Wertz further describes these movements as demonstrated on dry skull material. These findings were essentially the same as those of the clinical findings. A mixed dentition skull showed severe displacement of the maxilla from the nasal, frontal, and ethmoid bones. The vomer completely loosened and fell out. There was not the same degree of opening in an adult skull as the rigidity of the skull prevented opening beyond $22\frac{1}{4}$ turns of the screw. The maxilla still opened in a pyramidal manner, with the fulcrum of rotation close to the frontomaxillary suture. Wertz felt that the increasing resistance with age was not due to the resistance of the midpalatal suture, but to the increasing rigidity of the other maxillary articulations preventing maximum repositioning of the maxillary halves. He also suggests that clinically a reduction in the rate of expansion allowed for more successful opening probably by allowing more time for cellular adjustments at the other articulation sites. Furthermore, he felt that other undesirable compensations were probable, such as, increased extrusion of the teeth, a greater degree of bending of the alveolar process, and greater orthodontic tooth movement. Thus although orthodontic correction was achieved, the skeletal repositioning may be less than desired and the results less stable.

Kudlich (1974) also describes dry skull material. He concluded that, except for the sphenoid bone, all craniofacial bones directly articulating with the maxilla were displaced, the cranial base remained intact. Displacement of the maxillary halves was asymmetrical. The sphenoid bone, rather than the zygomatic arch, was the main buttress against maxillary expansion and although the amount of resistance to expansion in each skull varied, the basic patterns of displacement described previously were evident.

Wertz and Dreskin (1977) did a statistical review of expansion by a number of operators using a variety of appliances. On considering age effects they found that there was a decrease in the amount of expansion achieved in both the nasal cavity and maxillary width as age increased. Further, there was significantly greater relapse of maxillary skeletal gains in the older groups, whereas the younger groups had little or no change. Following retention, the maxillary width continued to expand in the younger group, due to resumption of normal growth, but contracted in the older group, probably due to uprighting of the overexpanded segments. The maxillary dentition showed major changes after appliance removal. Wertz and Dreskin found 30% relapse in younger patients and 70% relapse in the older group. They conclude that this highlights the need for overcorrection to allow for uprighting of buccally inclined teeth and relapse of alveolar bending. They further felt that subsequent extraction procedures and space closure would have contributed to the loss of gained arch width.

There have also been a number of computer analyses of the effects. Halpern (1970), describing anteroposterior radiographs, found significant coefficients of correlation occurred between mechanical suture opening compared to, transocclusal opening, apical base measurements, and increases in intermolar and intercanine widths.

Davis and Kronman (1969) felt that the anteroposterior radiographs did not produce significant results because of the unreliability of tracing structures. They felt that there was a need for metallic implants to clarify this type of investigation. This was suggested earlier by Isaacson and Murphy (1964) particularly in relation to nasal measurements and marked variability due to tissue engorgement.

White (1972) on the other hand found no change in interorbital widths;

there were significant increases in intranasal widths, midpalatal suture width, and appliance width. Angular changes indicated that expansion therapy produced identical mean differences of expansion on both sides of the maxilla with no significant deviations of the nasal spine and no significant changes in the position of the appliance except for the lateral expansion achieved.

A number of animal studies demonstrate additional bony movements. It must be remembered that the maxillae of these animals has been expanded from a normal situation to an abnormal one. In addition quite often very high forces are used. Brossman et al. (1973) used six quarter turns on insertion, followed by two quarter turns per day for eleven days. As Timms (1981) says, "these reactions are probably more extensive than you would see in a clinical situation". Brossman et al. include in their explanation of the movements achieved, the relative thinness and elasticity of individual parts of the affected area of the facial skeleton and that this is probably more exaggerated in the monkey experiments than it would be under clinical conditions.

Brossman et al. (1973) using four cynomalgus monkeys found that additional remodelling occurred, not only in the nasal cavity, the lateral alveolar processes, and inferior surface of the palate, but also the lateral and medial walls of the orbits. The roof of the orbits and thus the cranial base remained unchanged.

Walters (1975) used monkeys with implants placed either side of the midpalatal suture. From prepared sections, the appearance of widespread deposition of vital staining at growth sites throughout the face and calvarium, together with marked changes in the internal architecture of the nasal sinus complex suggest that a more pervasive remodelling of the face accompanies expansion of the maxillary arch than is usually emphasised. The general conclusions he reached include:

- Opening of the midpalatal suture induced an outward movement of the maxilla with superior rotation of the lateral borders.
- Other characteristic changes occurred such as, initial separation of the upper incisors, a widening, lowering, and flattening of the palatal vault, and enlargement of the intranasal space.
- Compensatory changes included bone growth at the midpalatal suture, and lateral expansion of the mandibular arch.
- Extensive remodelling of the midface was suggested by the increase in both width and height of the nasal sinus complex.
- Unlike human study reports, the expansion in the monkey induced posterior movement of the premaxillary segment with a loss of prominence of the face.

Hoffer and Walters (1975) using a split acrylic appliance found similar conclusions, but found that there was no evidence of premaxillary retrusion. The only difference between the two experimental methods was the type of appliance and its anchorage, the former being simple splints on the abutment teeth and the latter had the addition of palatal acrylic.

Gardner and Kronman (1971) again used Rhesus monkeys and the pattern of fluorescence of tetracycline stained bone under ultraviolet light to indicate the extent of bony remodelling during expansion. They found changes in the lambdoid, parietal and midsagittal sutures of the skull associated with maxillary expansion. In addition the sphenooccipital synchondrosis opened on all the experimental subjects. They concluded that the fluorescent tetrocycline clearly showed a stimulation of growth or remodelling in many bones in proximity to the midpalatal suture, the infra-temporal region of the maxilla, the greater wing of the sphenoid, zygomatic arch, pterygoid plates, and hamular notch. Again Timms' comment bears repeating: "those changes are probably more extensive than you would see in a clinical situation".

Support for this comment of Timms is confined to the description of gross bony movements during abnormal expansion and their comparison to similar human movements. The writer emphasises that he does not include all the animal studies in this comment. The histological studies of the midpalatal suture by Cleall and associates would seem to be a valid use of animal studies.

Timms (1981) describing the bony movements as the suture opens felt that because the maxilla articulates superiorly and posteriorly, the general movement may be likened to the opening of a fan. The most anterior and inferior points moving the greatest distance, with the fulcrum somewhere within the nasal airway. He later describes this fulcrum as being along a curved line superio-posteriorly with the movement increasing as it moves away from the cranial base. Krebs (1958), Brogan (1972), and Timms (1981) describe an age effect in relation to the fulcrum of rotation of the maxillary segments during expansion. They describe the resistance to expansion being due to the increasing resistance of the circummaxillary sutures, probably due to increased calcification. In young children the fulcrum of rotation may be as high as the fronto-maxillary suture, while in adolescence it is much lower, even to producing a pivoting effect where the area above the fulcrum in the frontal suture may move medially. Brogan (1972) from an unpublished seminar on rapid expansion (Timms, 1981) makes the observation that under five years of age, the fulcrum of rotation is very high, even producing a slight expansion of the orbits. Between five and eight years of age, the fulcrum is lower, probably somewhere in the ethmoid region. Over eight years of age it moved down into the nasal region.

Brogan (1977a) suggests another age-related effect. While he agreed with the triangular description of the sutural opening, he felt that in very young patients there was more true lateral development of the maxilla with little downward movement. Older patients with more rigid bone structures show a downward and possible forward movement. The downward movement is sufficient in some cases to straighten the nasal septum.

(iv) Palatal changes

Further discussion of the effects on the palate are necessary to clarify the palatal lowering effect described by Haas but not agreed with by a number of other authors.

Davis and Kronman (1969) split dental casts at the molar regions, superimposing the pre- and post-expansion models on graph paper. They found that as the suture opens the palate does not drop when analysed in this fashion. The problem is that they are relating the palate to the molar teeth which have also moved. Other cephalometric studies relate these structures to the cranial base. Wertz (1970) used Frankfurt horizontal as a reference line to establish that the palatal vault does move inferiorly.

Byrum (1971) did a cephalometric analysis of thirty cases treated with rapid palatal expansion involving a variety of malocclusions, both sexes, and an age range from eight to fourteen years. The data was subjected to a range of statistical tests. He showed that the maxilla did move inferiorly a significant amount, and while the maxillary first molar was carried with it, the molar itself exhibited only slight extrusion.

Starnbach et al. (1966), in animal experiments, describes the palate as being flattened with the palatal plates seeming to rotate about the midpalatal suture. Composite diagrams demonstrate an upward and outward swing of the lateral aspects of the maxilla to the central portion. For this to occur they accept that a considerable degree of reorientation of the bones of the facial complex would be required. Ohshima (1972) also observed lowering of the palatal process in monkeys, he also attributes this to the superio-lateral movement of the palatal process with a simultaneous inferior swing of the median margins. He felt that these bony movements created tensile forces from the tissue bands of the oral mucosa, leading to stimulation of the periostium and resulting in active bone deposition on the oral surface. He found that this reaction was predominant in the retention period of rapid expansion and during the expansion period of his slow expansion group. On the other hand, tissue remodelling reactions on the nasal side tended to restore the original vertical dimensions of the palate.

Linder Aronson and Ingram (1979) and Rinderer (1966) measured changes in palatal height by relating changes in the palatal vault to a plane drawn at the occlusal level of the molars, in Rinderer's case using Pont's measuring points. Linder Aronson and Ingram found no significant changes in the height of the palatal vault, while Rinderer using monkeys found that this height increased in seven cases, there was no change in two cases, and that it decreased in three cases.

Again I would repeat that I question the validity of those measurements that relate the palatal vault to the molars as both reference points are capable of movement during expansion. The molars may be extruded increasing this height; lateral tipping may reduce it; lowering of the vault of the palate combined with extrusion of the molar may result in it being unchanged. As Linder Aronson and Ingram point out normal growth would result in both points being lowered yet no change occurring between the two reference points. In addition I feel that the descriptions of a superior lateral movement of the lateral margins of the palatal process seem to be confined to the animal experiments and I wonder if this apparent movement is due to differences in facial morphology and while present in the monkey experiments is not apparent in clinical trials. In summary, I feel we should give priority to those clinical studies by Wertz (1970), Byrum (1971), Wertz and Dreskin (1977), and Haas (1961, 1965, 1970) who utilize external landmarks to analyse these changes on cephalometric radiographs.

4.3.2 Horizontal Plane (Transverse Plane)

Wertz (1970) from occlusal radiographs describes the palatal void as almost always appearing non-parallel with the widening being greater anteriorly than posteriorly. He found on the dental casts, the anterior and posterior abutments widened in approximately equal amounts. The degree of opening was dependent on treatment goals. At appliance removal the occlusal films showed that the palatal void had filled with apparently osseous tissue. Following three months fixed retention no abnormality of the suture could be detected. On the models the abutment teeth had been maintained by the appliance and as a result there were no changes.

From his dry skull material Wertz showed that there was complete opening of the suture including the palatal bones, with the opening being definitely greater anteriorly, progressively decreasing as the posterior nasal spine was approached. This was apparent in both the adult and mixed dentition skulls. Wertz concluded that the palatal shelves do not open in a parallel manner, the exact posterior termination being difficult to detect. The palatal shelves are usually, but not always, separated and usually to a lesser extent than the palatal shelves of the maxilla.

Implant studies have been done by Krebs (1959, 1964) and Mayoral and Aristeguinta (1973). Both studies demonstrated greater opening anteriorly than posteriorly. Krebs found that in general terms the expansion decreases in the direction from the dental arch towards the cranial base. Mayoral and Aristeguinta noted in their subjects the great variation in contributions of basal expansion and coronal expansion. They only had three subjects and while their experimental method seems valid, the sample size is too small to place too much significance on their findings.

Timms (1980) studying basal movement with maxillary expansion felt that Wertz (1970) expressed doubts about the opening of the palatal bones, and the possibility of slippage at the maxillopalatine suture and at the pterygopalatine junction. If slippage occurred it would minimize movement of the pterygoid process of the sphenoid bone. Wertz quotes West (1970) who, using monkeys, studied histologically the suture between the maxilla and adjacent bones. His observations led him to conclude that only the maxilla moved. Viewed on frontal sections the medial wall of the maxilla was seen to have moved away from the perpendicular plate of the palatine bone at the level of the nasal floor, leaving an inverted V-shaped opening between the two bones.

Timms (1980) used the pterygoid hamulus which is the inferior extremity of the pterygoid process of the sphenoid bone. He felt that changes in the dimensions between the pterygoid notches would indicate basal movement. The hamuli were palpated and marked. Calipers were used to measure the dimensions intra-orally and these were compared to intra-maxillary dental arch changes. The increase in interhamular notch width was expressed as a percentage of increased intermolar width. Timms found that it varied from 35% to 89%, age being the probable cause of the wide variation. Thus these results, according to Timms, show that the pterygoid process was moved significantly, and that the palatine bones must have separated as well. In view of the amount of movement, it is probable that there was very little slippage at the intervening sutures. Timms felt that the only realistic interpretation of the result is to accept that the maxillary bones, palatine bones, and pterygoid process act as a single bone, in the context of maxillary expansion. The first two separating and the latter which cannot separate, because it is one bone, splaying outwards as far as its lower portions are concerned. The movement of the pterygoid notches was far greater than was to be expected and the variable results could indicate a significant contribution to the increased buttressing effect with age, that is experienced in rapid expansion, could come from the sphenoid bone. This supports the findings of Kudlick (1974).

Haas (1961, 1973) describes the midpalatal opening as being clinically parallel, but adds that it may be fractionally greater anteriorly than posteriorly. This is shown by the authors above to be not true on occlusal radiographs. Possibly the molars demonstrate a greater orthodontic effect than the premolars and this could be related to their greater root area, delaying the initial onset of the hyalinizing effect, allowing more initial tooth movement. Timms (1974) felt that the increased rigidity of his appliance led to a more parallel opening but still argued that the sutural opening was slightly greater anteriorly than posteriorly. Brogan (1977a) found that midpalatal separation was parallel from the incisors to the molars, then, behind the molars, it tapers into the distal margins of the palatine bones. Thus Haas (1961) in saying that the opening was parallel, in the introduction to this section, must be assumed to be making a clinical observation as the majority of authors agree with Wertz (1970) who found on occlusal radiographs that the opening was greater anteriorly than posteriorly.

Biederman (1973) proposes an hypothesis for the opening of the suture in the horizontal plane (Fig. 4.7), to explain the forward movement of point A. He proposed that the maxillae rotate outwards against their skeletal abutments at their lateral margins or as Timms (1981) put it "The forward movement is caused by the lateral buttressing of the zygoma providing points of rotation". As the figure shows, if the centre of rotation is in the midline, the lateral aspects must move distally, involving resorption, but the time factor would discount this. However, if the rotation occurs about the lateral margins the result is a forward movement of point A during activation. The variability found by Wertz and Dreskin (1977) could be explained by the degree of wedge-shaped effect which then could be related to the type of appliance used, rate of activation, age of the patient, and variations in facial morphology.

I include here that Biederman has a similar theory for movements in the vertical plane (Fig. 4.8). Here several thin bones are involved; for example, nasal bones and walls of the ethmoid, and these are conceivably capable of bending rather than disarticulating. Haas (1965) indicated that in half his cases point A moves downward as well as forward. Wertz and Dreskin (1977) again report wide variations, from 1.5 mm backwards to 3 mm forward movement of point A and variations in the changes in the angulation of the palatal plane. Biederman illustrates the source of this

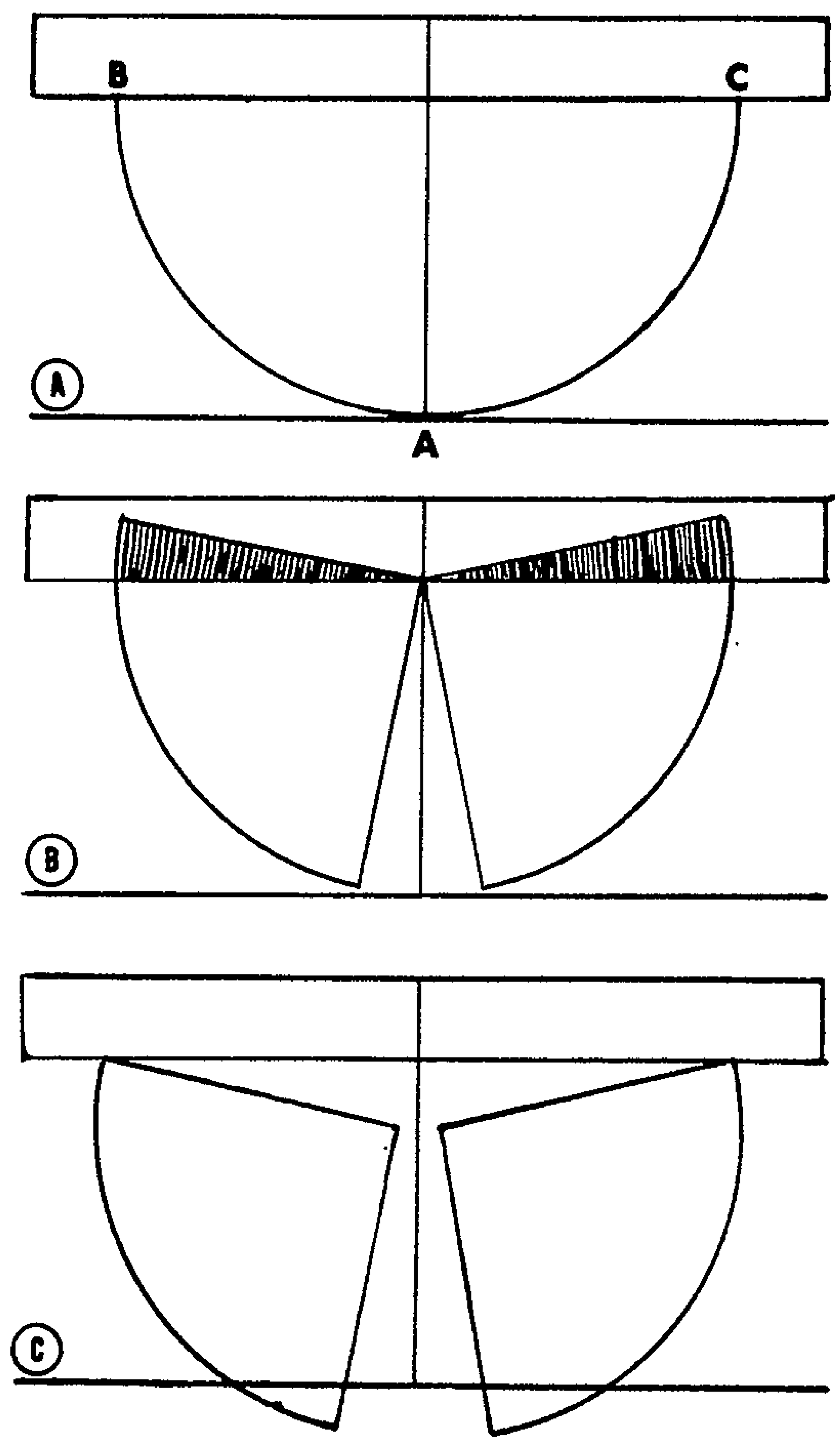

Fig. 4.7 (A) The semicircle represents the right and left maxilla: the rectangle, the bone articulating with them posteriorly. Point A is the point of tangency to the semicircles at the midline.

(B) If the centre of rotation is anywhere in the midline point A moves slightly backward and the two lateral points B and C even more implying extensive bone resorption, something unlikely in two weeks time.

(C) If rotation occurs at the lateral aspects, points B and C respectively, point A advances.

(Biederman 1973)

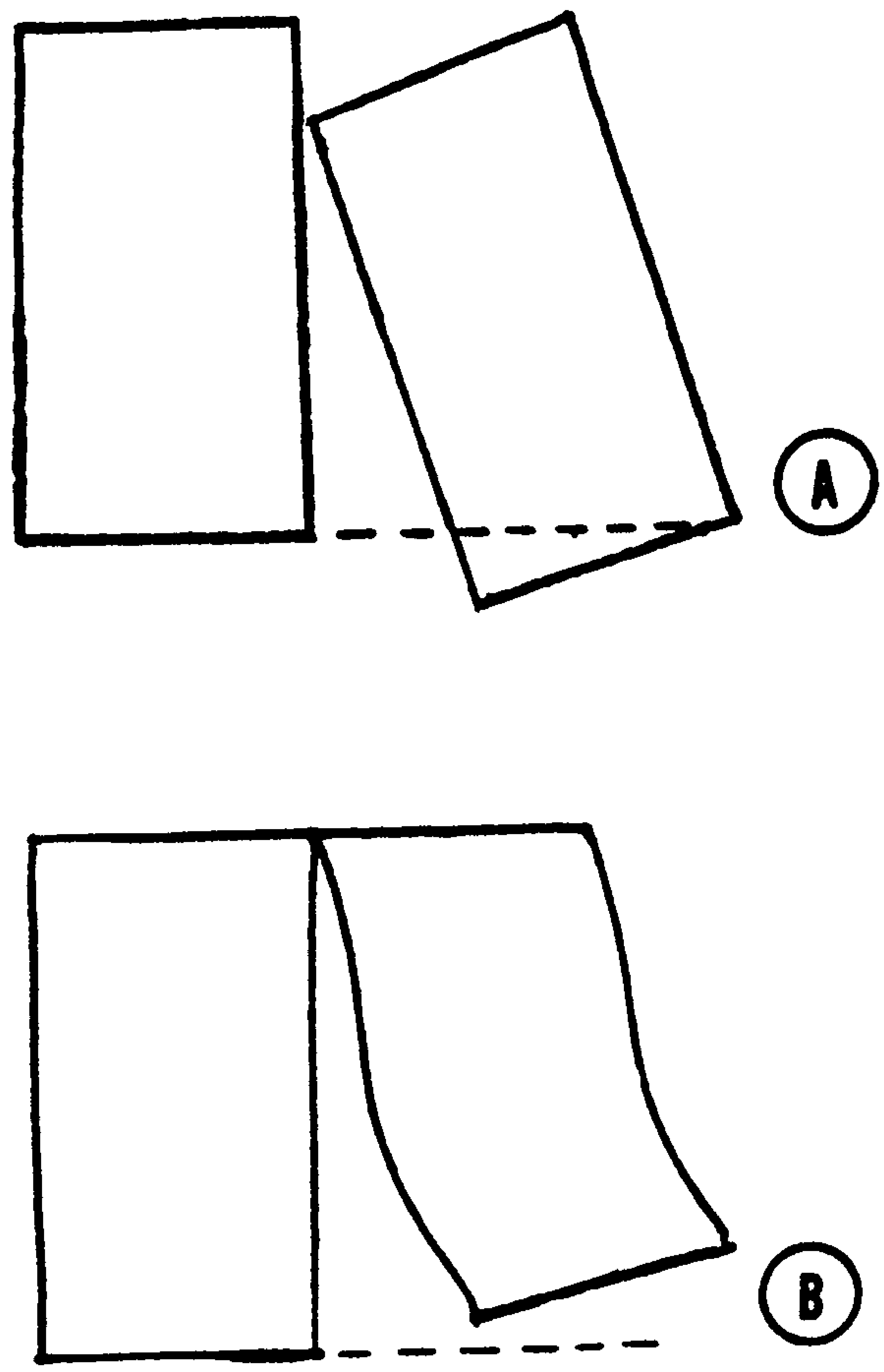

Fig. 4.8 In the vertical plane

(A) If disarticulation occurs the action is similar to that illustrated in Figure 4.7 and the bite closes.

(B) If the vertical elements bend, they tend to shorten and open the bite.

(Biederman 1973)

variability as occurring with alveolar bending which will usually lead to later remodelling or recovery towards the former positions during stabilization. Diagrammatic representations such as these are limited in their ability to account for all the variables involved, such as individual morphology, age differences, and mechanical differences of appliance construction and activation, but as generalized representations they have some value.

Disproportionate opening of the maxillary halves:

Korkhaus (1960), discussing rapid expansion, found that splitting can occur in different ways

- without a definite tear anywhere, but by expansion of the median suture;
- with a double tear, completely disarticulating the vomer;
- Unilaterally with a single tear on one side only.

These effects as far as he knows have no unfavourable consequences. Korkhaus also felt that the downward displacement of the palate was sufficient to straighten the septum in some cases. Brogan (1977a) found that the maxillae usually separate from each other and from the vomer, although the vomer may remain attached to one side. He found that there was no predictable pattern, and clinically it appeared that if the split occurred symmetrically better results were obtained. He also found, however, that there was no method of ensuring a symmetrical division and from the dental point of view it does not appear to be significant. Haas (1973) states that the response to rapid palatal expansion clinically was always symmetrical. Wertz (1970) reported that skeletal effects may be greater on one side than the other, in which case mandibular function should be checked. Wertz further found that there was no change in the septum following expansion. It should also be recalled that Cotton (1978) and Hicks (1978) found asymmetrical movements during slow expansion.

Timms (1981) felt that since both maxillae were free to move, he found that one maxilla may rotate through a greater angle than the other. This was suggested earlier by Krebs (1958) who felt that the ratio of movement could be as great as 2 to 1. Timms also questions complete disarticulation of the vomer. Gray (1975) is quoted as showing examples where the vomer remains attached to one palatal process. This Timms felt may be the result of eccentricities in original vomeromaxillary articulation, or another possibility is where one palatal process is much thicker than the other. Timms goes on that "straightening of septal deviations, claimed by Gray (1975), have been attributed to the downward pull of the palate, but if the vomer completely disarticulates one could argue that the improvement is due to disarticulation alone". Further consideration is given to deviated nasal septums in section 4.7 by Griffin and McGrath (1978).

4.3.3 Sagittal Plane; Lateral Plane

Haas (1961) found that in all cases point A moved forward during expansion and in some cases downward as well. The tendency to return to their former positions during the stabilization period Haas suggests, indicates that as the maxillae move laterally, marked activity and adjustment must occur at the adjacent sutures of the craniofacial bones with which the maxilla articulates. The altered position of the maxilla, together with concomitant disturbances in the occlusion results in opening of the bite, with a downward and backward movement of the mandible. Thus the mandibular plane angle to SN increases. There is a posterior movement of Pogonion with a resultant alteration to the Y axis. Haas found that this mandibular displacement was usually temporary and during stabilization tended to return to its former position. Haas (1980) felt that this effect was due to the pull of the extended viscera, muscles, and connective tissue about the disarticulated sutures.

This alteration in the anteroposterior relationship with the forward movement of point A and backward movement of point B is very helpful in ClIII and pseudo ClIII cases. This movement will in many instances correct an anterior crossbite. If more anteroposterior correction is necessary, the loosened maxilla comes forward easily in response to the pull of vigorous ClIII elastic traction. With ClIII elastic traction, the entire maxilla was pulled down resulting in sustained bite opening. Thus if a vertical discrepancy was evident Haas used a chin cup with the ClIII elastics attached to the chin cup. In general Haas felt that in ClII cases the maxilla tended to recover and move posteriorly whereas in ClIII cases it tended to stay forward. He felt this was probably a response to the altered forces of the occlusion, perhaps involving the correction of an anterior crossbite. He also observed that skeletal ClIII types often had an excessive freeway space to help sustain the bite opening, this may not be so in ClI and ClII types. Haas introduces a note of caution however, in that he believed that if the anterior maxillary displacement is desirable, the protraction effect should be sustained during stabilization to allow for favourable sutural reorganization and ensure permanency of the new maxillary position. His appliance of choice was the protraction head cap. In support of this concept McCracken (1970) found that the tendency for anterior overjet to increase was a temporary effect and he had not obtained any permanent effects in treating ClIII malocclusions. The effect he felt disappeared almost as quickly as the diastema. Thus in ClIII cases Haas felt that the whole facial pattern improved due to the increased midface convexity, increased lower face height, and posterior displacement of

Pogonion with lessened effective mandibular length.

Haas concluded that "due to the importance of the transverse dimension, in my opinion, any case that exhibits a need for maxillary width expansion or maxillary base manipulation, dependent on loosening the base, needs and should have rapid maxillary expansion. The occurrence of undesirable effects in other dimensions should be anticipated and dealt with in treatment planning. Skeletal open bite is not a contraindication to rapid maxillary expansion."

Summarizing the other authors descriptions of movements in the sagittal plane, Wertz (1970) found that the maxilla was routinely displaced downwards, but rarely was it displaced forward more than 1.5 mm, occasionally even distal displacement of the maxilla was seen. Vertical displacement varied at ANS and PNS but an opening of the SN to palatal plane angle predominated. This agrees with Bjork's (1966) findings on normal growth. The mandibular plane angle almost always opened, usually accompanied by a diminished SNB angle. Occlusal interference, he claimed, was responsible when the SNB angle increased or remained stable. At appliance removal, the predominant movement was in the direction of recovery, especially in the case of point A. Often, however, the maxilla appeared to remain stable or continue in the direction of change. The lack of consistency was fairly marked in that only 50% of cases demonstrated recovery, 30% remained stable, and the remaining 20% continued in the direction of change. Changes in the angulation of the palatal plane were even more inconsistent. Wertz felt that the mandibular plane routinely tended to recover and usually carried recovery of SNB and ANB angles with it.

Wertz and Dreskin (1977) felt that while the palatal plane descended faster during expansion than would have been expected with normal growth, full recovery was achieved during stabilization, indicating that rapid expansion has no permanent effect on the palatal plane. This they felt was further supported by the lack of change in older patients, whereas in younger patients there was subsequently further lowering of the palate, and forward movement of point A due to growth. The mandibular plane angle opened 2° and there was an average increase of 0.5 mm between the lower first molars. At the completion of retention the mandibular plane angle had closed 0.5° and there was no resultant change in intermolar width. Wertz and Dreskin interpret these figures by saying that "The mandibular rotation caused by the descent of the maxillary buccal segments shows 50% recovery when growth is allowed for. Cuspal interferences created during the expansion will be eliminated during uprighting of the buccal segments allowing for this recovery". They conclude that because of the resultant rotation being fairly minimal, the resultant bite opening should not contra-indicate rapid maxillary expansion. They did feel however, that recovery was poorest in the poor profiles who needed it most and thus clinically, they felt that poor skeletal patterns should have associated therapy to counter vertical bite opening.

These findings support the statistical analysis of lateral cephalograms, using computers, by Halpern (1970) and Heflin (1970). Halpern found significant coefficients of correlation between mechanical opening and change in angle SNA, linear increments in point A, changes in mandibular plane and occlusal plane angles, and the mesial movement of the maxillary first molars. He also found that between individuals, even those with similar malocclusions, there was a large variability of response.

Heflin after analysing his results found that:

- The cranial base was not significantly affected by rapid expansion.

- There was no significant anteroposterior alteration of the midfacial structures, although there were temporary changes during the expansion period.

- There was a significant downward and backward rotation of the mandible during expansion therapy, but the mandibular symphysis remained unchanged in its anteroposterior position. He attributes this to a significant increase in the length of the mandibular body.

- There was a temporary downward displacement of the maxillary molars with no significant change in their anteroposterior positions.

- The palatal expansion resulted in a significant increase in the vertical dimensions of the face.

These general findings also support those of Davis and Kronman (1969), Byrum (1971) and White (1972). Linder Aronson and Lindgren (1979) when summarizing cephalometric results five years following expansion treatment did not support the common belief that rapid expansion increases the overjet and reduces the overbite. They found that they were both unchanged, ANB angle changed very little and the angle of mandibular plane to SN decreased during the post-expansion period. Brogan (1977b) felt that an additional factor may be a functional repositioning in mouth breathers. He feels that mouth breathers tend to hold their mandible forward to allow more space for respiration at the back of the tongue. With the change to nasal breathing, associated with the expansion, there may be a slight tendency for the mandible to move distally to a more normal position.

4.3.4 Mandibular Changes

Haas (1961) felt that spontaneous expansion in the lower arch occurred with rapid maxillary expansion. He found in all cases an increase in lower intermolar width. The intercanine width showed no change in five cases, four increased 0.5 mm to 1.5 mm and one decreased 0.5 mm. Haas felt that there was no direct relationship between the time involved and the amount of change in mandibular arch width. In his 1958 pig experiments Haas demonstrated dramatic changes in the inclination of the lower buccal teeth. It was speculated that this was a consequence of the changes in the occlusion and the effects of diminishing pressure from the buccal musculature. Haas felt that the lingual pressure also increased due to the effect of the presence of the appliance forcing the tongue to be displaced totally to within the confines of the mandibular arch. In his discussion Haas felt that he had seen nothing clinically to cause an alteration of his opinion regarding a similar response in human patients, he adds that dental expansion in the lower arch may be a liability when seen in conjunction with maxillary expansion, but that it is good treatment if indicated. In clarifying the effective increases in the lower arch in clinical cases Haas emphasises the effect of occlusal forces, adding that, the normal lingual vector of force on the mandibular teeth was lost.

Cleall (1974) felt that mandibular changes were somewhat variable and poorly documented in the literature. Thorne (1956) mentions an increase in width between the lower molars of 0.7 mm, but felt that this was not significant. Davis and Kronman (1969) also felt that the lower intermolar width tended to increase as did the lower intercanine width. They did, however, admit that this result may have been affected by the presence of lower arch wires during the stabilization period. Wertz (1970) did not assess mandibular changes at all, as he felt that the time involved was too short.

Hoffer and Walters (1975) and Walters (1975) also mention compensating mandibular changes in their animal experiments. Wertz and Dreskin (1977) found an average increase between the lower molars of 0.5 mm which ranged from a decrease of 0.5 mm to an increase of 4.5 mm.

Gryson (1977) did a more comprehensive study of mandibular changes. He used 38 patients, treated with rapid maxillary expansion, who were stabilized for three months with fixed retention and then allowed to recover for two weeks before post-expansion dental casts were made. They were subsequently issued with a removable retainer or further treatment commenced. Gryson when analysing his results also considered normal growth using Moorree's (1959) study to estimate the changes in interdental distance that would have occurred even without treatment. His results showed that while there was no correlation between mandibular intermolar and intercanine widths compared to the amount of expansion in the upper arch, there was a significant increase in the lower intermolar width when allowing for normal growth. He felt that the fact that the mandibular intercanine increase being insignificant while the intermolar increase was significant would tend to lend credence to the theory that lower expansion is as much the result of occlusal forces uprighting the teeth as anything else.

Gryson concluded that the use of rapid expansion as an indirect method of increasing lower arch length cannot be justified, at least in the short term. Unfortunately, it is difficult to evaluate the potential for expansion in the longer term as these patients usually go on with various other additional orthodontic treatment.

This then should be compared to Haas (1980) who following his earlier comments referred to in this section, included the following.

Increasing lower intercanine width in the non-grower would be stable if three conditions are met:

- There is concomitant expansion of the maxillary apical base.
- The intelligent use of anchorage in the orthodontic phase of treatment. By this I presume he means avoiding any anchorage loss with the resultant proclination of the lower anterior segment.
- The need for prolonged retention. Haas used a lower fixed lingual for as long as six years or until the third molar problem has been resolved.

4.4 The Midpalatal Suture Effects During Rapid Maxillary Expansion

Debbane (1958) did early research on the effects of midpalatal expansion on cats. At that time there were two schools of thought on the effects of rapid maxillary expansion. One school of thought supported by Brodie, Downs, Goldstein and Myer (1938) felt that expansion of the maxillary dental arch was confined to the teeth and the alveolar bone immediately surrounding them. Wertz (1970), however, believed that Brodie and associates were not really considering midpalatal suture opening by rapid expansion in their study. Also Brogan (1977b) felt that one of the reasons for reduction in the use of rapid expansion was the orthodontic dogma, that basal bone cannot be altered and arch expansion is doomed to relapse. The second school of thought expressed the concept that expansion forces do open up the midpalatal suture, which encourages the apposition of new bone in the suture area. As a result of this, the maxillary palate is said to increase and the width of the nasal cavity to increase.

Debbane selected older animals to negate the effects of growth. He used both continuous expansion forces, in the form of a Minne expander, and intermittent forces, which were an activated gold wire spring. These springs required reactivation periodically. Debbane found that his results support the opinion that orthodontic expansion forces are capable of opening the midpalatal suture and a concomitant deposition of new bone occurs. The degree of opening was not uniform throughout the suture as they opened to a greater degree in the area of the premaxillary bones, than in the maxillary ones, in spite of the fact that pressure was applied to the canines which are firmly implanted in the maxilla. Debbane's suggested explanations for this included; that the connective tissue in the premaxilla is looser and not as thick or well organized as in the maxillary and palatine bones. In addition the more posterior bones are more closely interdigitated, whereas the edges of the premaxillary bones are more parallel; further that there is a variable distribution of the force resulting from the appliance in the more anterior region of the maxilla. Haas (1961) adds that he believes that the added buttressing effect of the zygomatic arch in carnivores may be stronger than in herbivores and humans and make them unsuitable for comparisons.

Debbane felt that deposition in the suture area, because the animals were non-growing, must have resulted from the influence of the orthodontic forces. He further suggests that it is a response to the stretching of the connective tissue fibres in much the same way as we get deposition occurring in response to stretching periodontal fibres during orthodontic tooth movement. In his histological discussion Debbane found evidence of trauma in the form of disorganized connective tissue with oedematous infiltration. These mechanisms are defensive in nature due to dilatation of blood vessels. Thus he felt that expansion forces were non-physiologic and perhaps excessive in the cat. Weaker forces may have produced similar results without the evidence of trauma.

Cleall et al. (1965) surmised that sutural opening occurred and felt that the important question was whether the resultant bony defect filled in with new bone and whether the deposition would remain stable. They quote Debbane (1958), Haas (1961), Krebs (1958), and Thorne (1956) as supporting the opinion that expansion forces of large magnitude cause an opening of the midpalatal suture and bring about gross and observable changes in the maxillofacial skeletons. Further they say that the increase in width of the palate, if coincident with separation of the midpalatal suture, should also result in widening of the nasal cavity. Cleall et al. used six monkeys, accepting the differences in morphology and the expansion from normal to abnormal conditions as limiting the comparisons to clinical conditions. Records included lateral and frontal cephalometric xrays and models taken prior to expansion and at sacrifice of the animals. They used a split acrylic expansion device. The first animal was sacrificed two weeks after initial activation in which 4 mm of expansion was achieved. The remaining three experimental animals were expanded 2 mm at four-weekly intervals for twelve weeks, producing 6 mm of expansion. The second experimental animal and one control was sacrificed at three months, the third experimental animal had three months fixed retention, and the fourth animal had a further three months retention after the appliance was removed, at which time the other control animal was sacrificed.

- The control animals showed a well-defined narrow suture. Histologically the controls showed a normal growing midpalatal suture which demonstrated interdigitation and was separated by a thin well-organised band of connective tissue.

- After two weeks expansion the animal showed severe disruption of the midpalatal suture, a widened flattened palate and buccal tipping of the posterior teeth. Histologically there was well vascularised disorganised fibrous tissue with irregularly positioned spicules of bone with a mild chronic inflammatory response, while damage to the suture was obvious, the cellular reaction was both reparatory as well as osteoclastic.

- After three months expansion, palatal widening and tipping of buccal teeth was more marked, palatal contour more flattened, but no increase in nasal width was detected because of the small dimensions involved and the radiographic inaccuracies. Histologically, the bony defect showed a complete disorganised suture filled with fibrous connective tissue containing numerous fibroblasts, with mineralised bony spicules projecting into the defect. The area was vascular with a slight inflammatory response. There was no interdigitation remaining, but the bony margins were irregular and very cellular indicating rapid bone formation occurring. Osteoblastic activity predominated, suggesting that after three months an attempt was being made to fill in the defect. The presence of reversal lines in adjacent bone suggested that bony resorption ocurred earlier.

- After a further three months fixed retention there was a similar gross appearance. The new bone was very cellular and irregular in nature and did not follow the normal lamellar pattern. Osteoblastic activity predominated, yet osteoclastic activity was more evident than in the earlier specimens suggesting considerable remodelling of the newly repaired suture.

- A further three months retention following removal of the appliance led to further reorganisation of the suture. It was now well organised and appeared to be histologically normal, although the interdigitating bony processes appeared more cellular, as if rapidly formed. It would appear that the defect continued to be repaired and reorganised following removal of the retention appliance and that there was no breakdown of the repaired suture.

Starnbach and Cleall (1964) used a similar method to investigate periodontal membrane effects and the other associated sutures. After three months expansion, the periodontal fibres were disorganised with a wider periodontal membrane on the palatal side. The alveolar bone showed resorption on the pressure surface. The zygomatico-maxillary suture, the nasal suture, and the zygomatico-temporal suture all showed signs of greater cellular activity. Animals retained for 4 months post-expansion showed progressively less reaction. It was also apparent that the longer the animals were retained after expansion, the less marked were these sutural reactions.

Murray and Cleall (1971) using similar methods and materials were investigating resorptive effects involved in suture splitting and the subsequent depositional effects to maintain sutural morphology. They sacrificed animals at 24 hours, 4 days, 7 days, and 14 days. Their appliance was activated initially with three quarter turns and then a quarter turn every 24 hours. In the radiographs of the control animals they describe the suture as a narrow radioluscent area bordered by well-mineralized bone. Less well-mineralized areas of new bone and scalloped areas of resorption could be observed along the edges of the bony processes.

Murray and Cleall describe the changes observed following rapid expansion as occurring in fairly distinct stages. In the first 24 hours there were no changes in the bony tissues. However, the sutural connective tissue appeared to be adapting to the force being exerted. By four days the connective tissue had proliferated and reorganized itself. Also heavy bone resorption was occurring. Thus it would appear that a combination of resorption and physical pressure are the dominant factors in suture splitting. After seven days the suture had opened. However, the bony tissue reaction was one of heavy bony deposition, which by fourteen days was still occurring. Thus once the maxillary processes could be separated without interferences, the bony reaction changed to deposition in an attempt to maintain the sutural morphology.

The reactions of the premaxillary-maxillary suture and the maxillo-palatine suture indicated that these adjacent sites initially provide resistance to opening of the intermaxillary suture and prevent opening of the interpalatine and interpremaxillary sutures. They showed patterns of alternate deposition and resorption. No gross evidence of these latter sutures opening was evident until the seventh to fourteenth day of expansion. In the human palate we only have the maxillo palatine suture and Murray and Cleall felt that the wedge-shaped or non-parallel opening of the human suture was due to the increased buttressing effect of the zygomatico-temporal complex which creates more resistance to opening in the posterior area of the palate.

Ten Cate et al. (1977) followed up the work of Cleall and associates and Murray and Cleall. They used rats and applied pressure with a spring appliance on the superior sagittal suture of the skull. Both young and old rats were selected and specimens prepared for histological study, others were sectioned for microscopic observation and a third group prepared for electron microscopic study of the areas of interest. The animals were sacrificed at various intervals from 24 hours up to 42 days. They describe the development and structure of the suture in terms of functional activity of two cell populations, namely the osteocytic population, osteoblasts, osteoclasts and osteocytes. The second group are the fibrocytic population of fibrocytes, fibroblasts and fibroclasts. Further differences then depend on variations in collagen fibre bundle orientation. While they make a distinction between the characteristics of the older and younger animals, their main subject of attention is the repair process within the suture. The immediate effect of applying force to the suture was one of trauma, albeit slight. Small localized tears occurred within the suture, frequently associated with blood vessels. The tears never involved the periostium or uniting layers which remained intact. Within three to four days bone formation had begun at the margins of the suture, achieved by the pre-existing and undamaged osteoblasts. In the subsequent period the structure of the suture area was one of overwhelming fibrogenesis and osteogenesis. New bone formation occurred along the same axis as the trabeculae, forming at right angles to the lamellae deposited initially at the suture margins. Post-expansion remodelling, two to three weeks later, of both the bone and the suture, occurred by fibrocytic and osteocytic cellular elements until the normal sutural dimensions were achieved.

In their discussion, Ten Cate and associates found that while rapid expansion initiates injury to the suture, it is the manner of healing which is critical. We have to distinguish between regeneration and repair. Regeneration is the complete reconstruction of an injured tissue or organ, with subsequent full restoration of the original architecture. Repair is replacement by new structures, scar tissue usually, with varying degrees of architectural distortion as one of its inevitable consequences. Both these conditions have their beginnings as an acute inflammatory response which results in multiplication of cells and the formation of new collagen to initiate repair. Thus expansion when initially completed must be followed by repair rather than regeneration. However, a little later, regeneration occurs along with a high degree of remodelling and reorganization. A parallel exists between the suture during expansion and that of the developing suture in a rapidly growing animal. Ignoring the inflammatory response, once the force exerted has diminished to a threshold level, the same events occur in both situations.

Thus Ten Cate et al. suggest that "sutural expansion involves injury, followed by a proliferative repair phenomenon which in other tissues leads to scar formation". However, the ability of sutural connective tissue to remodel, ultimately leads to regeneration of the suture.

While it is accepted that the animal experiments have limitations as to comparisons with clinical situations as to gross bony movements, I feel these histological comparisons of sutural effects are more valid. The only human histological research was done by Melsen (1972), who, using eight children 8 to 13 years of age, did an experiment using a similar appliance, but which was activated one full turn per day to produce 7 mm of expansion per week. Three, four, five, six weeks, and one year after expansion, frontal cephalometric radiographs were taken. At the same time, but on different patients each time, a biopsy was performed at the midpalatal suture.

The radiographs revealed, immediately post-expansion, a radioluscent area 3 to 4 mm wide. Three weeks later this area became more radio-opaque. At four weeks it could only just be discerned, and at six weeks the suture was radiographically almost identical to the suture pre-expansion.

The biopsy specimens, taken after three weeks from an eight year old, revealed that the width of the soft tissue zone between the maxillae had greatly increased. The resultant specimen consisted of fibrous tissue exhibiting hyperaemia and inflammation. There was marked osteoblastic activity around the bone fragments and collagen fibres were found extending from the suture into the bone. A second biopsy, four weeks after expansion, in a twelve year old, revealed that the soft tissue zone had reduced in size. The sample now included both bone edges of the two halves of the maxillae. Histologically great activity was still present with new bone formation, not only on major bone surfaces, but also of bony extensions into the middle of the suture. A clear demarcation could be seen on each side of the suture between matrix lamellar bone, and newly formed fibrous tissue. The third biopsy, from a thirteen year old girl, taken five weeks after expansion, revealed that the soft tissue zone was still widened, but that the histological picture was essentially different. Besides areas of active formation with osteoblasts, large resorption zones of osteoclastic activity were present, and throughout the soft tissue, true bony islands were seen. Compared to an untreated suture, the course of the suture was much more even with a broader soft tissue zone. The biopsy at six weeks was very similar to the above. These findings essentially agree with Debbane (1958), Cleall et al. (1965) and Murrayand Cleall (1971). A final biopsy one year after treatment, in a fourteen year old girl, revealed the suture was very narrow. The histological picture was characterized by resting bone surfaces with very few osteoblasts. Compared to the untreated individual, the expanded suture followed a more even course and the soft tissue zone was narrower. Of special interest was a bridge formation between the two halves of the maxilla in the oral part of the suture.

In his discussion, Melsen suggests that the differing histological picture in the older children, the numerous resorption zones, the bony processes, and bony islands are attributable to the initial stronger interdigitation of the bony processes. This prevents the two halves of the maxillae from separating without minor fractures occurring in the suture line (Figs. 4.9 and 4.10). The location of resorption lines opposite bony islands can also be explained in this manner, as osteoclastic activity is seen in the first stages of remodelling and repair following the fractures. The histological picture after complete healing, following rapid expansion, showed that if the expansion is performed at an age when sutural morphology can be expected to result in fractures occurring, healing may entail the formation of bone bridges between the two halves of the maxillae. Thus further growth of the sutures in these cases is prevented.

Linge (1972) using monkeys, histologically examined tissue responses to expansion. In this study he divided the reactions into firstly mechanical tissue responses; for example, the displacement of the tooth within the alveolar socket, general widening of the intermaxillary suture and deformation of bone. He found that practically all the collagen fibre bundles were stretched in the direction of mechanical pull, getting progressively thinner towards the ends at their insertion into bone. The second group were biologic tissue reaction. These included changes in cells, fibrous elements, and vascularization. Collagen fibre bundles tended to disintegrate into smaller units as they became disengaged from bone surfaces which were undergoing resorptions. Significantly he found no difference between the amount of bone deposition at the insertion sites of collagen fibre bundles under stress than at equivalent sites without such fibres inserted. This led Linge to conclude that Sharpeys fibres under tension did not in themselves induce increased bone deposition at the site of fibre insertion.

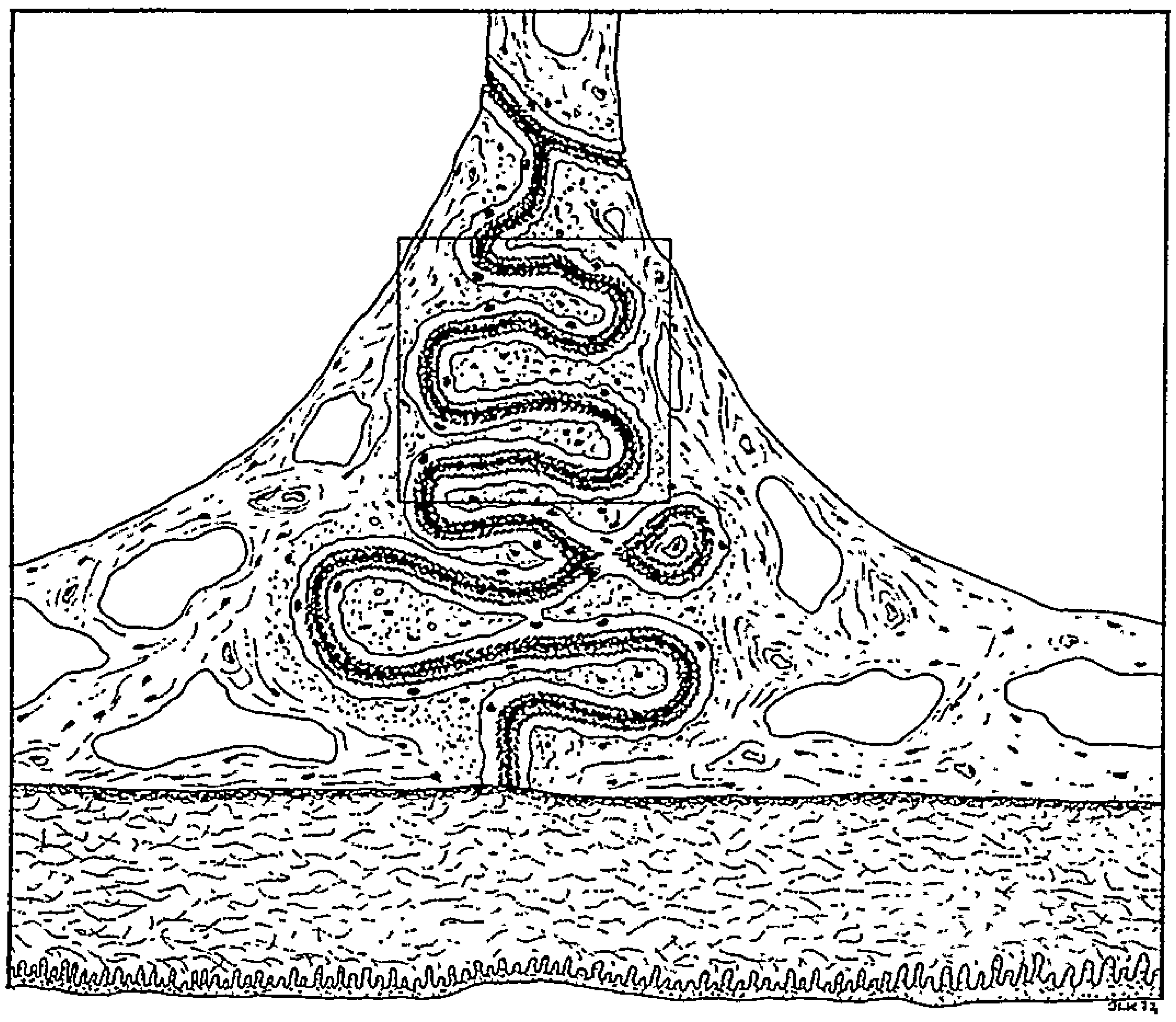

Fig. 4.9 Diagram of the midpalatal suture showing strong interdigitation, the outlined section becomes Fig. 4.10.

(Melsen, 1972)

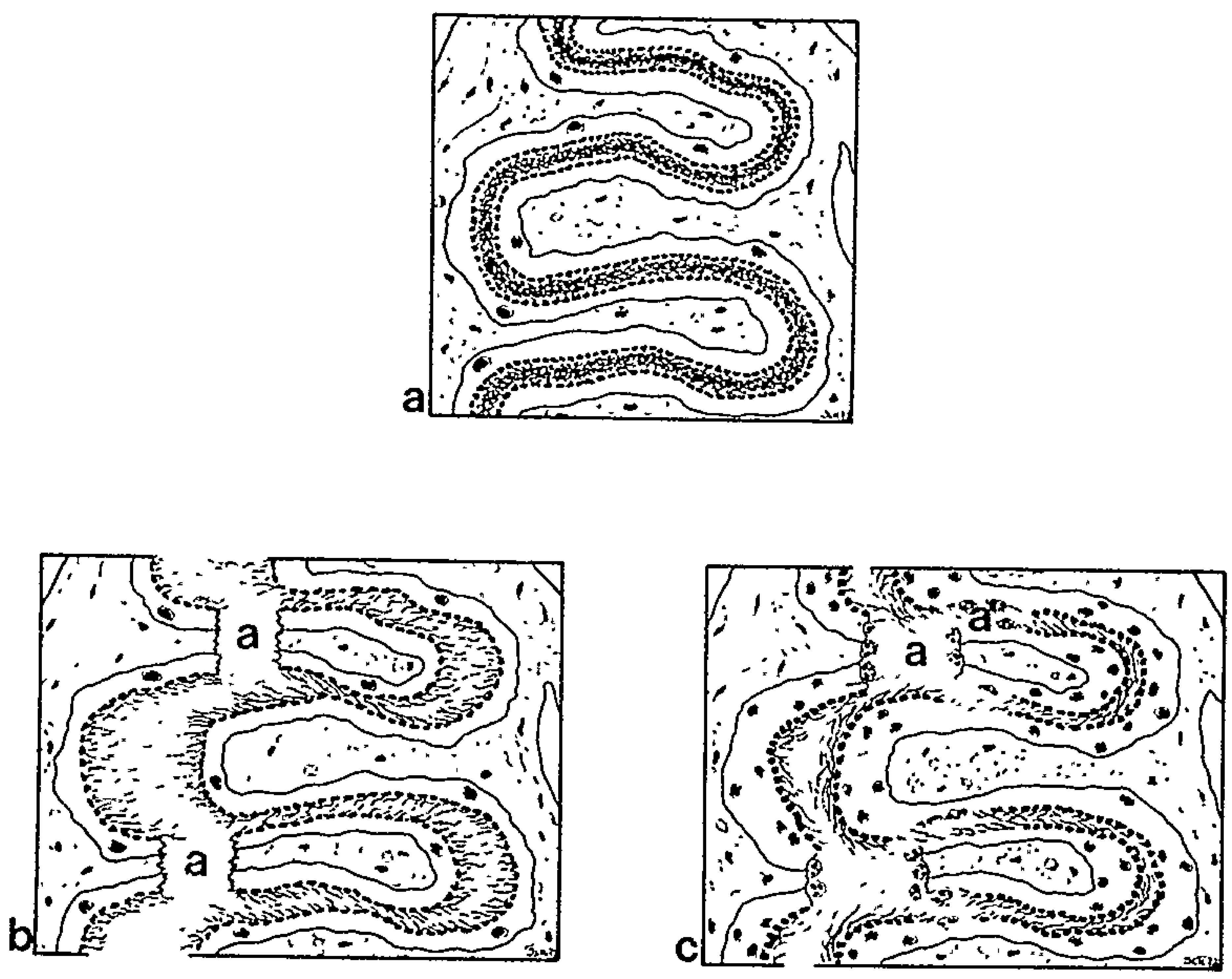

Fig. 4.10 (a) The suture before expansion

(b) Fracture accompanying expansion (a)

(c) Osteoclast activity (a) seen in fracture areas and pressure areas.

(Melsen, 1972)

A further observation was that bone growth in sutural interdigitations usually did not follow the direction of collagen fibre bundles. Changes in direction of collagen fibre bundles induced resorption in spite of tensile forces acting on the fibres. Again Linge concluded that the direction of collagen fibre bundles in sutural interdigitation was secondary to the direction of bone growth. Linge does not explain these observations, but feels that bone growth and connective tissue behaviour, as related to mechanical influences, would have to include factors other than simple pressure and tension in any attempt to explain this behaviour. He also felt that there should be a distinction made between regeneration subsequent to mechanical change and sutural growth under the influence of mechanical forces.

Ekstrom et al. (1977) investigated remineralization of the midpalatal suture after expansion using an isotope xray apparatus. His findings included that, at the first measurement week, which was three weeks post-expansion, the mineral content rose rapidly. This initial rise continued for the following two months, although considerably less rapidly. At the end of the three month retention period the mineral content was much the same in all the areas examined. These findings suggest that after a three month retention period, remineralization of the suture had become well established.

4.5 Root Resorption Associated with Rapid Maxillary Expansion

Timms and Moss (1971) felt that the forces generated by rapid expansion were undoubtedly high, sometimes as high as 20 lbs (Isaacson et al., 1964), and therefore some damage to the root should not be unexpected. They studied eight cases with fixed silver splints, on the majority of the maxillary teeth, connected by a dilating screw. This they felt distributed the force of expansion as wide as possible to reduce the pressure on individual root surfaces. Once the required expansion was achieved, they were placed into two to four month fixed retention, followed by removable retainers. Teeth were subsequently surgically removed together with their adjacent bone. They were then fixed and serially sectioned.

The results obtained by Timms and Moss showed that resorption was, in all cases, predominant on the distobuccal and mescobuccal aspects of the roots and not directly on the buccal surfaces (Fig. 4.11). This is explained later by Rygh (1977) as being related to hyalinization with the resultant lack of cellular material to produce root resorption on the buccal aspects of

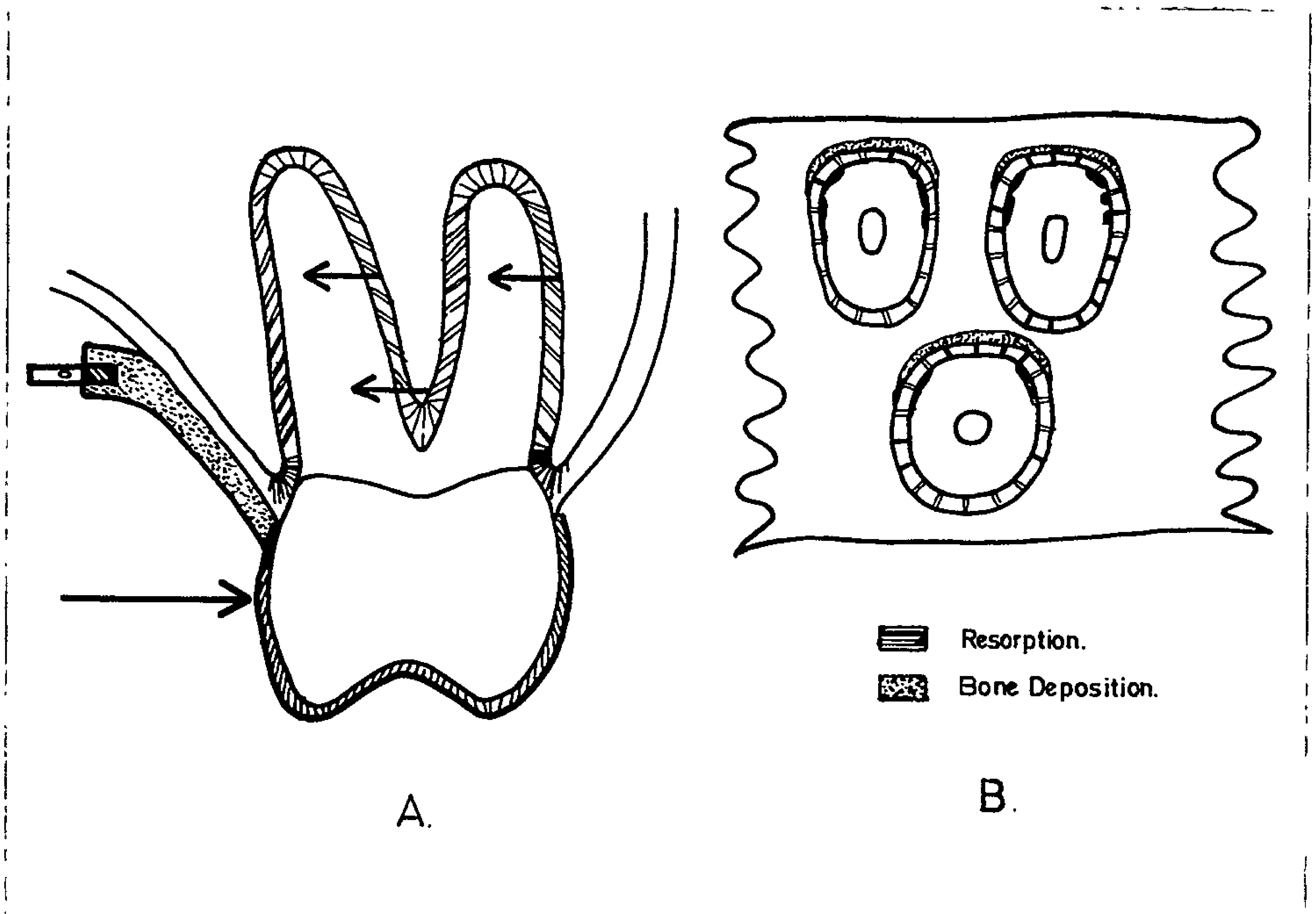

Fig. 4.11 (a) The direction of the forces against the crown and root of a molar tooth during rapid expansion

(b) The position of root resorption and bone deposition in a transverse section beneath the trifurcation of a first permanent molar tooth.

(Timms and Moss, 1971)

the teeth. Teeth removed six to seven months after expansion showed resorption mainly in the coronal third of the root. At this stage it was being repaired with osteoid tissue. After one year there was resorption and repair in the coronal and apical thirds, both were repaired with osteoid tissue. After the second year there was still evidence of resorption and repair in the apical third of the root, especially those which had been removed the longest time after expansion. This could be related to the continued retention device or as Barber and Sims (1981) found that teeth held in overcorrected positions continue their root resorption. Timms and Moss concluded that the ongoing resorption was related to relapse forces. This was supported by evidence of reversal lines in the buccal bone which indicated that after the osteoclastic activity new bone had been laid down to accommodate the teeth tipping lingually. Thus there was deposition of buccal bone at the alveolar crest with resorption and repair at the root apex. This could be indicative of the essential uprighting of the teeth in response to external forces such as the buccal musculature or from occlusal contacts which according to Reitan (1974) supply enough pressure to sustain the root resorption effect. Timms and Moss felt that this evidence confirmed the need for lengthy retention. Langford (1982) will be shown to have a contrary opinion.

Rinderer (1966) also removed teeth surgically to examine the effects of root resorption. He also reported repair followed resorption which he found on the buccal surfaces, but the most active resorption, he says, occurs on the mesiobuccal and distobuccal aspects of the roots. He felt the deposition of secondary dentine should be interpreted as a repair process. In addition he found newly developed bone formed in a broad zone opposite the resorbed areas although osteoclasts were not evident. From these observations, he also believed that with a sufficiently long retention period that results in fixation, a favourable situation is created for re-establishment of normal paradontal conditions.

Rygh (1977) studied root resorption by electron microscopy. His general concept is that root resorption is frequently observed adjacent to persisting hyalinized zones or in areas where the hyalinized tissue has been recently eliminated with re-establishment of the periodontal membrane. Reitan (1974) suggests, from his studies, that apical root resorption tends to start adjacent to a hyalinized zone, and is more likely to occur in cases where the compression is strong and of some duration. Rygh further suggests that every individual has a certain resorption potential but a high degree of root resorption should be expected in approximately 10% of the population. He felt that there are certain features which appear in common for various situations leading to root resorption. These include, increase in pressure, tissue damage within the periodontal membrane, increased blood supply associated with an inflammatory response, possibly infection, and the individual predisposition of the patient. Within this last group he includes systemic diseases or endocrine disorders.

In his summary, Rygh (1977) suggests root resorption takes place simultaneously with, and after, the elimination of hyalinized tissue. The cementoid layer and the more mature periodontal fibres adjacent to the cementum are barriers preventing root resorption. The unmineralized precementum or cementoid layer is continuously deposited and thus the uncalcified precementum layer will always be present on the root surface. Again Reitan (1974) is quoted as demonstrating that the presence of a cementoid or predentine layer on the root surface delays the resorption process. Due to the intolerable pressure, the hyalinized zone is characterised by cessation of circulation and degenerative changes of the periodontal structures. The adjacent undamaged periodontal ligament in the border areas is characterised by active hyperemia. Thus it was clearly established that the circulatory conditions are well-suited to the development of hard tissue resorbing cells. This study indicates that during hyalinization there are three stages, degeneration, elimination and re-establishment. Rygh felt that there is reason to believe that the initial breakthrough of cementum is connected with the elimination of the hyalinized parts of the periodontal ligament. Thus the elimination of the hyalinized area results in the removal of the more mature collagen fibres adjacent to the cementum and the cementoid layers. This then leaves a new cementum surface without its protective barriers which is readily attacked by odontoblasts. Once resorption lacunae are established the cementum is resorbed from the root as an undermining process. By continued orthodontic force application, the resorption process will proceed even after all hyalinized tissue is eliminated. If the orthodontic force is discontinued or falls under a certain level the resorption lacunae are repaired.

Barber and Sims (1981) describe normal cementum. They demonstrated that acellular cementum consists of closely packed, low, rounded, and relatively smooth surface mounds. This is formed through continued mineralization of attached periodontal fibres. Following organic specimen preparation when the unmineralized portion of the principal periodontal fibres are dissolved from the mineralized front, the areas of attachment of principal periodontal fibres are represented by depressions. The surface area occupied by Sharpey's fibres is characteristically 50%, with variations at different sites on the root and with age. Sharply defined Howships lacunae form the topographic basis for identifying zones of active resorption. Barber and Sims considered two groups of teeth. They examined bicuspids extracted following rapid expansion. One group were attached to the appliance and the others were not. In the unattached group which were carried laterally with the expanding maxillary process, there was no evidence of either resorption or repair after thirty six weeks due to the absence of direct pressure and thus no hyalinization of the periodontal membrane. In the other group of teeth which were attached to the appliance and thus had direct pressure exerted upon them, root resorption was evident in all cases.

Barber and Simms describe major defects located in the cervical and middle thirds of the buccal root surface and in the apical third of the palatal root surface. This they relate to the initial tipping movement of the teeth in the periodontal membrane immediately following the application of the expansion force. A further possibility they suggest is that the alveolar bone in the cervical region, being thinner and more flexible, may have a tendency to mould closely around the buccal aspects of the displaced teeth exerting a compressive and consequently resorptive effect over a more extensive area when compared to the apical areas.

Barber (1978) describes the appliance used in this study as a relatively rigid appliance. The use of 1.1 mm diameter wire soldered to the central screw induces more flexibility than those available from the supply companies. Barber considered it unnecessary to add buccal bars soldered to the bands and although he mentions the care taken during soldering to avoid annealing effects on the wires, this too could contribute to increased flexibility. Barber also notes that like Thorne (1956) he found significant lateral tipping of the anchor teeth. Thus I feel that the description of resorption in the buccal cervical region being different from Timms and Moss (1971) may be related to the reduced rigidity of the appliance used allowing significant flexing and thus a tendency to produce unequal distribution of force over the full depth of the periodontium. The resorption effects observed were thus greater towards the alveolar crest than deeper on the root surface.

Premolars extracted after two weeks of expansion were compared with their antimere kept in fixed retention for sixteen, twenty four, and thirty two weeks, after active treatment. These comparisons showed that, the longer the tooth was held in an overcorrected position during retention, the more comprehensive the resorption. It was also observed that rarely was resorption or repair encountered alone. Most lesions showed these processes occurring simultaneously. Active resorption areas were characteristically smooth in appearance and were well delineated by a rim of relatively shear and undermined cementum. At low magnification, previously smooth surfaces of Howships lacunae took on a more granular appearance. At high magnification it had a coral-like appearance. As remineralization proceeded the resorption bays were filled in and root contour re-established. All evidence of Howships lacunae were lost, but the recontouring process was not always precise and some defects were either under- or overcontoured. Small groups of Sharpeys fibre depressions were occasionally identified within the forming mineral front of repair cementum, but were not a regular feature. Thus the repair process will not be synonymous with re-attachment of principal fibres in the restored areas. The presence of very few Sharpeys fibres suggests that only very limited fibre reattachment occurs, although the possibility remains that this may occur at a later stage. Continuing resorption within incompletely repaired resorption bays was represented by a fragmented mineral front. Resting mineral fronts of repaired resorption bays demonstrated extreme variation in topography. However, all such fronts were characterized by a mineral surface free from discrete particles. If particles were present, they were fused or joined with others into a confluent mass.

Barber and Sims felt that the residual loads stored in the appliance were responsible for the ongoing resorption. They felt that the continuation of resorption after fixed retention suggests that significant relapse forces are still active, causing the alveolar bone to be compressed towards the buccal aspects of the anchor teeth which are being held rigidly by the retention appliance. Langford (1982) felt that after three months retention, the area of resorptive damage did not appear to increase markedly. He also quotes Reitan (1964) who felt that once root resorption was started by strong continuous orthodontic forces much lighter pressure could maintain or increase the resorptive process. Langford felt that strong relapse forces have dissipated after approximately three months and quotes Zimring and Isaacson (1965) to support this idea. He then suggests that the continuing root resorption may possibly be maintained by light and diminishing medially directed forces. Occlusal forces may be sufficient to perpetuate a small amount of ongoing resorption as generally the teeth are held in an over-corrected position. Barber is quoted as arguing against this concept, as he could find no significant resorption on the roots of extracted mandibular premolars, but here Langford is assuming that Reitan's theory of small forces will perpetuate resorption but not be sufficient to initiate it without the hyalinization effect being present.

Langford and Sims (1982), following up on a note of caution sounded by Watson (1980) to avoid indiscriminate expansion, examined the roots of first bicuspids for evidence of periodontal reattachment following expansion and varying periods of retention. They found fibre and fibre like bundles of varying diameters entering the repair tissue. They appeared to be continuous over the entire repair cementum surface. At the junction with the repair cellular cementum, these fibres become indistinguishable from the repair cellular cementum. These direct fibre attachments could explain the occurrence of Sharpey fibre depressions observed occasionally on the advancing repair tissue. Mineralization may occur around the attaching fibre bundles initially, forming surface depressions similar to Sharpeys fibres. Later, as repair progresses outwards, the depressions may become mineralized as the fibres become incorporated as repair cementum matrix. Although Sharpeys fibre depressions were not a feature of repair surfaces, and particularly of more advanced repair, principal fibre reattachment as a possibility is not precluded. Indeed this study provides evidence of wide-spread insertion of fibres of varying dimensions directly into the surface of repair cementum. It is difficult to establish the precise nature of this fibre attachment as the disruption of the periodontal ligament due to the extraction procedure makes definite interpretation of surface fibre direction and patterns of repair difficult to ascertain. Thus the conclusions reached must be guarded.

One point of clinical observation requires emphasising. Although these studies revealed extensive resorption of root surfaces, there was no evidence of this resorption on periapical radiographs. That is, the clinician has no way of accurately estimating the full extent of "in situ" root surface resorption caused by expansion therapy. This point was further emphasised by Odenrick et al. (1982) who studied two cases of root resorption with rapid maxillary expansion. They concluded that root resorption should be expected with the rapid expansion technique, but its buccal location prevents its detection by radiographic means. This they felt could explain why Linder Aronson and Ingram (1979) found no evidence of unfavourable dental effects after treatment with rapid expansion appliances.

It would be logical to expect that the 500 gms of force suggested by Ricketts et al. (1979) to achieve orthopedic movement with slow expansion would also be sufficient to cause root resorption. McNeil (1981) examined teeth after both rapid and slow expansion. He found that resorption occurred in all the teeth examined, but it was less pronounced in the teeth subjected to lighter orthodontic forces. The slow expansion group tended to have more areas of repair within their resorptive bays, whereas the rapid group showed more evidence of destruction in that their outlines were more ragged and undermined.

Generally speaking he found both groups showed comparatively shallow lesions with only superficial layers of dentine exposed and from his study there is nothing to indicate that Nature will not take care of the teeth by repairing the lesions. McNeil's conclusions included that

- The greater the force used the more destruction one can expect on the root surface;
- The quad-helix appliance allowed repair to keep pace with resorption.

4.6 Retention and Relapse

4.6.1 Retention

The majority of authors recommend utilizing the expansion appliance as a fixed retainer for the first three to four months.

Haas (1973) found that some people recommend 120 days. This he felt could be overtreatment as it has been demonstrated that with 90 days fixed retention the expansion is permanent (Thorne, 1960). Haas, however, could see nothing contradictory in leaving the appliance another thirty days. With the split acrylic type of appliance the space opened during expansion may be filled with cold cure acrylic. An alternative is to stabilize the screw with brass wire to prevent it from turning back.

The three months period of retention is usually based on the work of Isaacson and Ingram (1964) and Zimring and Isaacson (1965) who found that residual loads were demonstrated at the termination of expansion in all patients. These loads dissipated within five to seven weeks, with the greatest decrease occurring during the first week, with succeeding smaller losses in the following weeks thereafter. Zimring and Isaacson did not follow the fixed retention with a removable plate and found only slight variable decreases in intermolar and interbicuspid dimensions. They suggested that the dissipation of residual loads was due to either, further displacement of the maxillary segments, or the teeth supporting the appliance move independently of the skeletal structures, and felt it is probably a combination of both. Zimring and Isaacson felt that the retention appliance must be absolutely rigid until a state of equilibrium is reached at the contiguous articulations of the maxilla. The time required for skeletal readjustment is dependent upon the amount of residual load remaining at the end of activation. Thus they felt a slower activation schedule would avoid large accumulated loads and thus lead to a reduced retention time, while total treatment time would remain essentially the same. It should also be noted that they suggest a judicious overexpansion to compensate for a predictable amount of relapse due to dental and alveolar changes. The problem arises of being able to determine at what point activation becomes so slow that there is a resultant increase in these dental and alveolar changes rather than the desired skeletal changes especially in the older patients with increased skeletal rigidity.

As described in section 5.4, Ekstrom et al. (1977) found that remineralization of the suture had become well-established after a three month retention period. The animal experiments by Cleall et al. (1965), Starnbach and Cleall (1965) and Murray and Cleall (1971) show that midpalatal integrity is re-established within three months following rapid maxillary expansion. Melsen (1972) further supports this with his human studies. He reaffirms, however, the problem of stimulation of growth in growing children, as opposed to fracture creating the need for repair, in older patients. This then introduces the concept of repair occurring within the three month retention period, but then there exists an ongoing period of reorganisation and remodelling which will vary with the severity of the original condition, the age of the patient, the rate of expansion with subsequent residual loads, and the need to create an equilibrium with the adjoining facial structures and muscles.

An issue raised by the advocates of split acrylic appliances including Haas (1961, 1970, 1973 and 1980) and Wertz (1970) is the need for skeletal support during the first three months of fixed retention that is not provided by the all wire framework appliance. As described in section 4.2 Wertz (1970) felt that if the teeth only, are to be held stable in an unstable maxillae, and there exists a force to the maxillae that would move them toward each other, then we can figuratively see the maxillae moving through the stabilized teeth. This Wertz felt could result in partial relapse of the basal and nasal cavity expansion. This is not the case with the split acrylic appliance where the acrylic buttons provide support for the maxillary base.

Haas (1980) with regard to the major resistance to expansion wrote that "If the major resistance to expansion is the maxillary articulations and not the midpalatal suture, does retention depend on bone formation within the suture or the creation of stable articulations of the maxilla with the other bones within the facial skeleton?" Timms (1981) would also suggest a dissipation of forces within the sphenoid bone. Haas felt that with the palatal maximum anchorage appliance relapse will be prevented from happening until reorganization has occurred in both these regions at the same time and so we will probably never know which is the more significant. Clinically he bases his judgement on repair within the suture, as Thorne (1960) shows cases with no retention demonstrate complete relapse.

Thorne (1956) using a split acrylic (Derichsweiler) appliance varied retention from three weeks up to three months. He found that with correction of the crossbite, the new position was stable, in the most part. In cases which had fixed retention for three months, Thorne felt that the question of retention and relapse was often confused because, after the expansion, other therapy, including extractions or extra-oral traction was used, and this made assessment of the original expansion therapy difficult. Thorne (1960) related relapse to the fixed retention period by reassessing previous cases. He followed twenty-eight cases by measuring the apices of the lingual roots of the first or second molars on serial occlusal radiographs; nasal widths were also measured. The five cases which lost some of their increases, (the other twenty three either remained stable or had further increases), wore stabilized appliances for two months or less. In one patient where the appliance was removed after three weeks because of tissue irritation, the apical base expanded 4.7 mm lost 1.2 mm, and the nasal cavity, expanded 5.7 mm lost 3.3 mm. Even though a labial arch wire had been placed as a substitute retainer, it was insufficient to sustain the basal expansion.

Timms (1981) suggests that the forces involved in relapse could be divided into three groups:

(i) Genetic factors - over which we have no control, and it is unlikely that they will be of any assistance.

(ii) Environmental factors: usually we expect the tongue to raise into the widened maxilla to help retain the expansion. Haas (1961) quotes Brodie (1954) as suggesting that the use of a loose fitting acrylic plate is a possible means of training the tongue to a more normal posture. Brogan (1977a) felt that a tongue posturing was associated with mouth breathing and adaptation to nasal breathing will result in a change in tongue posture. Subtelny (1980) believed that the tongue should be encouraged to adapt to a higher position as early as possible. He felt that the tongue was forced to maintain its low position, if the expansion appliance remains in place, simply because of its bulk. It would seem desirable according to Subtelny to remove this obstruction as soon as possible to allow the tongue the opportunity to reposition into the maxillary region.

Viniegra (1977) used an electromyographic study on six children following rapid expansion to determine muscle changes and whether these changes had a tendency to become permanent or not. He found several muscles presented significant differences without being specific. He concluded that the muscles of mastication, following palatal expansion, showed a tendency to become readjusted to the new positions on the bones. Haas (1970) also mentions this muscular adaptation when he refers to the increases in the mandibular intermolar width.

(iii) Expansion forces generated

The stretching of soft tissue and deformation of hard tissue can only be controlled by the retention devices. Timms further divides these forces into three groups.

- Elastic recoil of bone is seen only if the expansion device is removed soon after expansion is completed. It is due to the undissipated residual forces described by Zimring and Isaacson (1965) considered earlier.
- Repair and reorientation refers to the collagenous connective tissue and may involve the restructuring of oedematous areas in regions where stress remains high. This is in effect for longer periods than elastic recoil.
- Remodelling, is an indeterminate factor. To satisfy changes elsewhere in the maxillary complex, further adjustments must be assumed to take place. The time scale is long and is influenced by a retainer maintaining the corrected positions while the remaining skeletal and muscular structures adapt to the new positions.

Timms (1981) and Haas (1970, 1973, 1980) felt there was a need for prolonged retention and that this could extend up to five years before stabilization is reached. Haas (1970) suggests that an acrylic plate should be fitted within forty eight hours of the appliance being removed. Timms (1981) felt that little change occurs if this is left for up to one week and that this gives the palatal mucosa time to recover. Haas also suggests trimming acrylic from the lingual aspects of those teeth which are be permitted to tip lingually at this stage. Thus a unilateral dental expansion can be controlled by trimming on one side more than the other. Haas (1973) adds that he is able to upright buccal teeth through the expediency of the fulcrum provided by the acrylic abutting the teeth. Considering mandibular retention, Haas says "I do not advocate expansion of the mandibular intercanine width. It is possible to demonstrate increases averaging 2.5 to 3.0 mm approximately one year after expansion, where only functional and environmental changes are responsible." Haas feels that a lower fixed lingual appliance should be in place for at least four years, the average age of removal of the lower fixed lingual was twenty years of age. Retention appliances in the form of a Hawley retainer are worn for two years full-time followed by one and a half to two years part-time wear. Haas (1980) says he has treatment results which demonstrate total stability of 4 to 5 mm intercanine increases in the lower arch many years out of retention. In the upper arch buccal teeth expanded 9 to 12 mm with the expansion device remained absolutely stable. All cases showed stability of overbite correction, skeletal pattern correction, as well as dental correction. Haas felt that this was the result of both the treatment and long retention, but in addition there was the need for careful diagnosis to delineate the degree of skeletal and dental anomalies.

At the other extreme are Sain (1973) and Zimring and Isaacson (1965) who did not follow the fixed retention period with any removable retainers. Zimring and Isaacson felt that the implant studies of Isaacson and Murphy (1964) and Krebs (1959) suggest that skeletal remodelling occurs until equilibrium is established between the maxilla and other facial bones. They felt that the variable further changes following retention may be attributable to influences of the muscular drape, facets of occlusion, and relapse of that part of the expansion contributed by orthodontic movement alone.

As explained earlier, the question of continued retention is more often than not confused by the need for further treatment. The middle ground favoured by the majority of the remaining authors is expressed by Krebs

(1964), who followed the three months fixed retention with a removable retainer for nineteen months. His general conclusion was that during the fixed stabilization period the expansion was maintained by the appliance. During the subsequent retention period there remained a tendency for relapse and final stability was not achieved for five years. His implant studies showed that immediately following therapy there was a small but definite reduction in width of the maxillary base and nasal cavity. This ceased during the following years and was followed by an increase over the next three years until final stability was reached (Fig. 4.12). There were marked effects during the pubertal growth spurt, but individual variations were also observed. He comments on the stability during the fixed retention period but found in some cases the removable retainer was not completely effective and when discontinued there was usually a reduction in the dental width which often continued for up to four to five years, but in no case was there complete relapse.

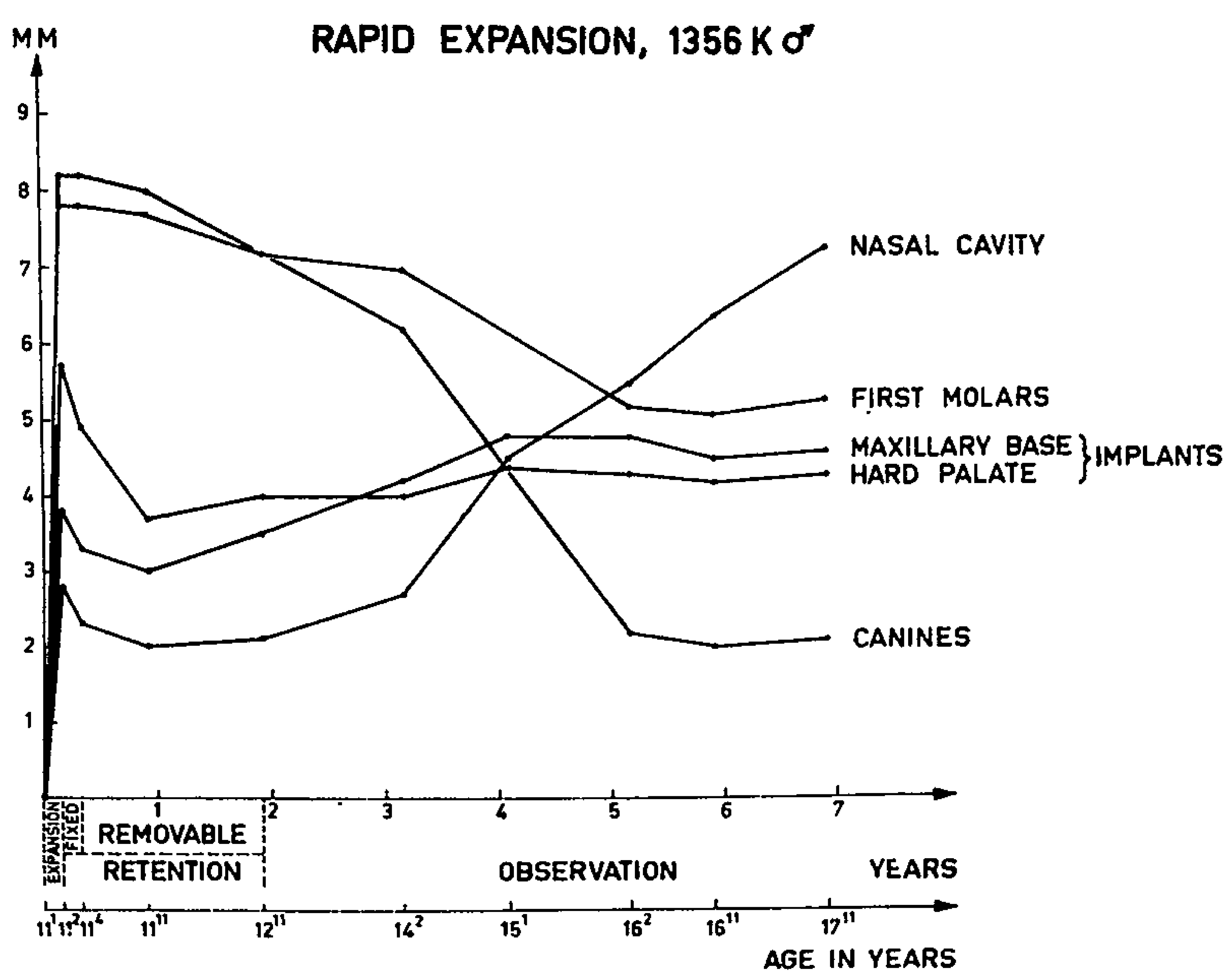

Fig. 4.12 The effect of rapid expansion therapy in five facial zones followed over seven years.

(Krebs, 1964)

Langford (1982) related root resorption to retention, discussed in more detail in section 5.5. He found that the recommended periods of retention varied from a period of months (Thorne, 1956), to many years (Timms, 1976, and Haas, 1970). Timms and Moss (1971) found signs of root resorption as long as two years after expansion. Barber and Sims (1981) reported evidence of root resorption nine months after expansion. It is Langford's contention that the prolonged period of retention of the teeth in overexpanded and possibly occlusally traumatic positions which is the cause of the ongoing resorption and that it does not demonstrate a continuing tendency to relapse. Langford quotes Reitan (1951) who found that once root resorption was started by strong continuous forces, much lighter forces could maintain the resorption process. Langford concluded from his investigation that it appears that relapse forces capable of causing significant resorption operate up to three months following rapid expansion. Beyond this the strong relapse forces have dissipated; however, light forces causing a tendency to relapse may originate from soft tissue pressures and traumatic occlusal forces. Thorne (1960) and Krebs (1964) according to Langford (1982) found that the greater part of the apical base widths and nasal cavity widths gained during expansion were not lost. Thus Langford felt that the great majority of relapse referred to in the long term studies must refer to dental and alveolar relapse which all authors agree is inevitable. A recommendation on a safe period of retention based on the findings of this study, Langford felt, would be unwise. Langford felt he could support the concept that the retention periods of up to one year used in this study indicate that a shorter retention period may be contemplated for some patients, with three to four months as a minimum. Each case still demands individual assessment and a degree of "clinical judgement" when deciding on retention.

4.6.2 Relapse

Stockfish (1969) followed up 150 patients, from five to fifteen years of age, following rapid expansion. He found relapse varied depending on the initial amount of expansion. If expanded 14 mm, all patients relapsed to at least 10 mm. In those that were initially expanded 10 mm, eighty percent relapsed 2 to 3 mm and twenty percent were stable. Of the relapsed group, seventy percent achieved ideal measurements when all post retention adjustments had taken place and the remaining thirty percent had a more marked relapse to less than ideal dimensions. Stockfish (1969) felt that this could have been improved if in some cases fixed retention had been continued longer as the removable plates were inadequate. Stockfish concluded that an overexpansion of 2 to 4 mm was adequate and that relapse potential should be considered against individual variations in morphology. Furthermore the differential changes or adaptations during function and mastication should be distinguished from true relapse of expension. There are many unpredictable factors acting on the widened dental arches and as long as ideal measurements are approximately achieved and maintained one cannot speak of typical relapse.

Timms (1976) assessed twenty six cases at least five years post-expansion. He expressed his results as percentages of residual expansion when compared to the original expansion achieved. He found an upper limit of 81% down to a lower limit of 10% retained expansion. This is less favourable than Stockfish (1969) who also had less variation. Timms found that some of the poorer results were associated with shorter periods of retention. In his conclusions Timms felt that "stabilization will ultimately depend on a balance of oral pressures being achieved, probably aided by a change in the pattern of function with the new arch form. There was in many cases spontaneous change in the lower arch form mostly, but not always, a diminution which could point to tongue behaviour". Timms later continues that after overexpansion and lengthy retention, minimum of two years, we must accept the verdict of nature, and here two environmental forces will determine the final occlusal relationships.

- Buccolingual pressure is exerted by muscular forces particularly during function. The anatomical changes and concomitant functional changes should produce a new pattern of pressures in harmony with the widened maxilla.

- Articulation, the detailed cuspal morphology where cusps are high with good interdigitation would provide some natural retention. In addition an anterior overbite may be achieved to retain antero-posterior corrections.

Linder Aronson and Ingram (1979) examined twenty three patients approximately five years after expansion. Their results show that the final increase recorded was 45% or not quite half that originally achieved. Of particular interest was that the mean increase in intercanine width was quite small and only 23% of the initial expansion. Thus they concluded that expansion as such gives very little in the way of extra space within the dental arch and cannot be regarded as an alternative to extraction in cases of real crowding. This supports the conclusions of Wertz (1970) in section 4.3.

4.7 Nasal Effects of Rapid Maxillary Expansion

4.7.1 Nasal Stenosis and Mouth Breathing

Haas (1961) reported that spreading of the maxilla increases intra-nasal capacity. Changes in nasal width varied from 2.0 to 4.5 mm, occurring in from 12 to 27 days of expansion, depending on the requirements of the individual case. Haas felt that as the maxillae separate, the outer walls of the nasal cavity move laterally. The conchae, being attached to these walls, retreat from the septum. The floor of the nose drops as the alveolar processes bend laterally and the free margins of the horizontal palatine processes move inferiorly. The total effect is an increase in intra-nasal capacity which makes nasal respiration a much easier function. In addition Haas felt that there is a variable response to breathing improvement wherethe patients who had the greatest degree of respiratory difficulty initially seemed to notice the greatest improvement.

Wertz (1970) clarifies this movement by showing that the lateral walls of the nose consist of three bony units. Anteriorly there is the medial aspect of the body of the maxilla, more posteriorly, the wall is overlaid by the vertical plate of the palatine bone, and posterior to this are the medial pterygoid plates. Wertz felt that with only the maxilla being expanded, the extent of this effect on the more posterior bony components of the nasal cavity will be minimal. Wertz felt that the lesser movements of the palatine bones, and the stability of the pterygoid processes limit the nasal benefits to the anterior inferior position of the nasal cavity. Timms (1980), discussed in section 4.3, found a surprisingly significant alteration in the interhamular notch dimensions. He felt that it is now evident that the maxillary air passages widened throughout their entire length accounting for the improved respiratory changes found in so many patients.

Cleall (1965) found slight nasal increases, but felt there was a difficulty in obtaining standardized records, as well as the smaller magnitude of change being difficult to interpret in the monkey experiments. Starnbach et al. (1966) describe the superior lateral movement of the nasal floor, but as discussed in section 4.3, this may be limited to the monkey experiments.

Gerlach (1956) expressed the concern that not every mouth breather was cured by rapid expansion. Korkhaus (1960) writes, "It is very clear that the gain of space in the respiratory tract due to rapid expansion is very favourable for substitution of mouth breathing by physiological nasal respiration". Thorne (1960) added the precaution that recorded increases in nasal cavity gain with retention of less than two months were usually lost.

A number of studies have been done to assess improvements in nasal respiration following rapid expansion.

Linder Aronson and Ascham (1963) felt that an increase in nasal width of a few millimeters considerably augments the frontal cross-section of the nose, one of its results being anatomically widened nasal passages. Patients who are mouth breathers, owing to excessive constriction of nasal passages, can be expected to become nose breathers after expansion of the median palatine suture. This study judged results on nasal function because of the difficulties of accurate identification of this area on radiographs.

They used ten patients with both orthodontic and rhinologic indications for maxillary expansion. Seven patients had the Derischweiller split acrylic appliance and three had Thorn's appliance using cast splints and a central screw. They were activated one quarter turn per day for one week, then two quarter turns per day for two weeks. After sufficient expansion was achieved the appliance was used as a fixed retainer for three months. A subsequent appliance had to be used in every case both for alignment and continued retention. Recordings of nasal resistance made prior to expansion, immediately after expansion, and twelve months following expansion treatment, indicated that a decrease in resistance occurred in every case. Further decreases occurred with the use of a nasal decongestant which they suggest indicates an anatomical widening of the nasal passages associated with the expansion.

Wertz (1968) also felt that nasal assessments from radiographs had shortcomings because of the difficulty in determining the degree of tissue engorgement. Wertz tested his patients for respiratory function after a rest period, again after mild exercise, and again exhibiting maximum ventilation. All patients used neosynephrine intranasally to reduce engorgement to a minimum. Patients and parents were further questioned to gain a subjective opinion of the effects of treatment. Wertz's results showed only mild improvements after rest and mild exercise, but for those subjects tested after strenuous exercise exhibiting maximum ventilation, all cases exhibited a marked improvement. When questioned as to the ease of nasal breathing, two patients who had the greatest increase in capacity did not recognise any change in nasal breathing, while two patients who had the least change believed nasal breathing was much easier. Wertz explains his findings in terms of the expansion effects being confined to the anterior sections of the nasal passages. Considering the arc-like opening of the maxilla, Wertz postulated that stenosis caused by an obstruction in the anterior portion of the nose could be relieved by maxillary suture opening, while stenosis in the more posterior or superior area would get little benefit from this procedure. Thus Wertz concluded that "expansion for the sole purpose of improving respiration cannot be justified unless the obstruction is shown to be in the lower anterior portion of the nasal cavity and accompanied by a bimaxillary width deficiency.

Hershey et al. (1976) used both split acrylic and all wire framework appliances to test rapid expansion effects on nasal airflow. Treatment was similar to earlier descriptions. Records included dental casts, radiographs and nasal resistance measurements before treatment, after treatment, and after three months fixed retention. The patients were further questioned for their subjective opinions regarding improvements in relation to nasal permeability. Hershey et al. found that the initial nasal resistance of their subjects was higher than that of a normal sample and that this tended to result in a mouth breathing pattern of respiration. After expansion nasal resistance in the treated group was statistically similar to that of the normal group and significantly lower than that of mouth breathers. They add, however, that this lowering of nasal resistance will not necessarily cause cessation of mouth breathing. They found on average that resistance after expansion reduced by 45% and that there was no significant further change during the retention period. There was only a low correlation between changes in maxillary width and changes in nasal width. In general the data demonstrated high variability, low predictability, and a weak linear relationship between these variables.

While nasal width increased significantly during the retention period, the resistance measurements did not change appreciably. Their reasoning for this related to the residual stresses proposed by Isaacson and Ingram (1964) in both the appliance and bones of the midface. Two factors may limit the change in resistance:

- Swelling of the nasal mucosa due to airborne irritants is extremely variable between individuals.

- The locality of the nasal stenosis. If in the regions superiorly or posteriorly to those regions of the nasal passages affected by the expansion, for example enlarged adenoids, there would be little resultant effect on respiration from maxillary expansion.

Hershey et al. found that the greatest reduction in nasal resistance occurred in those patients with the highest initial resistance. Apparently a patient with a fairly adequate airway does not show as dramatic a change in resistance as one who experiences great difficulty in nasal respiration. A further degree of variability in the reports from patients could be due to the changes occurring relatively slowly and thus the unobservant patient is not aware of the changes.

Hershey et al. point out that their method of measuring nasal resistance was different from that of Wertz (1968) and Linder Aronson and Ascham (1963). Wertz measured the volume of air passing through the nasal passages at differing levels of respiratory effort, similarly Linder Aronson and Ascham measured pressure changes of air passing through the nose. Hershey et al. felt that these measurements relied too much on patient effort rather than the actual nasal resistance. They measured a ratio of pressure change to airflow to more effectively assess actual nasal resistance and felt that their figures should not be directly compared to those of the previous authors. Brogan (1977a) felt that present airflow meters operate under extremely artificial conditions, the results being suspect even for experimental purposes and useless for clinical testing. He felt that these effects can only be assessed by clinical follow-up and questioning. He further adds that asthma and allergy problems, being periodic, don't always respond well to this procedure, but that there is usually a general improvement.

Wertz (1968) felt expansion for respiratory function correction was not indicated unless it could be shown that the stenosis was inferiorly and anteriorly situated. McCracken (1970) held similar views. On the other hand, Timms (1974) felt that mouth breathing placed the patient at such a distinct physiological disadvantage in both the short and long terms, that any method of correction or improvement of this condition was warranted despite the dental conditions. He felt that the inability to maintain an anterior lip seal seemed to have questionable significance in mouth breathing and that causes of reduction of nasal airway and increased nasal resistance were the key factor in determining mouth breathing. Relief should be sought by increasing the size of the maxilla. Timms (1974) found that slightly more than 75% of his patients subjectively noticed an improvement in respiration following expansion. Patients and parents commented on more tranquility of sleep as it relieves restlessness and snoring. Long term effects are more difficult to assess but reduction in catarrhal and allergic rhinitis, improvements in hearing and speech were reported. Overall he felt that 75% of his patients showed improvement, 15% were difficult to assess and the remaining 10% showed no improvement. Timms stressed that he felt medical indications had priority over dental ones.

Kressner (1966), a rhinilogist, agreed with Timms. He felt that faulty position of the teeth and their adjustment are less important than the correction of the nasal restriction. He believed that the floor of the nose developed along with the secondary dentition and that expansion should precede this development. He suggests expansion as early as six years of age, as later treatment can no longer influence the airway to the optimum extent. In addition, early treatment will aid the complicated ossification of the skeletal structures of this area. Kressner felt that children with obstructed respiration tend to have poor posture, a flat chest, and form a great proportion of asthmatics. It is thus important and decisive to influence normal development of the crucial airway as early as possible.

Schulhof (1978), on considering airway changes during expansion, agrees that nasal resistance can be lowered using rapid expansion provided adenoid obstruction was not present. He points out that the tonsils and adenoids are lymphoid tissue which generate antigens and removal would increase the patient's susceptibility to illness. He felt we should, using cephalometric techniques, be able to selectively diagnose alternatives for complete or partial adenoidectomy and palatal separation or alternative treatment for such things as allergies.

Subtelny (1980), in an extensive consideration of this subject, felt that normal respiration involves adequate utilization of the nasal and naso-pharyngeal tracts. Unusual enlargement of structures within these anatomic areas, such as adenoids within the nasopharynx and nasal turbinates within the nasal cavity, can cause obstruction to the free passage of air. If the obstruction is sufficient to preclude nasal respiration, the result may be an adaptation to an oral mode of respiration. This can then lead to a postural adaptation of the head and neck and postural-related effects on the jaws and developing dentition. A reluctance, developing recently, to surgically remove these enlargements has resulted in a need to re-examine and re-evaluate the effects of obstructions in these regions.

The association between excessive adenoid tissue, developing mal-occlusion and facial morphology leads to frequent references to the so-called "adenoid face". This indicates an abundance of adenoid tissue, narrowed nasal apertures, and possibly narrowed nasal passages. These respiratory restrictions result in mouth breathing with concurrent lowering of the mandible and characteristic parting of the lips. It was hypothesised that dropping of the mandible removed lower lip pressure from the upper teeth and a greater degree of maxillary procumbency would evolve. Linder Aronson and Backstrom (1960) showed that this was not the case.

The adenoid tissue on the roof of the pharynx may extend

- anteriorly to cause encroachment on the posterior nasal conchae;
- downward to approach the nasal surface of the soft palate.

Either may result in enough obstruction to lead to mouth breathing. Superimposed on normal growth of these tissues may be the hypertrophic effects related to stresses of nasorespiratory infection and allergies. During development of these tissues the nasopharyngeal complex is growing as well and, with continued drop of the palate away from the cranial base, an adequate airway space is usually maintained. The necessity for oral respiration is not caused by the mere presence of adenoid tissue, but only when it is sufficient to cause obstruction. This then creates the need for further postural changes, lips apart, downward repositioning of the mandible, and forward tongue posture. It is then conjectured that this leads to a more downward growth pattern, the tongue helps to create an open bite pattern which is maintained by overeruption of posterior teeth and leads to increased lower facial height. Furthermore, it is possible that skeletal adaptations occur with mouth breathing. These patients usually show a steeper mandibular plane angle, greater divergence of the mandibular body relative to the ramus, and increased antigonial notching. Clinically, many cases were noted to have some degree of maxillary retrusion. This then raises the argument of "form versus function" or, "which comes first the mouth breathing or the inadequate nasomaxillary development", as it is further hypothesised that the muscle pull induced by mouth breathing posture may be a cause of reduced maxillary dimensions.

Subtelny (1980) then considers the nasal turbinates. Within the nasal cavity itself hypertrophied turbinates may be responsible for severely limiting nasal airflow. The turbinates, particularly the inferior turbinates, may be observed to approximate the nasal septum to such a degree as to create a mechanical blockage. The inferior turbinates may also project posteriorly to seemingly approximate the anterior and inferior aspects of the adenoid tissue, thus obstructing nasal airflow.

The form and function aspects of this mouth breathing pattern leads Subtelny to believe that correction should be undertaken during or before active growth periods. Subtelny recommends expansion in young children with nasal restriction and mouth breathing even in the absence of a crossbite. He felt that although a buccal crossbite may occur, the return to normal width can be anticipated and further mandibular growth will usually lead to a satisfactory occlusion.

Haas (1973) described rapid maxillary expansion and asthma. He felt that this was due to a number of factors,

- The initial severity of the condition determined the degree of relief achieved and the amount of nasal increase obtained.

- The maximum anchorage appliance produces greater increases in nasal width, and does not lose them after initial stabilization as would the all wire framework appliance.

- Patients and parents commenting on nasal respiratory change seemed to indicate that those in most distress initially notice the greatest change.

- Asthma as a lung condition is improved because after expansion air will now pass through the nasal filtering system to reduce the number of antigens capable of triggering an asthmatic attack, formerly with mouth breathing no filtration was possible. In addition a person inhaling freely through the nose would have a psychological awareness of well being that may retard an asthmatic response. This concept was extended by Braun (1966) who held the opinion that a control centre located in the nasopharynx is influenced in causing the reflex bronchial spasm. Examination of these patients shows that almost without exception they have a high arched palate. Of course every case of asthma was not cured by maxillary expansion but further progress of the disease was at least prevented. He too believed that dental considerations should by no means represent the only indication for expansion, and that expansion should be started as early as possible to avoid progression of the asthmatic condition. He felt that after ten years of age most of the irreversible damage has already occurred. Griffin and McGrath (1978), also Brogan (1977a) comment on a relationship between removal of chronic nasal obstruction and bronchial asthma.

4.7.2 The Deviated Nasal Septum

Haas (1961) quotes Black (1909) as theorising that in addition to the maxillary separation, the palatine processes of the maxilla were also lowered as a result of the outward tilting of the alveolar process. He felt that this action resulted in a straightening of the deviated nasal septum. Brown (1909) believed that when the suture opened and the maxillae moved laterally, the deviated septum dropped into the space created. The study by Haas supports the former view. Timms (1981), on the other hand, argued that although these alterations have been attributed to a downward pull of the lowering maxilla on the vomer, if the vomer completely disarticulates, the improvement could be due to the freeing alone, which is a modified version of Brown's view. Kressner (1966) discussing septal deviation felt that it was due to the nasal wall being composed of differing bones and cartilages, with differing growth rates, than the septum. This suggests that pressure exists between the base of the skull and the palate and that this pressure increases with the tendency towards a high vaulted palate.

Gray and Brogan (1970) describe two types of septal deformity with different causes which may occur independently or in association.

- An anterior cartilage dislocation. A bend or buckle localised to the anterior quadrilateral cartilage. This is due to direct pressure, occurs at any age, and there is often malalignment of the external nose.

- The combined septal deformity. This involves all the septal components, the vomer bone, perpendicular plate of the ethmoid, and exterior nasal cartilage. This is due to birth moulding pressure and is described by Gray and Brogan as an acquired congenital abnormality. There is no associated external malalignment of the nose. Incidence of septal deformity in adults is approximately 77%. The deformity is present at birth and becomes more apparent with age. In their conclusions they include the statement that "the development of septal and dental abnormalities can largely be prevented by manipulation at birth". They support this by saying that "The combined septal deformity is present in a severe form in at least 20% of normal vaginal deliveries and in only about 5% of Caesarean sections. Gray and Brogan expanded with silver splints and a jackscrew. Patients had a deviated septum, poor airway and a history of ear and nasal infection, usually associated with allergic or asthmatic conditions. Once the desired expansion was achieved, the screw was stabilised for six weeks. Some relapse occurred in the following month and in clefts and severe crossbites a permanent retainer was placed to maintain the occlusal relationship. Their results up to 9 months post-retention demonstrated an appreciable remission of symptoms and adequate nasal airway. They remark at the rapid patient response. After one week snoring ceases and speech improves. They believed that this was not simply due to physical expansion, but that the movement either triggers some reflex action or removes some chronic irritant. They also note that patients with broad shallow palates do not respond well either clinically or orthodontically. Responses of patients with marked bronchial problems they also found disappointing.

Martensson (1956) commenting on deviated nasal septums also found that approximately 75% of adult Europeans have some septal deformation. He prefers to explain these deviations in terms of disturbances of growth. He felt that the septum grows more than is permitted by the structures which bound it. He also felt that deviations of the septum were much more relevant in nasal obstruction than overgrowth of the turbinates which he considers a secondary factor. He felt symptoms vary, but usually consist of nasal obstruction, rhinitis, sinusitis, neuralgia and headaches, yet strangely enough some quite substantial deviations will often produce little distress. It is the locality of the deviation that is significant. In children significant deviations are rare before the development of the secondary dentition, but become more commonplace with advancing age. Surgical correction in children is strongly cautioned against as it is all too commonly followed by other deformities such as broadening of the nose, sinking of the bridge, or deficient development of the whole nose.

Martensson observed nineteen patients clinically and felt an improvement of the passages of the nasal cavity was demonstrated in five cases. In five more it was probably improved, and there were nine cases with no change. However, in five of these the passages were quite good and the nasal septum straight before treatment. He felt that there was too much uncertainty, and the sample too small, to justify any definite conclusions.

Brogan (1977a) agrees that surgical procedures to correct nasal airway problems are of doubtful benefit. The destruction of sound erectile tissue and the resultant formation of scar tissue does more harm than good. Orthodontic enlargement, or in the case of rapid expansion, orthopedic enlargement, is essentially a natural process. It produces an effective increase in the width of the nose and to a lesser degree the height. While not advocating expansion in normal occlusions, he felt a normal pretreatment occlusion in an adult was a contra-indication to expansion, an abnormal lingual inclination of the lower buccal segments was included as an indication for expansion. Younger patients with an obstructed airway associated with a high narrow palate, with possibly a dental crossbite were justifiable subjects for rapid maxillary expansion. He got best results in younger patients but gained successful medical benefits up to fourteen years of age. However, it is harder to balance the occlusion in the permanent dentition. Brogan found that 1.5 to 3 mm of nasal expansion is normally sufficient to provide a nasal airway, further expansion is only necessary for dental and stability reasons. There is no correlation between the amount of expansion and the degree of nasal improvement clinically. A lateral expansion of 1.5 mm gives a very significant increase in the volume of the nasal cavity and if it does not improve the airway other factors are involved. Brogan (1977b) says the ideal age for expansion was five to nine years as it allowed the corrected occlusion to settle into a more normal relationship prior to the establishment of the secondary dentition. Also the appliance is well tolerated, bone response is good and the shift from nose to mouth breathing more easily accomplished. Griffin and McGrath (1978) felt that the best results with asthmatic patients were gained at a slightly older age and the results were more stable. Griffin and McGrath admit that septal deformities respond well to early treatment, but in general timing of treatment relates to the severity of the symptoms.

Griffin and McGrath (1978) describe an association between the septal deformity and malocclusion as a diagnosis can be made from either field. Their diagnosis involves an inspection of the face and nose and an assessment of the occlusion. Check facial symmetry and relationships to the facial midline. In general the septum is deflected to the side of lesser tension. That is, it goes away from a unilateral crossbite, a supernumerary incisor, or unilateral malposition of an incisor tooth. It goes toward the side of a congenital absence of an incisor tooth. They describe the syndrome associated with septal deformity as: a history of nasal obstruction and mouth breathing, frequent infections, ear troubles, sore throats and colds, allergic rhinitis and bronchial asthma. It could also extend to temporomandibular joint dysfunction associated with the crossbite of the posterior teeth, lack of confidence, and inability to concentrate.

Griffin and McGrath believed that a major advantage of rapid expansion involves stimulation of the septomaxillary ligament, whereas Brogan was more concerned with the mechanical opening of the suture. Griffin and McGrath describe the septomaxillary ligament, while inserting into the intermaxillary sutures also passes across the floor and walls of the nasal fossa as well as attaching to the anterior surfaces of the maxilla and also becomes continuous with the periosteum of the palate. Griffin (1963) describes the relationship between the septomaxillary ligament and the embryonic development of the maxilla and premaxilla as well as its contribution to the etiology of the congenitally deviated nasal septum. In general the periosteal and perichondral distribution of the ligament when put under tension stimulates and orientates growth of the subperiosteal trabeculae. A further possibility is that tension on the septal cartilage, by virtue of the septopremaxillary ligament, facilitates its growth.

As Barber (1978) noted, it is interesting that these recent studies of Gray and Brogan (1970), Gray (1975), and Brogan (1977a and 1977b) and also the reports of Griffin (1958, 1961, 1965a, 1965b) reiterate or support the previously unsupported claims made by earlier investigators like Monson (1898) and Brown (1903).

CHAPTER 5

COMPARISONS: SLOW VS. RAPID EXPANSION

5.1 Forces Utilized in Expansion

5.1.1 Slow Expansion

Ricketts et al. (1979) designed the preformed quad-helix appliance in heat-treated 0.038" Elgiloy wire, the object being to develop 500 grams of force for orthopedic movement when desired.

Chaconas and de Alba (1977) found that initial activation of approximately 8 mm, or the buccolingual width of an average deciduous second molar, produced approximately 14 ounces (400 grams) of force from the quad-helix. Chaconas and de Alba found that this was generally not enough to create an orthopedic effect in adults. In children in the deciduous or early mixed dentition, when the resistance of the midpalatal and circum-maxillary sutures is often less than that in the dentoalveolar area, the appliance is capable of orthopedically widening the maxilla.

Birnie and McNamara (1980), in order to determine how much force was produced by the quad-helix appliance activated extraorally, bent seven appliances from 1.00 mm stainless steel wire. They were activated approximately 20 mm across the posterior helices. The mean force required to compress the springs to their original dimensions was 360 ± 20 gms. In general these figures agree with those of Chaconas and Caputo. McNeil (1981) makes the point that these forces would be greater with Elgiloy wire used by Ricketts because of its greater spring efficiency.

Cotton (1978), using Rhesus monkeys, quantified his force values with a Minne expander as 1 lb with 0.016" wire and 2 lb wire with 0.018" wire. Hicks (1978) also with a Minne expander, used 0.018" stainless steel wire designed to produce a 2 lb load when compressed to 10 mm. He found that the compressed length of springs varied from 8.5 mm to 9.0 mm. Each spring was calibrated on an Instron universal testing machine with an automatic recorder to produce load versus displacement curves. The springs were found to be consistent within $\pm$ 0.5 mm in producing a 2 lb force. An effort was made to adjust the springs weekly and calculated changes between adjustments were less than 10% of the original load determined at 10 mm compression.

Chaconas and Caputo (1982) tested a number of appliances for activation characteristics. They did not give precise figures, but found that for successive increments of expansion and for comparable number of activations, the quad-helix revealed less overall maximum force when compared to similar activations for other appliances used for maxillary expansion. They also found that the removable expansion screw appliance (Skieller, 1964), when fully and firmly seated, delivered the highest forces of all the appliances tested.

A further point made by Chaconas and Caputo on testing the quad-helix was that intraoral adjustments made to the anterior bridge, and interior arms of the appliance, showed an incremental decrease from the original force placed in the appliance, with each successive activation. See section 3.3.5 for further discussion.

5.1.2 Rapid Expansion

The classical studies of Isaacson, Wood, and Ingram (1964); Isaacson and Ingram (1964); and Zimring and Isaacson (1965) surprised many operators, as to the magnitude of the forces utilized by rapid expansion and has been the basis for criticism by many advocates of slower forms of expansion.

Isaacson, Wood, and Ingram designed a dynamometer, by which means the deformation of a beam by various loads was measured, using bonded filament strain gauges. It should be kept in mind that the upper limit of the gauge will depend on the proportional limit of the metal. Once permanently deformed, strained in excess of the proportional limit, the gauge is no longer valid. The gauges were then calibrated, waterproofed, and tested before clinical use.

Isaacson and Ingram (1964) used these gauges in a clinical trial. They designed an appliance for rapid expansion with orthodontic bands on the first permanent molars and first bicuspids. An expansion screw was selected and processed acrylic attached it to one side of the palate and the dynamometer connected it to the bands on the other side. The screw opened 0.8 mm on a full 360° turn of the screw or 0.2 mm per quarter turn of the screw. The clinical trial involved 5 patients, 8.6 to 15.6 years of age. The activation schedule was to activate the appliance three quarter turns at intervals during the first half an hour after insertion. They measured the force produced per activation and its decay.

Isaacson and Ingram found that:

(i) A single activation of the screw produced from 3 to 10 lbs of force, indicating the degree of facial skeleton resistance to that force. With the initial activations it dissipated entirely over the next twelve hours. Soon, however, the subsequent loads failed to completely dissipate. Thus, further activation resulted in even greater loads being produced. Zimring and Isaacson (1965) felt that the load produced on each activation, if not dissipated by movement of the facial skeleton, was stored as potential energy within the appliance itself. The progressive failure of succeeding loads to fully dissipate, with the resultant accumulation of residual loads, was interpreted as a gradual increase in skeletal resistance.

(ii) An age differential was also noted. As a general pattern, lower loads were produced per activation in the younger patients compared to the more mature ones. This suggests that the facial skeleton increases its resistance to expansion significantly with increasing age. On the other hand, the presence of the lower load values indicates only, that the facial skeleton yielded to the expansion more readily, and does not necessarily indicate that this is an optimum rate at which the expansion should be carried out. They also found that younger patients dissipated the load for longer periods before accumulating residual loads, than did older patients. In the oldest patient, loads accumulated until an estimated 34.8 lbs of expansion force had accumulated. This followed four days of twice daily activations. After a rest period even once daily activations still resulted in residual loads building up. This was later changed to one activation every three days which allowed accumulated forces to dissipate. This is compared to the youngest patient where a once-daily activation allowed accumulated loads to completely dissipate.

Isaacson and Ingram summarized their findings by saying that the increasing resistance of the facial skeleton with age was demonstrated in the oldest patient who produced, a higher total load, over a lesser number of activations. The older patients required more time to dissipate the loads, and acquired a higher residual load.

(iii) There was no significant change in the force values at the time that the suture was opened. Thus it must be concluded that the major resistance to rapid expansion is not the midpalatal suture, but the remaining facio-maxillary articulations. They go on that retention will not depend on the presence of bone in the mid-palatal suture, but rather on the creation of a stable unstrained relationship of the articulations of the maxilla and other facial bones of the skeleton. It will be further suggested below that the removal of stresses accumulated by elastic deformation of bone may be even more important than the articulations.

Zimring and Isaacson (1965) carried this study into the retention phase to determine what happens to the accumulated loads during retention and what is their duration. They then evaluated this information with regard to the optimal duration during which retention should be maintained. They used twice daily activations initially, but this was modified to produce loads not in excess of the proportional limit of the dynamometer. All patients were treated to achieve expansion to clinically correct the crossbite. They suggest a judicious overexpansion, to compensate for the predictable relapse due to orthodontic movement, may shorten the time necessary for fixed retention. At the completion of expansion the appliances were stabilized with brass wire and utilized as fixed retainers until the loads recorded had decayed to a level considered negligible in relapse potential. At this time the appliance was removed and no further retainer issued.

They found that residual loads were demonstrated at the termination of appliance activation in all patients. These loads dissipated within approximately six weeks. The greatest decrease in load occurring within the first week, with succeeding smaller increments in the weeks thereafter. This reduction they explain by:

(i) Further displacements of the maxillary segments

(ii) The teeth supporting the appliance move independently of the skeletal structures. They felt it was probably a combination of both.

Zimring and Isaacson describe a post-retention phase. Measurements done on models 10 and 30 days following removal of the retention revealed only slight variable decreases in interbicuspid and intermolar dimensions. However, at no time was the integrity of the crossbite correction jeopardised. The variable decreases following retention may be attributable to influences of the muscular drape, facets of occlusion, and relapse of that part of the expansion contributed to by orthodontic movement alone. Again the stresses produced by bone deformation are implied but not mentioned. They concluded that "the amount of time required for skeletal adjustment is dependent on the amount of residual load remaining at the end of activation. Thus the use of a slower activation schedule, avoiding accumulation of large residual loads, may lead to a reduced retention time while total treatment time would remain essentially the same". In a similar way Isaacson and Ingram concluded that "total expansion may become physiologically stable in a shorter net treatment time with expansion at lower forces and slower activation schedules, or less expansion per activation". These conclusions are similar to those included in the introduction to this treatise and seem to suggest that a slower activation rate will still produce a similar result to rapid expansion.

5.2 Rate of Expansion

The significant difference commonly referred to between slow and rapid expansion is that slow expansion produces orthodontic movement while rapid expansion produces orthopedic movement. Cleall (1974) states that the division between orthodontic and orthopedic forces is somewhat "arbitrary and biologically unsound". A force system capable of invoking a cellular response to move a tooth, or group of teeth, is quite likely to evoke adaptive changes in bone at some distance from the specific tooth involved. Soft tissue function is also altered, which may in itself result in bone changes at some site quite removed from the tooth supporting structures. Similarly, so-called orthopedic force must evoke interactions between basal bone and alveolar bone. Thus Cleall concluded "the division into orthopedic and orthodontic forces must be viewed as a rough clinical guide which at this time is acceptable even if perhaps biologically unsound".

Isaacson and Ingram (1964) felt that "Orthodontic procedures produce constant loads over long ranges of action, in an attempt to produce as nearly as possible, physiologic responses in bone and periodontal membrane. Rapid mechanical procedures on the other hand utilize heavy forces to produce minimal tooth movement and maximal bone repositioning".

Haas (1970) commenting on the belief of Brodie (1938) that forces directed towards the oral cavity are orthodontic and only affect teeth and alveolar bone, agrees that orthodontic treatment is confined to the alveolar process. However, he goes on "there is no question in my mind that forces of a high magnitude, which greatly exceed the minimal forces required for tooth movement, do expand or inhibit the growth potential. These forces must be considered orthopedic". Haas later explains that the object of an orthopedic force is to maximise the effect on the denture base and jaws, and if the teeth are used as anchor units it is desired to prevent their movement as much as possible. At its source the orthopedic force must be great because it is dissipated over a wide area. Ohshima (1972) found that in rapid expansion tooth movement is arrested by vast hyalinization on the pressure side and while sutural opening did not completely account for the arch width gain, the remaining expansion could be accounted for by orthodontic movement and bending of the alveolar plate. This again suggests the introduction of bony stresses and strains by the appliance. The lower force used in slower expansion was more readily dissipated by tooth movement reducing the sutural opening effect.

Isaacson and Ingram showed above that there was no significant change in the force values involved at the time of suture opening, suggesting that the resistance to expansion is not the midpalatal suture but the remaining faciomaxillary articulations. It was suggested earlier that this carries the implication of stored stresses in the elastically deformed bone. Isaacson and Murphy (1964) and Krebs (1958) suggest that skeletal repositioning continues until late in retention, or until an equilibrium situation is achieved between the maxilla and other facial bones. This equilibrium again suggests biological adaptation to relieve the initial high stresses on the deformed bone.

Bell (1982) suggests that the initial changes resulting from application of biomechanical forces involve the lateral tipping of the posterior maxillary teeth as the periodontal and palatal soft tissues are compressed and stretched. Muhleman (1954a) studying tooth mobility showed the presence of an initial and secondary phase of tooth mobility. The initial mobility showed the periodontal condition and was related to movements within the limits of the periodontal membrane itself. The secondary mobility described by Muhlemann and Zander (1954) indicated that the initial width of the periodontal membrane had been exceeded. The transition from "initial" to "secondary" mobility occurs because the membrane width on the tension side cannot be further increased and the fibre bundles resist further displacement as collagenous tissue is practically inextendable. Thus in the secondary phase there was distortion of the whole periodontium and bone distortion on the "tension side". There was more variability of the effect on the "pressure side" in the amount the periodontal membrane was compressed. Compression was greatest when the alveolar bone was of low "elasticity" in fully-erupted functioning teeth. It was less pronounced in erupting teeth where the alveolar bone is more easily distorted. Differences in the thickness of the labial or lingual alveolar bone plate seem also to affect the tissue compression. Muhlemann (1954c) felt that forces higher than 100 gms lead to distortion and compression of the whole periodontium. Also forces applied with orthodontic appliances caused rapid alterations to tooth mobility, the tooth mobility increases being highest when artificial spring and elastic forces were used. Muhlemann (1960) felt that forces of 500 gms resulted in changes occurring simultaneously in the periodontal membrane and in the alveolar bone, which together become a functional unit. This then could account for the introduction of stored stresses within the elastically deformed bone referred to by Haas (1970) and Ohshima (1972) as alveolar bone bending which they consider contributes to the expected relapse following removal of the appliance. This relapse would of course depend on there being insufficient time for structural adaptation of the bone to relieve these stored stresses during the retention period.

We could extend this further using the concept suggested by Reitan (1951), that the application of higher forces causes hyalinization and prevents further orthodontic displacement. These forces are then transferred to the midpalatal and circummaxillary sutures. There is then the suggestion by Storey (1973) that the midpalatal suture morphology has similarities to that of the periodontal membrane. It then may follow, that the "tension side" effects, described by Muhlemann (1960) for the periodontium may be compared to the tension effect at the bony sutures. Thus once the normal width of the sutures had been exceeded there would be created bony stresses associated with further displacement of the bones. In the midpalatal suture these stresses would be relieved during reorganization, after initial healing of the midpalatal suture. It would be necessary for further reorganization to occur at the circummaxillary sutures. This then could explain the residual forces found by Isaacson and Ingram (1964) who felt that these forces were stored in the appliance, but may in fact be describing stresses within the adjacent bones. This may particularly relate to the sphenoid bone where, as Timms (1980) shows, the pterygoid processes move significantly during rapid expansion and, because this is a single bone without a suture to separate, must result in considerable stresses being introduced as its lower portions splay outward. There could also be possible comparisons to the "pressure side" effects described by Muhlemann with the amount of compression and bony distortion being influenced by the elasticity of the surrounding bony structures, which in turn would be directly related to the patient's age.

It could thus be suggested that the effects of a range of rates of expansion could be related to the stresses created in the bony structures. A very slow rate of expansion would result in light forces on the teeth and probable orthodontic movement or tilting of the teeth with very small stresses created with a resultant minimal tendency for further bony reorganization during retention. Slightly higher forces would introduce greater stresses in the alveolar bone without necessarily being high enough to introduce splitting of the maxillary sutures. This rate of expansion may involve the elastic deformation of the alveolus which results in relapse effects if not enough time is allowed for these stresses to be resolved during the retention period, and would also be affected by patient age. Higher forces would introduce separation of the maxillary suture and further stresses in the circummaxillary sutures, which would also require adequate time, during retention, for resolution if there is not to be a relapse effect. Thus it is possible that it is necessary to use forces in excess of that which results in elastic deformation of alveolar bone when the aim is to achieve true orthopedic movement. The dependence of these force levels on the age of the patient is considered below.

The suggestions by the antagonists to rapid expansion, that a more physiologic force may be more appropriate for maxillary expansion, including Storey (1973), who believed that slower separation would result in more mature bone formation and thus greater stability of the expansion, would depend on the effectiveness of these lower forces to produce true bony expansion. It would appear possible that, as the rate of expansion was decreased, the probability of more undesirable effects, such as increased orthodontic movement, and increased alveolar distortion, would also increase. It would then also be probable that these undesirable effects would be more likely to relapse following removal of the appliance, without adequate retention. Because the specific force levels necessary to minimise the undesirable effects of maxillary expansion are still unknown, it appears inappropriate to reduce the rate of expansion and thus risk not achieving the orthopedic goals desired with rapid maxillary expansion.

The importance of the residual stresses created within the facial skeleton may also be extended to the retention period of maxillary expansion. Fisher, Godfrey, and Stephens (1976), using the "functional matrix" type of growth theories, conjectured that the concept of a functional continuity of stresses across sutural junctions may contribute to the mechanism of bone growth, with the structural characteristics of grouping of bones being more important than those of individual bones. "The induced compressive and tensile strains distributed through the skeleton of the head influence continued bone remodelling, leading to the ultimate development at maturity, within the genetic determinants of the animal's "mould", of a mature structure with approximately equalized distributions of strains of small magnitude".

They found principal strain variation and magnitude was greatest in the infant, less in the adolescent, and least in the adult. These results they attribute to a negative feedback system modifying the genetically derived bone structure and form. This negative feedback system applied to the skull is described as occurring during growth of the skull from infancy to adulthood. The strains produced by the normal forces of mastication cause the skull to grow in such a way as to minimise these strains and to make them less variable over the entire skull as it matures. It would thus seem logical that if this is a significant factor in normal growth, then the artificial introduction of strains by maxillary expansion may cause a variation in the form of future growth in its attempt to again minimise or reduce strain variations within the system.

Justus and Luft (1970) present a mechanochemical hypothesis for bone remodelling based on mechanical stress applied to the bone as this is translated into osteoblastic and/or osteoclastic activity. They suggest that bone responds to mechanical stress (obviously more appropriately if growth is still present) by differential remodelling so as to resist the applied stress, and is probably regulated by a negative feedback system. Their hypothesis is that a change in the loading of bone results in an altered straining of the hydroxyapatite crystals in the bone. This in turn alters the solubility of the crystals providing the required negative feedback mechanism. The cells then take the appropriate action to compensate for the alteration in the localized calcium activity, either by building up bone to reduce an increased stress, or by removing bone which is surplus to the structural needs imposed by reduced stress.

Gjelsvik (1973a) writes on the piezoectric effects on bone remodelling and he suggests that the piezoelectric properties of bone play an important role in the development and growth remodelling of the skeleton. Gjelsvik (1973b) describes remodelling as involving two systems, a surface remodelling which is the deposition and resorption of surface bone, and internal remodelling which is the change in material direction of the bone. His theory is based on four postulates:

(1) The internal remodelling tries to keep the structural organization of the material and primary stress directions aligned. In a fully developed bone these directions therefore coincide everywhere.

(2) The signal for surface remodelling is the piezoelectric polarization vector at right angles to the bone surface.

(3) The material direction of new surface bone deposited coincides with the material direction of the bone on which it is being deposited.

(4) New surface bone is deposited such as to be stress free if the complete bone is unloaded.

Thus if after expansion we view the primary stress as that resulting from the forces of mastication, remodelling may occur to minimise this stress and be a contributing factor to the natural uprighting of teeth following maxillary expansion. The interdependence of the rate of expansion, the amount of bony stresses introduced, and the patient's age is obvious. The remaining growth potential may in fact be the difference between success and failure of these procedures as this may determine the patient's ability to undergo sufficient bone remodelling to achieve the desired equilibration of the introduced bony stresses. The older patient's inability to undergo sufficient remodelling along with the relative inelasticity of the bone in older patients (Melsen, 1975) results in greater stresses being produced and this may be the significant factor in the greater relapse occurring in older patients.

5.3 Patient's Age Related to Rate of Expansion

The general acceptance of the benefits of early treatment of maxillary crossbite has been considered in section 1.3. It is significant perhaps, that all the authors evaluating slow expansion use patients in the early mixed dentition stage of development. A possible result of this is, that the remaining growth available after expansion is the significant factor in correction of the basal arch discrepancies. It could be argued that the crossbite condition itself is a restriction to growth and its early correction allows a "latent growth" or "catchup growth" spurt to occur to achieve the increases claimed by Ricketts et al. (1979). A comparison of the results of Krebs (1959) Fig. 4.6, Krebs (1964) Fig. 4.12 and Skieller (1964) Fig. 5.1, shows nasal expansion decreased slightly following the initial expansion stage, Krebs (1964). It is during the subsequent period 3 to 7 years following expansion that the further significant increase in nasal width occurred. Skieller (1964) shows an increase in nasal width following the

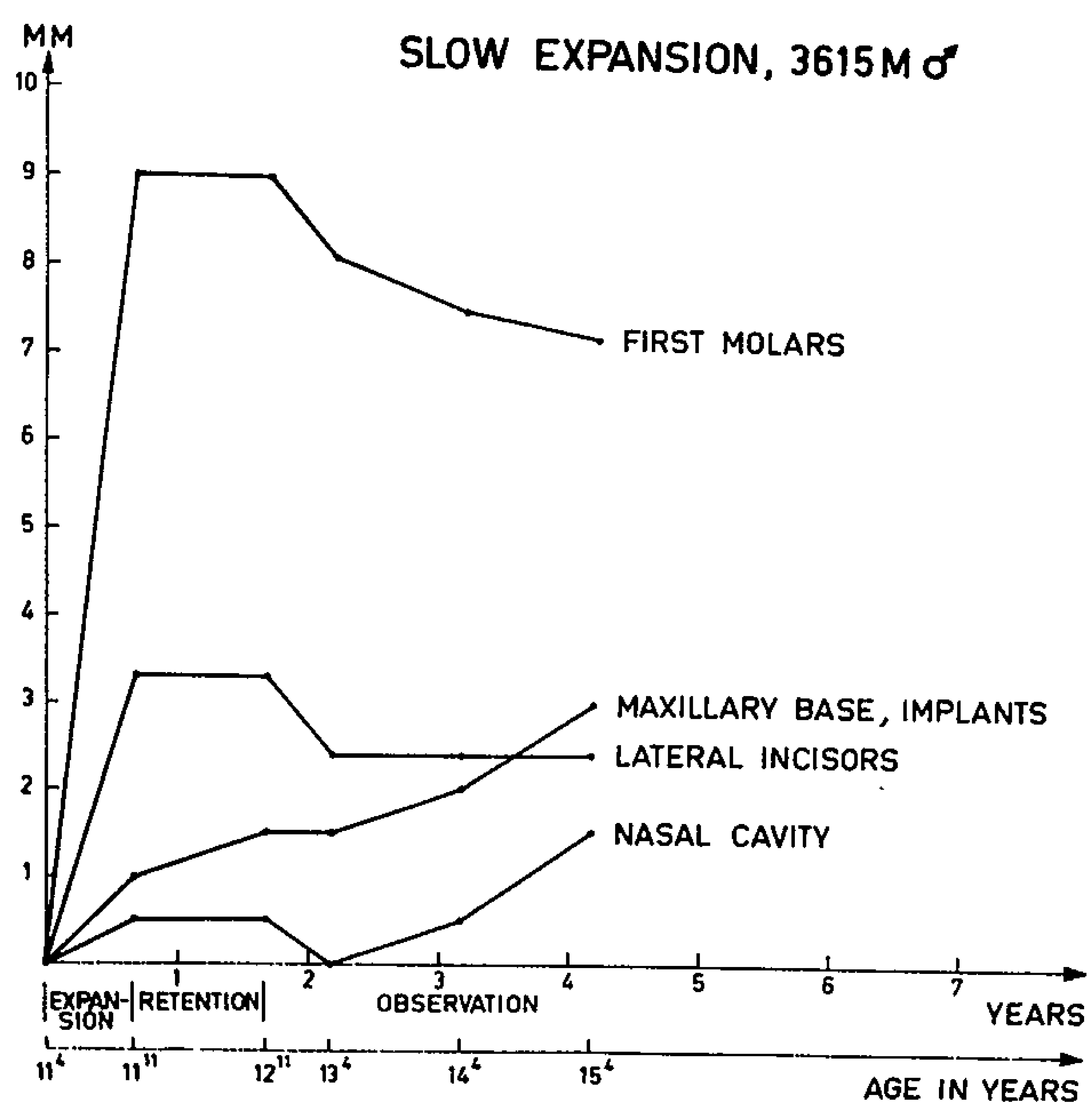

Fig. 5.1 The graph for a single patient showing the effect of slow expansion therapy in various zones of the maxilla during and after treatment.

Skieller (1964)

active expansion and a similar subsequent relapse following retention. She then indicates a similar significant increase in the nasal cavity and maxillary base implant dimensions due to growth when compared to the dental arches. Her observations also terminate at earlier stages than those of Krebs and there is no reason to believe that further increases would not be as significant as those of Krebs. This then supports the original hypothesis that the overall results of slow and rapid expansion could be similar within the restriction of the patient being young enough to have sufficient growth potential to achieve the desired results. I would additionally consider it probable that there is a limitation imposed by the severity of the original condition.

CHAPTER 6

CONCLUSION

Discussion of the dental and skeletal components of crossbites was included in Chapter 1. This along with the indications for rapid expansion discussed by Haas (1980) and the medical indications discussed by Timms (1981), in Chapter 4, must be given additional consideration when making a choice between slow and rapid maxillary expansion.

Bell and Lecompte (1981) felt that the advantages of slow fixed expansion appliances included superior patient tolerance, no complications of pain or possible tissue impingement, better oral hygiene considerations, lack of speech difficulties or eating problems, and the absence of the need for patient activation. Thus this may be the appliance of choice if in particular cases we believe that the overall benefits of slow and rapid maxillary expansion are comparable. It has further been suggested to the writer, by other orthodontists, that the use of slow expansion in the early mixed dentition, with the reliance on growth and natural uprighting effects introduced by the functional occlusal forces and the bony stresses and strains, may be supplemented, at a later age, with rapid expansion techniques if the desired expansion is not achieved. The reverse is also possible where rapid expansion may be followed by further slow expansion procedures to achieve the required result.

The use of slow expansion for dental conditions could be considered to be less age-dependent than expansion for basal conditions (Krebs, 1964). As the skeletal resistance increases with increasing age, the orthopedic effects of slow expansion will be reduced. The exception may be the pubertal growth spurt, before or during which, the effects of rapid expansion may be maximised, and there is insufficient growth potential remaining to achieve the same effects with slow expansion. Once again, careful diagnosis of the severity of the condition is essential and in the less severe conditions, slow expansion procedures remain, in the writer's opinion, a viable alternative to rapid maxillary expansion. In subsequent age-groups the effects of slow expansion are restricted to the dentition and as there will be a gradual reduction of the orthopedic effects of rapid expansion, up to the age of palatal synostosis, there will again be transfer of interest to slow expansion, now opposed to the alternative of surgical intervention, as the ideal method of achieving the required correction.

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