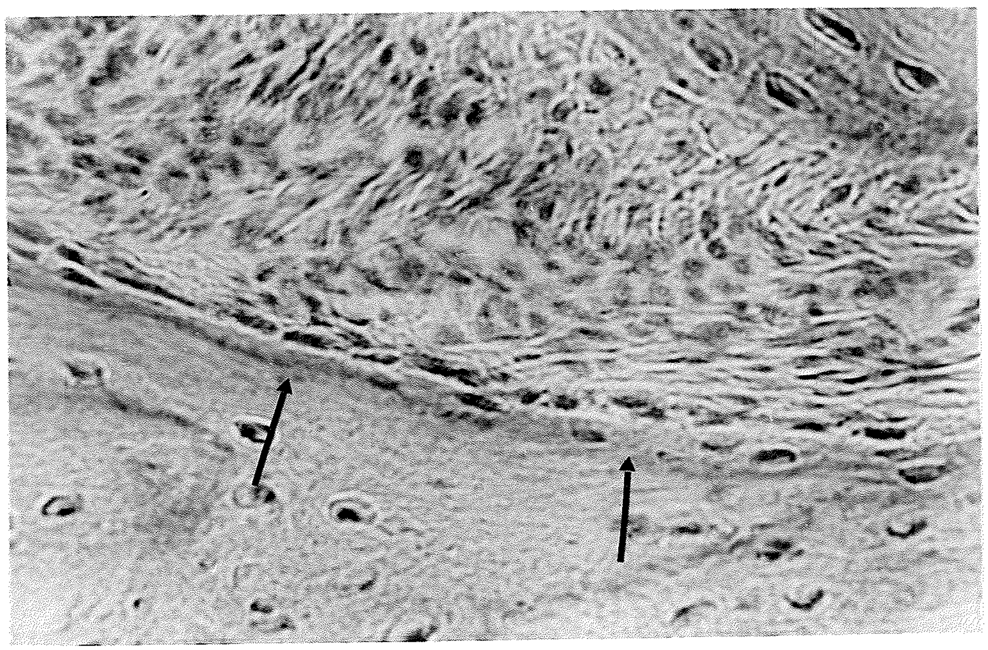

Figure 73. High power photomicrograph showing osteoblasts lined up along the edge of the bone (arrows). (X960)

Figure 74. High power photomicrograph showing an isolated area of osteoclastic activity (arrow) amid regions of bone deposition. (X400)

the edges of the bones, indicated the probability that heavy bone deposition was occurring (Figure 75.). Osteoclastic activity was rarely seen in this suture.

At this stage of expansion, the premaxillary-maxillary and maxillo-palatine sutures showed a different picture from that seen in the earlier experimental animals. No longer did the sutural connective tissue present alternate areas of stretching and compression. Rather, generally it appeared to be somewhat disorganized, but slightly stretched in some areas, and there were numerous blood vessels present. Some osteoclastic activity could be observed, but bone deposition would seem somewhat more predominant (Figure 76.).

The interpalatine suture showed some degree of separation of the bones, but this was not marked. No areas of compression or hyalinization of the connective tissue were seen, and there had been no increase in vascularity (Figure 77.). The connective tissue appeared very cellular and stretched in many areas. Osteoblastic activity was predominant and heavy as in the other sutures. Some isolated areas of osteoclastic activity could be seen (Figure 78.).

Examination of the teeth and periodontal structures revealed that tooth movement was no longer a tipping movement as it had been in the 7 day experimental animal. Rather, it appeared to be bodily movement in a buccal direction. The buccal surface of the roots showed compression of the perio-

Figure 75. Photomicrograph of the interpremaxillary suture. Observe the stretched sutural connective tissue, and the osteoblastic activity. (X150)

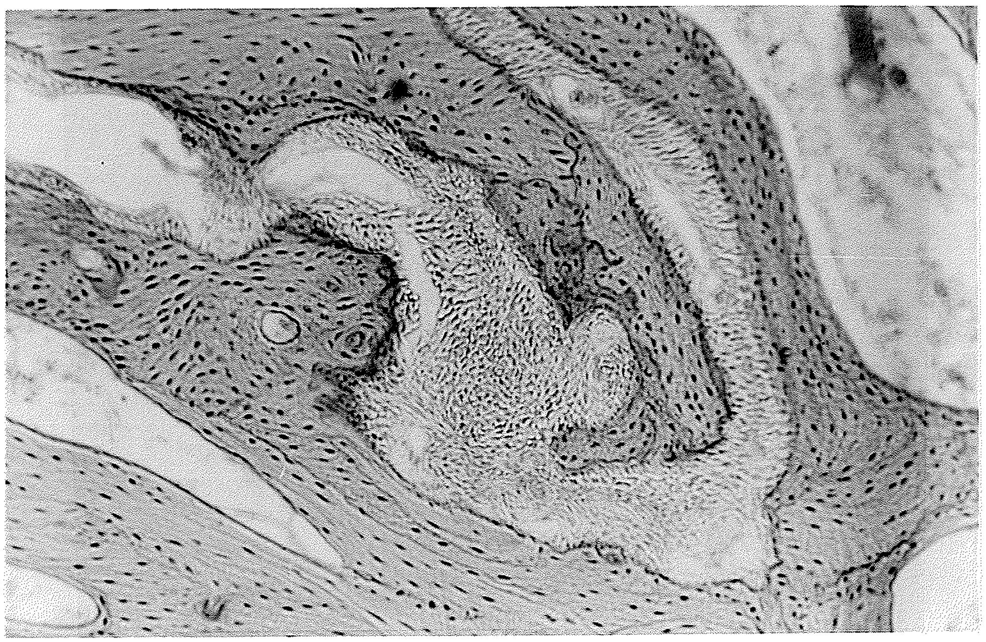

Figure 76. Photomicrograph of the premaxillary-maxillary suture. Note that bone deposition is now predominant as compared to the earlier experimental animals. (Compare with figures 28, 43, 60.) (X150)

Figure 77. Photomicrograph of the interpalatine suture. Observe the relative separation of the bones. (X60)

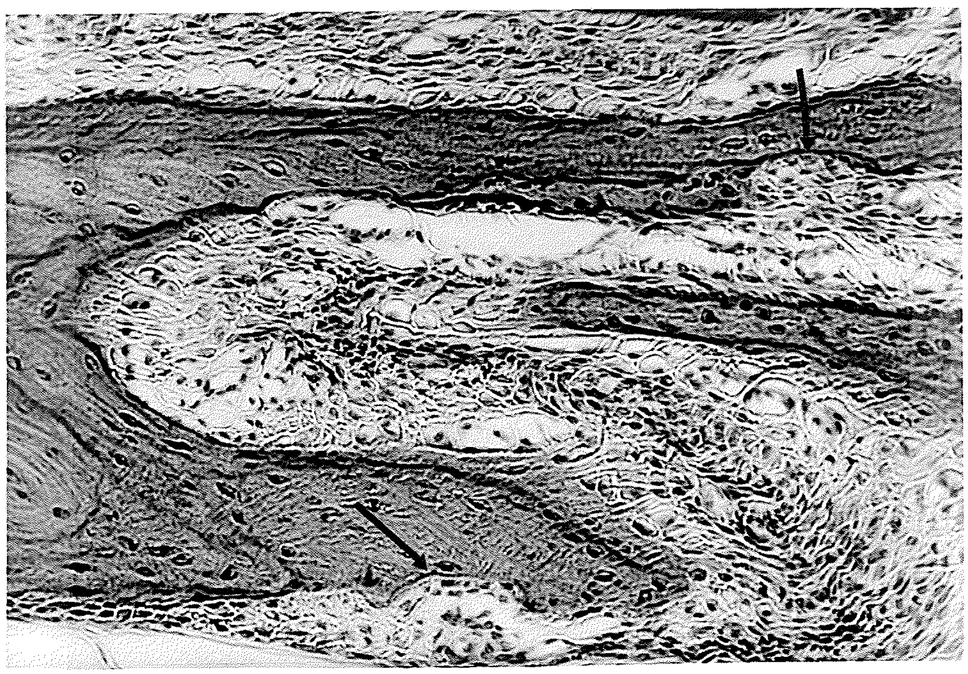

Figure 78. High power photomicrograph of the interpalatine suture. Observe the isolated areas of resorption (arrows) amid a predominance of osteoblastic activity. (X400)

dontal ligament and resorption of alveolar bone along the whole length of the root. Some areas of the periodontal ligament had become hyalinized. Conversely, the lingual side of the roots showed extreme stretching of the periodontal ligament and bone deposition. Occasionally, small cementum lesions could be seen (Figure 79.).

The undecalcified sections confirmed that some separation of the bones had taken place. Most of the tetracycline marker, injected two weeks before sacrifice (Table I), had been removed by resorption at some earlier stage in the expansion therapy. Consequently, it was difficult to determine the extent of new bone formation from these slides (Figure 80.).

In the soft x-ray radiographs, the separation of the bones appeared as a relatively large radiolucent midline sutural defect. This defect was much greater at the palatal side than at the nasal side (Figure 81.). While many areas of much less well mineralized bone could be discerned (Figure 82.), some bony edges of the suture were quite distinct and well mineralized. In comparing the size of the defects observed in the spectroscopic plates and in the histological sections of the animal, the indications are that heavy osteoblastic activity is occurring. However, mineralization of the tissue has not occurred quite so rapidly.

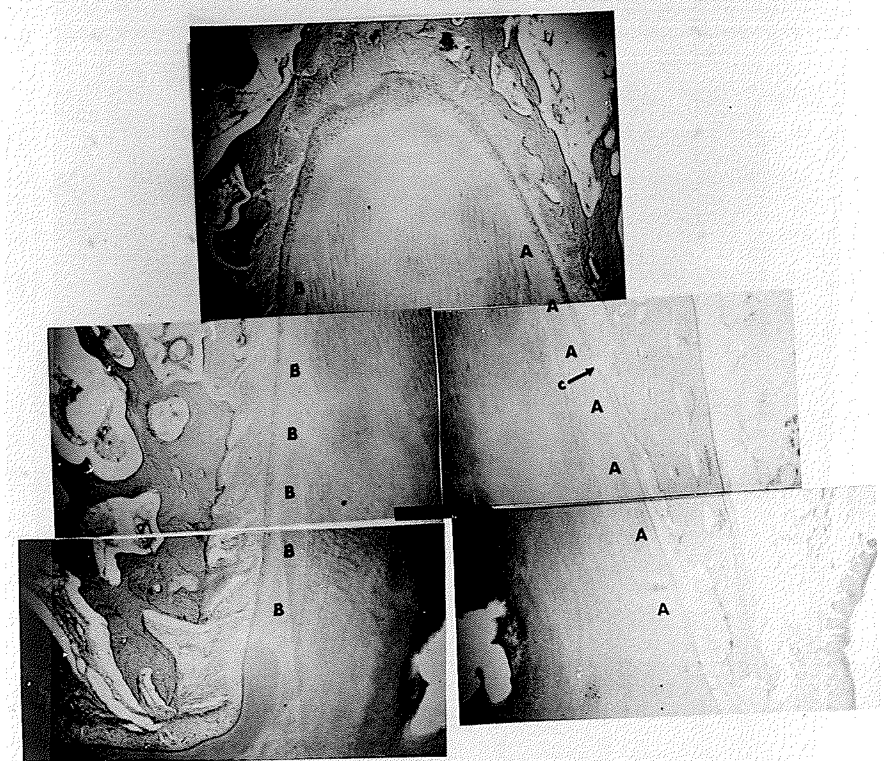

Figure 79. Composite photomicrograph of the root of a tooth. Note the compression of the periodontal ligament and bone resorption (A) on the buccal side and ligament stretching and bone deposition (B) on the lingual side. Also observe the cementum lesion (C). Tooth is moving in the direction of the arrow. (X60)

Figure 80. Photomicrograph showing the undecalcified midpalatal suture as seen with ultra-violet light. Observe the degree of separation of the bones, and the lack of tetracycline marker in the suture. (X150)

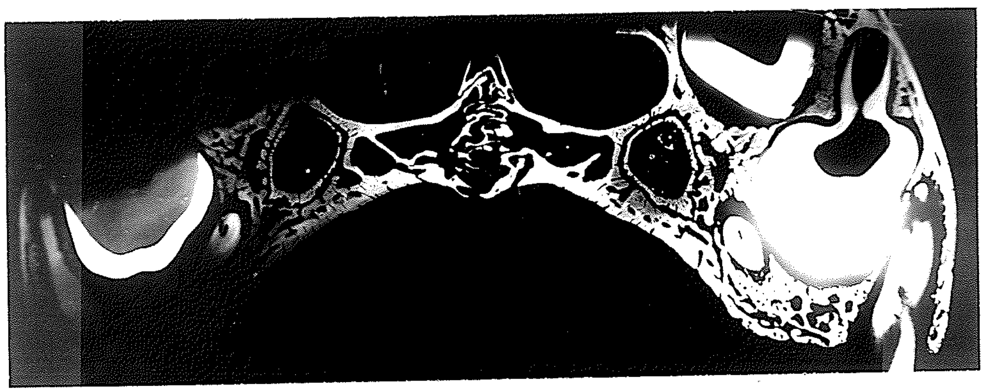

Figure 81. Soft x-ray radiograph of the 14 day experimental animal. Observe that the defect is greater at the palatal side than at the nasal side. (X4)

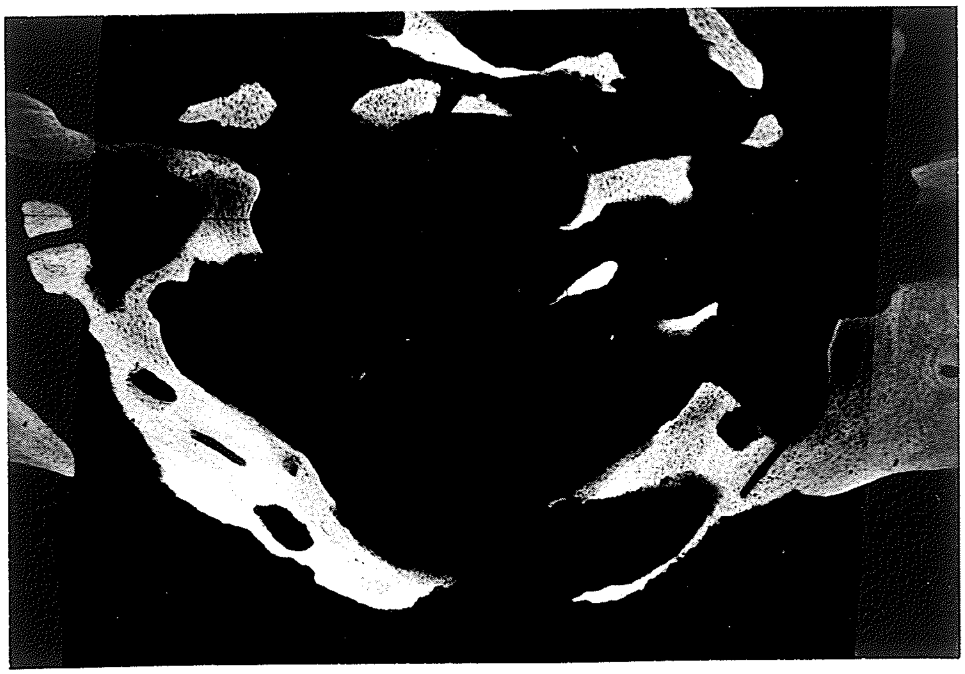

Figure 82. Photomicrograph of soft x-ray radiograph. Observe the spicules of less well mineralized bone. (X60)

This animal did not receive an injection of H^3-proline; hence, autoradiographs were not prepared (Table I).

In summary, the fourth experimental animal, after 14 days of maxillary expansion therapy, showed a number of differences when compared to the control animals and the earlier experimental animals.

Grossly, the study models showed a 3 millimeter increase in maxillary intermolar width. There was no indication of change in the mandibular intermolar width. From the occlusal radiographs, gross changes were seen in the midpalatal, interpremaxillary and interpalatine sutures, yet no changes were seen in the remaining palatal sutures.

From the histological sections, a moderate separation of the bones was observed particularly in the anterior portion of the midpalatal or intermaxillary suture. There appeared to be no increase in vascularity, no haemorrhage and no inflammation.

The sutural connective tissue seemed to be highly cellular, disorganized in many areas, and stretched in some areas. Very few regions of connective tissue compression or hyalinization were observed.

Bone activity was predominantly osteoblastic and was very heavy in most areas. However, some isolated regions of bone resorption could be seen. A similar reaction was seen in all the remaining sutures of the palate, but not to the extent seen in the midpalatal suture.

As indicated by the pattern of resorption and deposition in the alveolar bone, tooth movement was shown to be bodily movement in a buccal direction.

The undecalcified sections, as well as the soft x-ray radiographs, confirmed that the suture had been opened. Also, the soft x-ray radiographs indicated that mineralization of the bone was not occurring as rapidly as matrix deposition.

CHAPTER V

DISCUSSION

The technique of rapid maxillary expansion, used in modern Orthodontic practise differs very little from the technique used in this investigation. In fact, the appliance is identical. The main difference is the sequence of activation of the appliance. It has been stated previously that Derichsweiler (1957) and Haas (1961) each suggested different activation sequences for the human.

In this study, the activation sequence chosen was a combination of the suggestions made by the above-mentioned authors. Using Derichsweiler's ratio of 2:1 for man:monkey, the sequence was approximately half the number of activations suggested by Haas for humans. It was felt that, since the monkey is a much smaller animal than man, a stronger activation sequence would not be well tolerated. Also, it was desirable to produce proportionately the same effect in the monkeys which would be produced clinically in humans.

The results of this investigation showed that the midpalatal suture was opened during rapid maxillary expansion, which confirmed previous studies. The actual mechanism of splitting the suture would appear to be a combination of physical separation of the bones and heavy bone resorption.

Within the first 24 hours after commencing rapid expansion, there had been no apparent change in the bone tissue reaction when compared with the control animals. However, the sutural connective tissue had become quite disorganized in appearance and had lost much of the fibre orientation pattern seen in the control animals.

It is probable that the connective tissue fibres were adapting to the new force which had been applied via the appliance. Moreover, judging by the lack of change in the bone reaction, it is apparent that the cellular elements had not been able to differentiate in so short a period of time.

After 4 days of expansion, the connective tissue had reorganized to some extent and was stretched in many areas which indicated that some separation of the bones was beginning. There had been an increase in the amount of connective tissue, and the cellular elements had differentiated predominantly into osteoclasts. This was apparent by the large amount of resorption taking place. However, some bone deposition was evident.

It was between the fourth and seventh days of expansion that the actual opening of the suture had taken place. As stated previously, this probably occurred due to physical separation of the bones as well as to bone tissue resorption.

The physical separation was not extreme, since no connective tissue-tearing and only minor haemorrhage and inflammation were observed in any of the animals.

From clinical investigation on human patients, it has been found that, during expansion, they experience no pain in the palatal area. This would be a good indication that little or no tissue-tearing, haemorrhage or inflammation had occurred. Thus, the findings in this study were corroborated.

After 7 days of expansion, a definite bony defect could be seen in the midpalatal suture area. This defect was observed to be much greater at the palatal side of the suture than at the nasal side. The sutural connective tissue was very stretched in appearance. The reaction in the bone tissue was one of almost total deposition.

From the evidence it would appear likely that the resorption reduced the size of the bony processes to allow them to separate more freely. Once the processes could move past one another without interference, the bone reaction changed to deposition.

At the 14 day stage of expansion, the defect in the midpalatal suture was not significantly larger than the defect observed in the 7 day animal. However, gross evidence of separation could now be seen in the interpremaxillary suture, in the interpalatine suture and in the midpalatal (intermaxillary) suture.

In spite of the fact that the suture was shown to open in this investigation, the degree of opening after 14 days of expansion was not nearly as extensive as was previously reported by Cleall et al (1965). Since Cleall and his co-workers did not describe the number or timing of their turns of the screw, a possible explanation for the different findings could be the result of different activation sequences. Further study would be required to determine whether or not different activation sequences significantly alter the degree of suture opening.

Derichsweiler (1957) has shown differences in suture opening with different activation sequences, but his experiments also involved differing periods of time.

In addition, it must be borne in mind that the 14 day experimental animal lost its appliance at some point during the 24 hours immediately preceeding sacrifice. Consequently, it must be assumed that some relapse occurred during this period. It is impossible, however, to determine the extent of this relapse.

Since, in the experimental situation, the maxillary dentition in the monkey is being moved from a "normal" relationship to one of buccal crossbite, the relapse from this unphysiologic position may be great. On the other hand, when maxillary expansion is applied to the human, it is done to move the maxillary arch from a constricted position to a more ideal position.

From the results, it can be hypothesized that bone deposition prevented the bony defect from becoming extensive. It was shown that, by the seventh day of expansion, the bone reaction was predominantly osteoblastic. By 14 days of expansion, the bone tissue continued to show heavy deposition. Therefore, it is possible that rapid deposition was occurring in order to keep abreast of the expansion and to maintain the integrity of the sutural morphology as much as possible. Moreover, as the animals used in this study were young and in a period of active growth, they had the potential to react rapidly to the expansive force. Similarly, in the human situation, it is deemed advisable to engage in maxillary expansion at a time when the child is actively growing.

The changes observed in the interpremaxillary and interpalatine sutures were much less severe than the changes seen in the midpalatal (intermaxillary) suture. No gross evidence of opening of these sutures was noted until the seventh to fourteenth day of expansion, and the degree of opening was significantly less than that which had occurred in the midpalatal suture. Generally, bone deposition was the predominant reaction observed in these sutures.

The reactions seen in the premaxillary-maxillary and maxillo-palatine sutures would seem to indicate that these sutures are adjustment sites which disallow a greater opening in the interpremaxillary and interpalatine sutures.

As the maxillary halves are moved laterally, they encounter the resistance offered by the premaxillae and palatine bones at the premaxillary-maxillary and maxillo-palatine sutures. This was observed in the pattern of alternate resorption and deposition seen in these sutures. Once the resistance to separation of the two halves of the premaxilla and palatine bones had been overcome; that is, when some slight degree of suture opening had taken place, the pressure exerted in the premaxillary-maxillary and maxillo-palatine sutures was relieved and the severe reaction at these sutures was no longer noted. This had occurred at some point between 7 and 14 days of expansion. However, it is probable that some degree of adjustment continues at these sutures for the duration of any further expansion. The degree of the adjustive bone reactions would be much less severe.

Since the human lacks a separate premaxilla at this stage of development, the main resistance to expansion in the palatal area would be from the palatine bones at the maxillo-palatine suture. This could be a possible explanation why the human midpalatal suture opens in a "V" shaped manner in the earlier stages, with the widest part of the

"V" towards the anterior. In the later stages, when the resistance of the palatine bones has been overcome, the suture opening becomes equal throughout the length of the palate. This type of initial "scissor-like" opening, and later parallel opening, has been reported by Haas (1959), Timms (1969) and Wertz (1970).

Also, the attachment of the maxilla to the other bones of the face results in a greater resistance at the posterior of the maxilla than at the anterior. In the anterior, and at the fronto-nasal suture area, the two maxillae articulate with each other. However, in the posterior, the maxillae are buttressed by the zygomatic bones, which in turn articulate with the frontal and temporal bones.

Previous studies have shown that reactions occur at all these sutures (Starnbach et al, 1965). Therefore, it is likely that this additional resistance at the posterior of the maxilla is responsible for the "V" shaped opening of the midpalatal suture. Zimring and Isaacson (1965) feel that these facial sutures constitute the major resistance to maxillary expansion.

The monkey also has this additional buttressing of the posterior part of the maxilla. This might account for the fact that some gross opening of the interpremaxillary suture was noted by the seventh day of expansion, but opening of the interpalatine suture was not observed until the fourteenth day of expansion.

Similarly, the presence of the separate premaxilla in the monkey, and limited opening of the interpremaxillary suture, results in the absence of a transitory diastema between the maxillary central incisors. This temporary, self-correcting diastema has been the classical sign of suture splitting in the human.

Debbane (1958) showed, however, a "V" shaped splitting of the suture through the premaxilla and the anterior portion of the maxilla in his experiments on cats. As a result of expansion, he failed to find any changes in the palatal portion of the premaxillary-maxillary suture. These results can be accounted for since his simple spring appliances were applied across the cuspid area in the anterior of the palate rather than across the maxilla in the intermaxillary suture region.

From the histological findings in the periodontal ligament and alveolar bone, it was evident that some tooth movement was taking place. However, as Haas (1965) has remarked, it is doubtful that much tooth movement could occur in so short a period of time.

The patterns of periodontal ligament compression and stretching, with the respectively concomitant patterns of alveolar bone resorption and deposition seen in the 7 day experimental animal, indicated that, up to that stage, tooth movement was primarily of a tipping nature with the crowns tipping buccally. By 14 days of expansion, the reactions seen in the periodontal ligament and alveolar bone indicated a bodily type of tooth movement in a buccal direction.

These results confirm the work of Cleall et al (1965) and Starnbach et al (1966), who also observed bodily tooth movement after 14 days of expansion. In addition, Starnbach found no statistically significant change in the axial inclinations of the buccal teeth which indicated a minimal tipping movement.

The reason for the change from a tipping movement to a bodily movement is uncertain but, generally, the type of tooth movement is dependent upon the magnitude and direction of the forces exerted; that is, the 'component of force'. A possible explanation could be due to the supero-lateral rotation of the maxillary halves. This rotation would result in a change in the direction of the force exerted on the teeth by the appliance.

The results of this investigation revealed that, even after 14 days of expansion, there had been no significant change in the mandibular intermolar width. Previous studies (Derichsweiler 1953, Thorne 1956, Haas 1961, Timms 1969, Davis and Kronman 1969) have all reported increases in the mandibular arch width following expansion therapy.

However, these studies were clinical studies on human material, and were continued well beyond the time used in the present study.

Since maxillary expansion is employed in humans to correct a narrowed or constricted maxilla, this condition has generally been present for a long period of time. Consequently, the mandibular dentition is trying to compensate for the decreased maxillary arch width. When expansion is employed and the maxillary dental arch is widened, the mandibular dentition can upright to its more normal physiologic position.

In experimental procedures on monkeys, the maxillary dentition is moved from a physiologically normal position to one of buccal crossbite. It is conceivable that it might require some time before the mandibular dentition attempts to compensate for this abnormal relationship. In recent investigations on animals (Derichsweiler 1957, Debbane 1958, Cleall et al 1965, and Starnbach et al 1966), no reports were given on any changes in the mandibular arch. However, it is interesting that Wertz (1970) also reported no change in the majority of his human subjects.

Examination of the undecalcified sections with ultraviolet light in order to observe the tetracycline bone markers, proved to be of only slight supportive value in this investigation. Turpin's (1968) suggested dose level was indeed adequate to mark the bone. However, his minimum interval of seven days between injections proved to be too short a period. As stated previously, the fourteen day interval between injections used in three animals in this study also proved inadequate to give two discernable marks in most areas of the bone.

The remodelling bone in the controls and 24 hour experimental animals picked up the tetracycline only randomly. After 4 days, the resorption process had removed most of the bone markers. Due to the changeable nature of the bone reactions, it was difficult to analyze the precise changes in these sections.

To use bone marking techniques with accuracy in order to investigate bone changes in the monkey, further study should be done which either allows longer time intervals between injections of the marking agent, or which employs a multiple marking technique, again with longer time intervals between injections.

The soft x-ray radiographs were a useful adjunct to the histological findings in the midpalatal suture region. They gave a graphic demonstration of the extent of the bony defect, and the variation in size of the defect between the palatal and nasal sides of the suture. More importantly, by comparing the relative degrees of radio-opacity, they showed the degrees of mineralization of the bone in the sutural area.

While it is generally conceded that the radiographic picture lags somewhat behind the histological findings, a simultaneous comparison of the two will elucidate any uncertainty in the radiographic evidence.

As seen in the 7 and 14 day experimental animals, the radiographic picture of less well mineralized bone could possibly indicate bone being decalcified or bone being deposited. However, the simultaneous histological findings show that heavy osteoblastic activity is taking place. Thus, the less well mineralized bone in the x-ray picture can be assumed to be newly forming bone.

Furthermore, when bone resorption takes place, it does so in "chunks" or lacunae rather than in a straight smooth line. Consequently, a radiographic picture could only be interpreted as bone resorption when the edges of the bone appear "scalloped", which was the case in the 4 day experimental animal.

The autoradiographic evidence from the second control animal and the 4 day experimental animal proved to be extremely useful in confirming parts of the histological evaluation in these two animals. From the histological picture, the impression was that there had been, when compared to the control animal, an increase in the amount of fibrous connective tissue in the suture of the 4 day experimental animal.

This was confirmed by the autoradiographs, which showed an increased number of silver grains located over the sutural connective tissue of the 4 day animal.

Furthermore, as there were a larger number of silver grains located over areas of new bone in the 4 day animal, it was ascertained that bone deposition, where present, was taking place in this animal at a more rapid rate than in the control animal.

As radioactive proline was not injected into 7 and 14 day experimental animals, the histologic interpretation of a further increase in collagen formation could not be confirmed. Further study with radioactive precursor elements would be most useful in determining both connective tissue proliferation and the rates and amounts of bone deposition in both control and experimental animals. Autoradiographic results also lend themselves to quantitative analyses.

Several comparisons have been made between the experimental findings in the monkeys and the clinical situation in humans. In general, it is not wise to extrapolate information from experimental animals to humans. However, in view of the basic similarity of the material and the technique, it may be assumed that the early reactions to maxillary expansion in the human would be reasonably similar to the reactions seen in the intermaxillary suture of the Rhesus monkey.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The present study was undertaken to determine the bone and connective tissue responses in the midpalatal suture during the very early stages of rapid maxillary expansion. The sample consisted of six female Rhesus monkeys in the early mixed dentition period; they consisted of two control animals and four experimental animals.

By means of a split acrylic jackscrew-type appliance, cemented to place with orthodontic bands, the four experimental animals were subjected to 24 hours, 4 days, 7 days and 14 days of rapid maxillary expansion.

Each animal received one or more injections of tetracycline. The 4 day animal and one control animal each received an injection of tritiated proline.

The animals were studied by means of pre- and post-expansion study models, occlusal radiographs, routine decalcified histological sections, undecalcified thin sections, soft x-ray radiographs and autoradiographs. The data was subjected to a qualitative analysis only. From this study, the following conclusions may be drawn:

1. As a result of the rapid expansion procedure, the midpalatal suture was opened. The point at which the suture split occurred in the period between

4 and 7 days of expansion. The bony defect was greater at the palatal side than at the nasal side of the suture which indicated a probable rotation of the maxillary halves.

2. The actual mechanism of opening the suture involved a series of distinct stages: a) a period of connective tissue adaptation as a result of the external forces applied, b) connective tissue proliferation combined with relatively heavy bone resorption to "free" the processes, and c) heavy bone deposition, with probable continued proliferation of connective tissue. The rapid bone deposition appeared to be an attempt to maintain sutural morphology.

3. The premaxillary-maxillary and maxillo-palatine sutures seemed to be adjustment sites which caused different rates of bone separation in the premaxilla and palatine bones, as compared to the maxilla. The activation sequence over a given period of time may also influence the degree of suture opening.

4. Maxillary arch width at the molars increased as expansion progressed, but no significant changes took place in the mandibular dental arch. The maxillary buccal dentition underwent a tipping movement during the first week of expansion but, by the fourteenth day, bodily tooth movement was

occurring.

5. The undecalcified sections, marked with tetracycline, proved to be difficult to analyze precisely. In order to accurately observe bone changes in the monkey by this method, longer intervals between injections and/or a multiple marking technique should be undertaken.
6. The soft x-ray radiographs were a useful adjunct to the histological findings. They indicated the relative size and location of the defect and the relative degree of mineralization of the bone.
7. The injection of radioactive proline and the autoradiographic technique, as used in this investigation, proved to be a useful confirmation of the histological interpretation of connective tissue proliferation.

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