Experimental Studies On The Interrelations Of Condylar Growth And Alveolar Bone Formation

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INTRODUCTION

Condylar growth increases the overall height and length of the rat mandible while appositional growth and modeling resorption bring about its adult shape.[1] As the dimensions of the mandible change, the vertical and anteroposterior location of the molar teeth change also. Weinmann and Sicher have pointed out[2] that these changes in tooth position serve to maintain the masticatory apparatus workable while its size changes. Although there is no doubt as to the adaptive value of the tooth movements, we are far from understanding the mechanism by which this harmonious adaptation of the parts to the whole is brought about.

The present report is concerned with the growth of alveolar bone and the movement of the molar teeth following the release of the molars from occlusal contact with their antagonists. This study is intended as the first in an experimental series designed to explore the interrelations between condylar and alveolar bone growth.

MATERIAL AND METHODS

This study is based on measurements made on roentgenograms and on ground sections of the alizarin-stained mandibles of 66 male rats of the Holtzman strain. Thirty-three experimental animals were subjected to surgery at 54 days of age and given alizarin injections on the same day (Group II). A second alizarin injection was given 9 days later and the animals were killed 7 days later. Thirty-three control animals were also given alizarin injections at 54 and 63 days of age and were killed at 70 days of age (Group 1).

Surgical Procedure: The animals were anesthetized with sodium-pentothal. Using routine dental equipment, the crowns of the three left maxillary molars were ground down until the level of the gingival tissue was reached, i.e., for about 1 mm. This reduction in height of the maxillary teeth took the mandibular molars out of occlusion for about 9-10 days, by which time masticatory contact was re-established. Exposure of the pulps of the ground teeth resulted in the majority of cases, but no precautions to prevent infection were taken. The animals were given the standard purina rat pellets and water ad libitum. Initial, periodic, and final weights were determined.

Alizarin: Alizarin was given by intraperitoneal injection using a two percent solution of alizarin red S in tap water. The dosage was 1 cc for every 100 grams of body weight.[3]

Roentgenograms: The animals were killed with ether and their heads severed and fixed in ten percent formalin. After fixation, the heads were bisected and roentgenograms of the two halves taken. A standard dental x-ray machine and occlusal films were used.

This study was supported in part by Public Health Service Grant DE-00968 from the National Institute for Dental Research, N. I. H.

To increase accuracy of measurements from roentgenograms, enlargements (X 2.80) were printed. The prints were made on Kodak commercial ester-base film which was found to minimize distortion.

Ground Sections: For measuring bone apposition in the alizarin-marked mandibles, ground sections of the molar-bearing areas were prepared. The sections were so oriented that the distal roots of the first and second molars were sectioned centrally, and they were ground down to a thickness of 250 to 150 μ. Attempts to make the sections thinner resulted in too much loss of fundic bone. After grinding, the sections were dehydrated, cleared and mounted on troughed slides.

Measurements from the Ground Sections

Since the alizarin lines were clearest in the region of the first molar, the measurements were made in the vicinity of this tooth (Fig. 1). The sections were projected at a magnification of approximately 38 times and tracings of bone and alizarin lines were made. Bone apposition during the first 9 experimental days was measured as the distance between the first and second alizarin lines and that during the last 7 days as the distance between the sec-

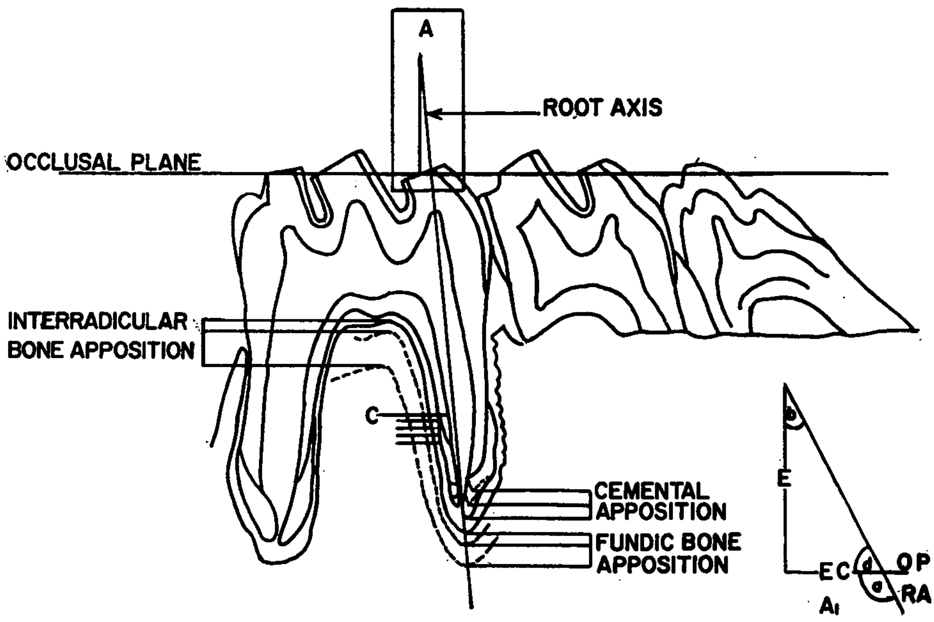

Fig. 1: Diagram of a sagittal section of the three mandibular molars showing the sites of measurement on the ground sections. C: Center of root. For description of methods see text. Alizarin lines: -------

A_1: Enlarged diagram of area A to show method of computing the eruptive component of the measured anteroposterior displacement. EC: unknown eruptive component, E: measured amount of eruption, OP: Occlusal plane, RA: continuation of axis of distal root of first molar, a: angle between distal root and occlusal plane, b: angle between distal root and a line perpendicular to the occlusal plane, and d: 180° — a. EC was determined as follows: (1) Angle a was measured; (2) Angle b was computed as: b = a — 90°; (3) EC was calculated from the equation: $\frac{EC}{E} = \tan b$.

ond alizarin line and the surface of the bone. The tracings included the outlines of the crowns of all three molars in order to allow determination of the inclination of the occlusal plane. This was determined by careful inspection of the configuration of the cusps of the three molar teeth and a line indicating it entered into the tracing. Bone apposition relating to anteroposterior changes was measured parallel to the occlusal line, bone apposition relating to changes in height perpendicular to it. The measurements as made in the drawings were corrected for magnification and converted to microns of bone apposed per day. The quantitative effects of relieved and re-established occlusion were determined by comparing the measurements on the left (operated) side of the experimental animals with three sets of control readings: the measurements on the unoperated side in the same animal and the measurements on both sides of the control animals. As a rule, the measurements on the unoperated side in the experimental animals tended to slightly smaller averages than those in the control animals. In order to obtain a conservative estimate, the average of all control measurements was used to quantitate the experimental effects.

Vertical Measurements: Vertical measurements were made of the apposition (1) of alveolar bone at the crest of the interradicular septum. These measurements were made in the distal portion of the bone where the alizarin lines were clearest, (2) of the alveolar bone in the fundic area of the distal root, and (3) of cementum at the apex of the distal root. Here again, the alizarin lines were clearer in the distal portion, and this portion was used for measurement. Further vertical measurements were made of the periodontal space at the interradicular crest and at the apex of the distal root.

Horizontal Measurements: Horizontal measurements of bone apposition were made at the posterior surface of the interradicular septum. Measurements were confined to levels where the first and second alizarin lines were approximately parallel to one another and to the surface of the bone. This was usually apical to the middle of the root. A line bisecting the root was drawn parallel to the occlusal plane, and below it a series of equidistant parallel lines were entered. The distances between the first and second alizarin lines and between the second alizarin line and the bone surface were measured along these lines and averages taken.

Estimation of Tooth Movement

Two components of tooth movement were estimated from the amount of alveolar bone and cementum formation, vertical displacement and anteroposterior displacement. Shifts in the buccolingual direction were disregarded.

Vertical Displacement: Given approximate constancy of the width of the periodontal spaces, the eruptive component of tooth movement can be estimated as the sum of cementum and fundic bone apposition[4] or as apposition at the crest of the interradicular septum.[5,6] In the present study and in the work of Hoffman and Schour[4] the estimates in the apical region came to about 10-20 percent more than those in the interradicular region. Because of this unexplained discrepancy, both estimates will be presented. The interradicular estimate seems the more reliable because the periodontal space overlying the interradicular septum is more constant than that at the apex and because the alizarin lines are clearer.

Anteroposterior Displacement: The apposition at the lateral surfaces of the bony septa is in part related to the eruptive movement of the tooth. In teeth with divergent roots, the interradicular distance widens toward the apex. When such teeth erupt, the ascent of the roots is accompanied by bone formation at the sides of the interradicular septum. The amount of bone formed in a given period depends on the degree of divergence of the roots and on the amount of eruption. It can be computed as shown in the inset diagram of Figure 1 and amounts to about a fourth of the total bone formed. This amount was deducted from the measured apposition at the posterior surface because it does not contribute to the anteroposterior displacement of the tooth.

ROENTGENOGRAPHIC MEASUREMENTS

A line touching the lower border of the mandible at the two lowest points, near the symphysis and near the posterior border, was used as a baseline. Length measurements were taken parallel to this line and height measurements at right angle to it.

Height Measurements: Vertical dimensions were measured from the baseline to the following landmarks: the highest point of the anterior alveolar septum of the first molar; the highest point of the first molar; the highest point on the superior surface of the condyle for the total height of the mandible; and the level of the occlusal plane. The inclination of the plane was determined by inspection of the cusps as in the ground sections, but its vertical level was considered as being defined by the point of transition from the mesial to the superior surface of the first molar. Its distance from the baseline was measured between the first and second molars.

Length Measurements: From the base line, perpendiculars to the following points were erected: the anterior border of the incisal alveolar bone; the mesial surface of the first molar; the posterior surface of the third molar; and the posterior surface of the condyle. Measurements of length were taken as the distances between these perpendiculars. The segment anterior to the molars, the molar-bearing segment, the postmolar segment and the overall length of the mandible were measured.

FINDINGS

BODY WEIGHTS

Control and experimental animals had nearly the same average initial weight (203 and 201 grams) and the same average final weight (254 grams). Postoperatively, however, the experimental animals grew for a time at a slower rate. By the sixth postoperative day, their weight averaged 10.5 grams less than that of the controls. Thereafter, their rate of gain exceeded that of the control animals until the 12th postoperative day, when both groups averaged the same body weight. This persisted to the end of the experimental period.

MEASUREMENTS ON GROUND SECTIONS

(1) Effect on Alveolar Bone Formation (Table 1a and b).

The relief of occlusion did not cause changes in the sites of bone apposition. In the experimental as in the control animals, apposition occurred along the posterior surfaces and the crests of the bony septa as well as in the fundic regions of the alveoli, and resorption on the anterior surfaces of the septa. The experimental effect was a marked increase in the rates of bone formation at all sites.

a. *Period of Relieved Occlusion: Controls:* The rate of bone apposition was about 10 μ per day at the fundus, 6 at the posterior surface and 20 at the crest of the septum.

Experimental: Apposition on the operated side was 26.7 μ per day at the fundus, 18.1 at the posterior surface and 47.5 μ at the crest of the septum. The acceleration of the rate of bone formation due to absence of occlusal contact ranged from more than 2-fold to nearly 3-fold.

Table 1
Amounts of Bone Formed in Different Regions of the Alveolus.*

Group	REGION: Fundic Bone		Posterior Surface of Interradicular Septum		Crest of Interradicular Septum	
1a. First 9 Experimental Days (Absence of Occlusion)						
Controls						
Group I Right	9.96	± 0.75	5.99	± 0.33	19.91	± 0.79
Group I Left	11.26	± 1.81	6.54	± 0.52	20.90	± 1.03
Group II Right	9.68	± 1.08	5.66	± 0.48	18.20	± 1.13
Average	10.30		6.06		19.67	
Experimental						
Group II Left	26.71	± 2.62	18.09	± 0.29	47.52	± 2.62
1b. Last 7 Experimental Days (Re-established Occlusion)						
Controls						
Group I Right	10.20	± 2.03	7.84	± 0.57	19.79	± 1.21
Group I Left	12.88	± 1.61	7.13	± 0.40	19.94	± 1.17
Group II Right	9.34	± 1.21	7.48	± 0.45	19.41	± 2.27
Average	10.81		7.48		19.71	
Experimental						
Group II Left	13.49	± 1.79	8.95	± 0.51	19.92	± 1.51

*Unless otherwise stated, the first figures given in this and the following tables are the group averages in micra per day; the figures preceded by ± are the standard errors of the averages.

b. *Period of Re-established Occlusion: Controls:* In the second period of the experiment the rates of bone formation at the fundus and the crest of the septum in the control group remained statistically the same as in the first period. At the posterior surface the later rates were about 20 percent higher than the earlier rates. This increase was of borderline statistical significance.

Experimental: With occlusion re-established, the averages of the rates of apposition at all three sites were of the same order of magnitude as in the controls. At the crest of the interradicular septum, the controls averaged 19.7 and the operated side 19.9 μ; at the fundus, the experimental rate still averaged 25 percent higher than the control rate. This difference was statistically not significant. At the posterior surface, the experimental rate was 20 percent higher than the control rate, and this was of borderline statistical significance.

(2) Effects on Cementum (Tables 2a and b).

At the bifurcation of the molar roots, where cementum forms only a thin layer, no differences between control and experimental animals were noticeable. At the apex, cementum apposition in rats between 56 and 70 days of age still contributes a considerable amount to the lengthening of the root. Measured perpendicular to the occlusal plane, it is of about the same order as the apposition of fundic bone.

Only a slight acceleration of apical cementum formation was observable in the experimental animals.

a. *Period of Relieved Occlusion: Controls:* Cementum formation at the apex averaged 11.5 μ per day with insignificant differences between the three sets of control measurements.

Table 2
Experimental Effects on Apical Cementum Formation

2 a. First 9 Experimental Days (Absence of Occlusion)			2 b. Last 7 Experimental Days (Re-established Occlusion)	
Group			Amount Formed	
Controls				
Group I Right	11.63	± 0.64	12.79	± 0.85
Group I Left	12.19	± 0.62	12.56	± 0.88
Group II Right	10.73	± 1.16	11.61	± 1.55
Average	11.52		12.32	
Experimental				
Group II Left	14.80	± 0.58	13.74	± 1.35

Experimental: The experimental measurements averaged 14.8 μ per day, or 29 percent higher than the control average. This effect, though slight, was statistically significant.

The contrast in the marked experimental effects on bone and slight effects on cementum was striking when the ratios of fundic bone and cementum formation were compared. In the three sets of control measurements, fundic bone apposition averaged 86 to 92 percent of cementum apposition, but on the experimental side it averaged 180 percent of cementum apposition.

b. *Period of Re-established Occlusion: Controls:* Rates of cementum formation in the second period were slightly, though not significantly, higher than in the first period.

The *experimental rate* was 12 percent higher than the control average. This difference was not statistically significant. The ratio of fundic bone to cementum formation had returned to control values.

Both fundic bone and cementum formation remained slightly accelerated in the period of re-established occlusion. The effect of relieving occlusion may have lasted longer at the apex than at the crest of the interradicular septum.

(3) Effects on Apical and Interradicular Width of the Periodontal Space (Table 3).

The measurements showed no sig-

Table 3
Width of Periodontal Space Near the Distal Root of the First Molar.
(At the End of the Experiment; in micra)

Group	REGION Above Interradicular Septum		Above Fundic Bone	
Controls				
Group I Right	122.4	± 5.07	235.6	± 11.24
Group I Left	106.6	± 4.56	227.7	± 11.30
Group II Right	106.8	± 4.79	259.0	± 16.11
Average	111.9		240.8	
Experimental				
Group II Left	95.3	± 9.03	245.5	± 22.62

Table 4
Estimates of Eruptive and Anteroposterior Movement of the First Molar
4 a. First 9 Experimental Days (Absence of Occlusion)

Group	Eruptive Movement Cementum Plus Fundic Bone	Eruptive Movement Interradicular Crest	Anteroposterior Movement Posterior Apposition minus Eruptive Component
Controls			
Group I Right	21.6	19.9	4.11
Group I Left	23.5	20.9	5.06
Group II Right	20.4	18.2	4.03
Average	21.8	19.7	4.40
Experimental			
Group II Left	41.5	47.5	14.91
4 b. Last 7 Experimental Days (Re-established Occlusion)			
Controls			
Group I Right	23.0	19.8	5.95
Group I Left	25.4	19.9	5.73
Group II Right	21.0	19.4	5.78
Average	23.1	19.7	5.82
Experimental			
Group II Left	27.2	19.9	7.53

nificant differences between groups. The periodontal space at the bifurcation was about 16 μ wider on the right than on the left side, both in control and experimental animals. The apical space showed an asymmetry of lesser magnitude but in the same direction, which also was noted in both control and experimental groups. These differences are probably due to the inevitable asymmetry in preparation of ground sections.

Thus, no experimental effect on periodontal width was demonstrable after occlusion had been re-established for some time. Although earlier measurements are not available, the absence of all signs of compression damage makes it likely that the periodontal space was never markedly narrowed. While the teeth were out of occlusion, bone apposition at the crest of the septum averaged 47.5 μ per day. The width of the periodontal space in this area was only 95 μ and compression damage would soon have occurred if the tooth had not moved at the rate at which bone was formed beneath it. Thus a *decreased* width of the periodontal space at the bifurcation does not seem to have occurred, but an *increased* width at the apex seems possible, as will be seen.

(4) Tooth Movement

First Period: Controls: In the three sets of control measurements, eruption estimated at the interradicular crest averaged 19.7 μ per day (Table 4a). Eruption estimated as the sum of the apposition of cementum and fundic bone was about 10 percent higher in each group. The distal movement averaged 4.4 μ per day.

Experimental: Estimated at the interradicular crest, eruption on the experimental side was 47.5 μ. Estimated as the sum of cementum and fundic bone it was 41.5 μ. Since the periodontal space above the interradicular septum is narrow, it is probable that the tooth erupted according to the larger rather than the smaller rate of bone formation.

Table 5

Roentgenographic Measurements at the End of the Experiment

5 a. Vertical Dimensions (mm) and Vertical Dimensions in Relation to Total Height of Mandible

Group	Mesial Alveolar Crest, First Molar	Ratio	Height of First Molar	Ratio	Height of Crown First Molar	Height of Occlusal Plane	Ratio	Overall Height
Controls								
Group I Right	6.46 ± .039	.571	8.04 ± .037	.710	1.58 ± .018	7.78 ± .032	.687	11.32 ± .158
Group I Left	6.37 ± .052	.573	7.95 ± .054	.716	1.58 ± .028	7.77 ± .048	.699	11.10 ± .174
Group II Right	6.23 ± .046	.573	7.84 ± .049	.722	1.62 ± .034	7.67 ± .043	.706	10.87 ± .244
Experimental								
Group II Left	6.39 ± .065	.587	8.19 ± .063	.753	1.81 ± .044	7.87 ± .051	.723	10.88 ± .224

5 b. Horizontal Dimensions (mm) and Ratio of Horizontal Dimensions

Group	Antemolar Segment	Molar Bearing Segment	Retromolar Segment	Ratio Antemolar: Retromolar Segment	Overall Length
Controls					
Group I Right	6.48 ± .052	7.3	10.60 ± .066	0.61	24.38 ± .101
Group I Left	6.41 ± .042	7.4	10.15 ± .085	0.63	23.91 ± .113
Group II Right	6.26 ± .064	7.4	10.26 ± .104	0.61	23.87 ± .129
Experimental					
Group II Left	6.67 ± .056	7.3	9.95 ± .118	0.67	23.86 ± .178

This suggests a widened apical periodontal space at the end of the first period.

The distal movement on the experimental side was 14.9 μ per day, or nearly 3.5 times that of the control average.

Second Period: Controls: According to both estimates, eruption in the control groups was not significantly different during the second period from that in the first period (Table 4b). The measurements at the apex were again slightly larger than those at the crest. The anteroposterior movement was slightly larger than before.

Experimental: Measured at the crest, the eruptive movement following re-established occlusion exactly equalled that in the controls. Measured at the apex, some acceleration persisted.

Whereas in the period of relieved occlusion the apical estimate of eruption was 14.4 percent smaller than the estimate at the crest, it was 36.7 percent larger in the period of re-established occlusion. This discrepancy between the two estimates is larger than any encountered in control groups. The smaller apical estimate in the first period was due to the fact that cementum showed only a slight acceleration of growth. Its larger size in the second period was due to the fact that growth at the crest had returned to control values, whereas growth at the apex remained accelerated. The early deficit in apical growth may have led to a widened periodontal space at the apex at the time occlusion was re-established. This "vacuum" may have permitted the persistence of accelerated bone and cementum formation, until normal periodontal dimensions were re-established.

The anteroposterior movement was still somewhat accelerated but had returned to the same order as in the controls.

Measurements from Roentgenograms

(a) Effects of Relief of Occlusion on Intramandibular Dimensions.

The roentgenographic measurements were made at the end of the experiment, after occlusion had been re-established for about seven days.

The experimental animals had body weights identical with the group of normal animals but had slightly smaller mandibular dimensions. This was true for the overall size of the mandible on both sides and for the intramandibular dimensions on the intact side.

Measurements Perpendicular to the Occlusal Plane: Comparing the experimental side of the jaw with the intact side, significantly greater heights were measured for: the mesial alveolar crest of the first molar; the total height of the first molar, the height of the crown of the first molar, and the level of the occlusal plane (Table 5a). The experimental side exceeded the control side and also both sides in the normal animals. Because of the larger size of the latter animals the differences were usually not statistically significant.

Not only the absolute, but also the relative heights of these landmarks were greater than in the three control sets of measurements. Thus relief of occlusion, resulting in excess apposition of alveolar bone, caused shifts in the relative vertical position of the occlusal plane that were marked enough to be demonstrable on roentgenographic measurements made a week later.

Horizontal Measurements: A marked effect of the relief of occlusion was observable with respect to anteroposterior dimensions and the relative anteroposterior position of the molars (Table 5b). The length of the molar-bearing segment was similar on right and left sides of control and experimental animals. In the experimental animals the antemolar segment on the operated side of the jaw was longer and the retromolar segment shorter than in the other three sets of measurements. The difference in antemolar length from each of the three control averages was statistically significant; the difference in retromolar length was of borderline statistical significance.

The relative anteroposterior position of the molars was altered in the direction of a posterior displacement on the experimental side. Relief of occlusion thus resulted in excessive posterior drift of the molars that was marked enough to be discernible on x-rays as a change in their relative position seven days after re-established occlusion.

(b) Effects of Relief of Occlusion on Overall Dimensions of Mandible.

Relief of occlusion had no effect on the overall dimensions of the mandible (Table 5). Both mandibles of the experimental animals were of identical height and length and were smaller than those in the group of normal rats. Thus accelerated alveolar bone growth did not lead to parallel increases in size of the mandible; instead it resulted in a change in the relative position of the molars in an upward and posterior direction.

Discussion

1. Relation Between the Growth of Alveolar Bone and Condylar Growth

In undisturbed postnatal development, the height of the ramus of the mandible is chiefly dependent on condylar growth,[7] but the height of the body is chiefly dependent on alveolar bone growth.[8] The mandible cannot grow into its normal adult shape unless the rates of condylar and alveolar growth are correlated. The present study has shown that in the absence of masticatory function these two rates are out of step. Removal of the molars from occlusal contact resulted in growth of alveolar bone at two to three times the normal speed. The rate of growth at the condyle did not change. The result was that the body of the mandible grew to a disproportionately great height.

In our experiment the molars were out of occlusion for nine days and the observed disproportion between the height of the body and that of the ramus was at the borderline of accuracy obtainable with roentgenograms. Cimasoni and Becks,[9] however, have recently reported on rat molars kept out of occlusion for longer periods by extraction of antagonists, beginning with animals of a similar age as ours. Their quantitative observations were limited to measurements on roentgenograms, and a direct comparison of the rates of bone growth is not possible. However, they observed that after 60 days the vertical dimension of the mandible in the molar region was 1.7 mm greater on the experimental side than on the control side. This corresponds to an average daily difference of 28 microns, a figure which is comparable to the 27 microns of excess bone formation per day observed in our animals. Thus the acceleration of alveolar bone growth seems to have persisted during the whole two months' period of Cimasoni's and Becks' experiment. The overall height of the mandibular ramus was unchanged in their animals also. The prolonged absence of occlusal contact thus gave rise to a progressive distortion of the shape of the mandible, because the rate of alveolar growth remained speeded up but that of condylar growth remained normal. The effect of masticatory activity therefore must be a reduction of the rate of alveolar growth.

These experiments show that alveolar growth can be accelerated without affecting the rate of condylar growth. Condylectomy produces a situation in which condylar growth is abolished, but alveolar growth continues, at least for as long as the positioning of the mandible is such as to provide space for tooth movement.

In these experimental situations, the condyle does not have an inducing or regulating role in determining the alveolar growth rate. Alveolar growth has been independent of condylar growth, and has expressed its own inherent high growth potential. Nevertheless, it remains a fact that, in undisturbed postnatal development, condylar growth and attrition are the mechanisms by which space for tooth movements is provided. Condylar growth clearly does not induce alveolar growth. But inasmuch as it determines the rate at which space becomes available, it determines the degree of inhibition to which the inherent alveolar growth potential will be subjected.

Condylar growth may therefore be called an indirect determinant of the growth in height of the body of the mandible, and masticatory activity its regulating mechanism.

2. Role of Mastication

A second conclusion from our experiment is that masticatory function has a regulatory action on the growth in height of the alveolar process. The operating principle is regulation by inhibition: an inherently high potential growth rate is reduced to one correlated with the rate at which space for tooth movement becomes available. Since mastication also causes attrition of the crowns and thus adds to the provision of space through condylar growth, masticatory forces also exert a slight influence in the opposite direction. The resultant of the two effects was assayed in the present study.

It is clearly of adaptive value that growth in height of the body of the mandible occurs through formation of bone in and about the dental alveoli, because occlusal movements of the teeth thus become a concomitant of postnatal growth, and a mechanism is thereby provided for maintaining the level of the occlusal plane despite the downgrowth of the growing mandible. It is of further adaptive value to put masticatory activity itself in the service of regulating the amount of alveolar growth, since by this means the occlusal contact of the teeth remains adapted to the needs of the developing masticatory apparatus.

3. Anteroposterior Drift

Whereas accelerated vertical eruption after release from occlusion has previously been reported,[10,11,9] the finding of accelerated growth of bone at the posterior surfaces of the septa has not previously been noted. According to our measurements, this acceleration was even more marked than that of bone growth on surfaces parallel to the occlusal plane.

Apposition on posterior surfaces of the septa results in anteroposterior displacement of the teeth. Since increase in length of the mandible is more rapid posterior than anterior to the molars,[12] distal drift counteracts a potential relative shortening of the antemolar segment. Thus it serves to maintain a mechanically efficient position of the molars and therefore represents an adaptive mechanism to the mode of longitudinal growth and to approximal attrition.[2] Unlike apposition of bone on surfaces parallel to the occlusal plane, which is an element in the postnatal growth in height, apposition on alveolar surfaces perpendicular to the occlusal plane does not contribute to the enlargement of the mandible in any direction.

The anteroposterior component of tooth movement is not dependent on provision of space through condylar growth; instead it depends on coordinated apposition and resorption of bone at the sides of the moving tooth. But for preservation of proper proportions during postnatal development, the anteroposterior component of tooth movement also requires correlation of its rate with that of condylar growth and of contact attrition. An inherent high potential for bone growth is found to exist on posterior septal surfaces also, and again the developmental task consists in reducing the full potential rate to a rate in harmony with the condylar rate of growth. As in vertical growth, the inhibitory regulation is through masticatory function. This finding directly contradicts theories of horizontal tooth movements based on functional forces as the causative agent.

4. Comparison of Incisors and Molars, and Response of Cementum

As has often been observed, removal of the antagonists results in a more than doubled rate of incisor eruption.[13,14,15,16] Eruption of the incisors does not depend on the growth of alveolar bone but on the growth of the tooth itself. In the absence of masticatory function, the incisor, a continuously growing tooth, increases its rate of tissue proliferation and differentiation. This may be viewed as the direct opposite of the response of the molar, a tooth with limited growth. At the age of our animals the cementum still contributes one-half to the eruptive movement by lengthening of the roots. However, it responded to the relief of occlusion with a barely demonstrable degree of acceleration. A similar lack of response of the cementum to experimental interference in contrast to the marked response of the alveolar bone was noted in the condylectomized series to be reported elsewhere.[6]

The findings of this study have led us to conclude that the postnatal changes in height of the body of the mandible and in tooth position occur in adjustment to, but not by adjustment through, the events at the condyle. Correlated changes are mediated through (1) a high potential for alveolar bone growth at all surfaces parallel to the occlusal plane and at the posterior surfaces of the bony septa (and a correlated potential for resorption at anterior surfaces), and (2) an inhibitory regulating mechanism which resides in the rat's own masticatory activity, and through which alveolar bone formation and tooth movements are adjusted to the space provided through condylar growth and attrition.

When subject to masticatory control and also when released from it, bone formation at the different alveolar surfaces proceeds at different rates. Release from masticatory control caused these rates to accelerate to similar degrees and therefore probably did not cause a major change of direction of the resultant occlusodistal movement of the molars. It remains to be explored whether all experimental procedures which affect alveolar bone growth likewise have comparable effects on the rates at all surfaces.

The growth of cementum is not subject to the same controlling mechanism.

Summary

The effects of release from occlusal contact and of re-establishment of contact on the growth of alveolar bone and the movement of the molar teeth were studied in 66 male rats of the Holtzman strain aged 54 days at the beginning of the experiment. Release of the mandibular molars from occlusal contact for about nine days was secured by grinding the maxillary molars to the level of the gingiva. Re-established occlusal contact was observed for the seven days following. Alizarin was given at the time of grinding the maxillary teeth and nine days later. Bone growth was estimated from measurements on roentgenograms obtained at the time of sacrifice and on ground sections of the alizarin-stained mandibles.

The alveolus responded to relief of occlusion by forming bone at two to three times the control rates at surfaces parallel to the occlusal plane and at posterior surfaces of the bony septa, and by accelerated resorption at ante-

rior surfaces of the bony septa. Growth of apical cementum was only slightly accelerated. Re-establishment of occlusion was followed by return to control rates of bone formation. Increased vertical dimensions, an increase in the relative height of the occlusal plane, and an increase in the relative length of the antemolar segment of the mandible were noted in the roentgenograms. Total height and length of the mandible were unaffected.

It was concluded that the postnatal changes in height of the mandibular body and in tooth position, although occurring in adjustment to events at the condyle, are not mediated by these events. Correlated changes are mediated through (1) a high potential of alveolar bone growth, and (2) an inhibitory regulating mechanism which resides in the animal's own masticatory activity, and through which alveolar bone formation and tooth movements are adjusted to the space provided by condylar growth and attrition.

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