The Effects of Reduced Attrition on Craniofacial and Dentoalveolar Development in the Rat

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Once teeth have erupted into occlusal contact further eruption occurs when there is space in the vertical dimension. In the rat such space occurs as the mandible is carried downward and forward during growth, but is also influenced by mastication and attrition of the molar teeth.[6,7,10,15,17,18]

Animal experiments have demonstrated that mastication has a dual and paradoxical role. The attrition resulting from mastication provides space for tooth eruption. Occlusal contact of the teeth, however, has also been shown to have an inhibitory effect upon the eruption rate of teeth.[11,13,19]

The present study was undertaken to study the effects on the teeth and their supporting structures by the elimination of attrition. For this purpose an experimental group of rats was given a liquid diet expected to eliminate or largely reduce molar attrition. By means of measurement on head radiographs, the effects on tooth eruption, alveolar bone formation, condylar growth, and overall craniofacial development were studied.

Materials and Method

Thirty-six male Sprague-Dawley rats were divided equally into two groups. The control group was fed the standard Rockland Rat Pellets and water ad libitum. The experimental animals received the same pellets ground to a fine powder and kept in suspension by a mixture of Metrecal and water (630 gm powder: 240 cc Metrecal: 1020 cc water).

The control animals averaged 89 days (± 1) of age at the beginning of the experiment while the experimental group averaged 90 days of age (± 1). The experimental period was 28 days.

Initially, each animal was anesthetized with nembutal and then placed in a holding device, the mandible being held in centric occlusion by means of an extraoral acrylic splint. A lateral cephalogram was taken at a five foot target-film distance utilizing a standard, occlusal-size dental X-ray film placed 1¼ inches from the midline of the rat. A small hole was then ground in the anterior surface of all four first molars with a round dental burr and impressions of the anterior aspect of the first molar teeth (still in centric occlusion) were taken using stick compound material. Each animal received a 4.0 mg/kg of body weight injection of lead acetate intravenously as a vital stain. Only the X-ray material will be discussed in this paper.

Lateral cephalograms were taken at the start and the conclusion of the experiment. After the animals were sacrificed, the heads were sectioned sagittally, a second set of roentgenograms taken of the half skulls, and used for final mandibular and incisor measurements. All other measurements recorded were from the full skull X-rays.

All X-rays were enlarged 3.55 × (± .03) and the films traced for measurements. To minimize error in identification of landmarks or measurements recorded each X-ray was traced no less than twice on separate occasions.

Given before the Univ. of Illinois Orthodontic Alumni Society, March 1976.

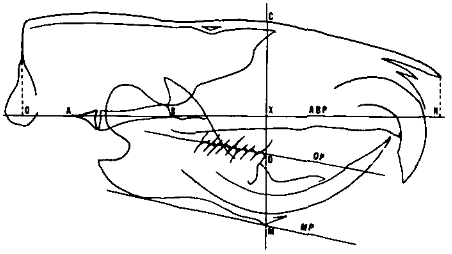

Fig. 1 Cranial landmarks and planes.

Roentgenographic Measurements

A grid coordinate system (Fig. 1) was constructed on the tracings utilizing radiographically recognizable points of the rat's cranial base.[9] A line connecting point A (the most posterior extension of basioccipital) and point B (the most inferior portion of the synchondrosis separating the presphenoid from the basisphenoid) was used as the abscissa. A perpendicular to this A-B plane was erected to lay tangent to the mesial surface of the mandibular first molar (point D). This line was extended to cross the superior border of the cranium (point C) and the lower border of the mandible (point M). All linear craniofacial measurements were made utilizing this coordinate system.

Angular measurements were taken between the occlusal plane, the mandibular plane, and the AB plane.

A tangent to the lower border of the mandible (mandibular plane) was used as a reference plane for all mandibular measurements (Fig. 2). From this plane, perpendiculars were erected so that the over-all length and height of the mandible and its various components could be measured.

The rates of incisor eruption and attrition could not be studied directly on the X-ray films. Instead, examinations of the X-rays for changes in the bevel angle, length of the bevel blade, and width of the pulp chamber of the incisor teeth were made, since all of these offer indirect evidence of the rates of incisor eruption and attrition (Fig. 3).

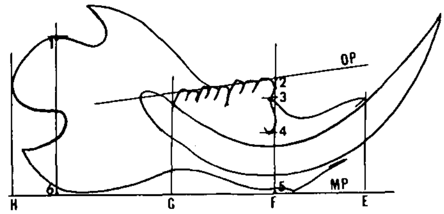

Fig. 2 Mandibular landmarks and measurements. A) Over-all length: Distance EH measured from the most anterior portion of the lingual alveolar crest to the most posterior portion of the condyle head. B) Over-all height: Distance 1-6 measured from the most superior aspect of the condyle head to MP. The remaining vertical measurements were taken along a line ⊥ to the mandibular plane and tangent to the mesial surface of the first molar. C) First molar crown height: Distance from OP (2) to the mesial alveolar crest (3). D) First molar height: Distance from OP (2) to the tip of the mesial root of the lower first molar (4). E) Height at the fundus: Distance from the apex of the mesial root of the first molar (4) to MP (5). F) Height at the crest: Distance from the mesial alveolar crest (3) to MP (5).

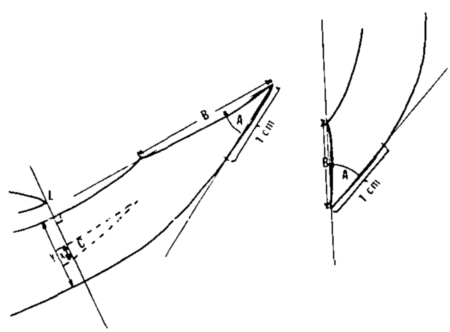

Fig. 3 Illustration of incisor measurements. A) Bevel angle: formed by the intersection of two lines, one defining the blade of the incisor and the other determined by the incisor tip and a point 1 cm from the tip on the curvature of the labial surface of the tooth. B) Length of the bevel blade: measured along the tangent to the blade passing through the tip of the incisor and the most posterior extent of the "chisel" edge. C) Relative width of the pulp chamber: the numerical value of the ratio x/y measured along a perpendicular to the long axis of the lower incisor at the level of the lingual alveolar crest of the lower incisor.

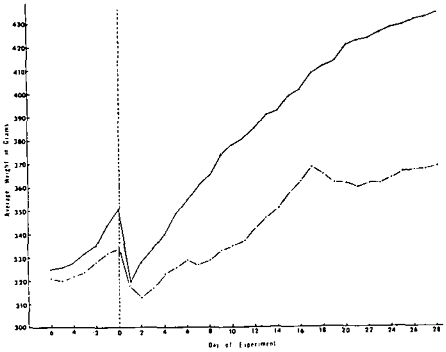

Fig. 4 Graph of weight gains. The experimental group is shown in solid line and the controls are represented in the broken line.

Results

Weight Gain

The average daily weight of each group is shown in Figure 4. Both groups of rats were allowed to acclimatize and adjust in their new environments for one week prior to the beginning of the experiment. During this observation period all rats were fed the standard unground pellets and weighed daily. By chance, the future experimental group had experienced a higher rate of gain in body weight during this period. Both groups experienced a drop in weight at the start of the experiment with the experimental group losing more. During the remainder of the investigation both groups recovered their initial weight loss and continued to gain weight at dissimilar rates, the experimental group growing faster throughout the experiment.

Craniofacial Measurements (Table I)

Over-all skull length increased at the rate of 48.3 μ/day in the controls and 59.4 μ/day in the experimental group. This represents an experimental rate of increase that is 25% higher than the control rate.

Skull height increased 17.1 μ/day in the control group and 24.1 μ/day in the experimental group. The experimental rate was 42% higher than the control rate.

Since the vertical differences were of a larger magnitude, the craniofacial components contributing to the over-all vertical dimensions were studied next. The dimensions above and below the occlusal plane were studied first.

The region above the occlusal plane

TABLE I - CRANIO-FACIAL MEASUREMENTS

DATA	DIFFERENCE (mm) (INITIAL VS FINAL)	RATE (u/day)	% CHANGE (EXPERIMENTAL VS CONTROL)
A) Overall Skull Length			
Control	1.36	48.3	25%*
Experimental	1.66	59.4	
B) Overall Skull Height			
Control	0.48	17.1	42%
Experimental	0.68	24.1	
C) Dimensions Above Occlusal Plane			
Control	0.54	19.1	-05%
Experimental	0.51	18.1	
D) Dimensions Below Occlusal Plane			
Control	-0.06	- 2.0	500%
Experimental	0.23	8.1	
E) Dimensions Above AB Plane			
Control	0.31	11.0	-45%
Experimental	0.17	6.0	
F) Dimensions Below AB Plane			
Control	0.17	6.0	300%*
Experimental	0.51	18.1	

*Significant (P<.05)
*Highly Significant (P<0.01)

TABLE II - MANDIBULAR MEASUREMENTS

DATA	DIFFERENCE (mm) (INITIAL VS FINAL)	RATE (u/day)	% CHANGE (EXPERIMENTAL VS CONTROL)
A) Overall Mandibular Length			
Control	1.46	52.3	25%*
Experimental	1.83	65.3	
B) Overall Mandibular Height			
Control	0.06	2.0	800%**
Experimental	0.45	16.1	
C) Measurements of the Molar Bearing Segment			
1. Total Height of First Molar Area			
Control	0.12	4.0	480%*
Experimental	0.54	19.1	
2. Height at the Fundus			
Control	0.06	2.0	450%**
Experimental	0.25	9.0	
3. First Molar Height			
Control	0.06	2.0	500%*
Experimental	0.28	10.0	
4. Height at the Alveolar Crest			
Control	0.06	2.0	450%
Experimental	0.25	9.0	
5. Molar Crown Height			
Control	0.06	2.0	530%*
Experimental	0.29	10.5	

*Significant (P<.05)
**Highly Significant (P<.01)

combines the nasal cavity and maxillary dentoalveolar area. The rate of growth was similar for the control and experimental animals, 18.1 and 19.1 μ/day, respectively. Below the occlusal plane are the mandibular body and the mandibular dentoalveolar area. This dimension showed a marked experimental effect with the controls decreasing at the rate of 2 μ/day, while the experimental group showed an increase at the rate of 8 μ/day.

To better understand the vertical nasomaxillary changes the areas above and below the AB plane were investigated. The area above the AB plane consists mainly of the nasal cavity while the maxillary and mandibular dentoalveolar structures and the body of the mandible lie below the AB plane.

The area above the AB plane increased at the rate of 11.0 μ/day for the controls and half as much, or 6.0 μ/day, for the experimental animals.

The dimension below the AB plane increased at a rate of 6.0 μ/day in the controls while it increased at a rate three times greater, or 18.0 μ/day in the experimental animals.

Mandibular Measurements (Table II)

Over-all mandibular length increased at a rate of 52.3 μ/day in the control animals and 65.3 μ/day in the experimentals, a 25% increase versus the controls.

Mandibular height measured at the condyle increased 2.0 μ/day in the controls and eight times that rate or 16.0 μ/day in the experimental animals. This multiple of increased experimental growth versus the control was the highest of any area measured in the study.

The vertical dimension of the mandibular molar-bearing segment was investigated in more detail to ascertain the adjustments occurring as a result of our diet. The location of the various components of this dimension can be found in Figure 2 while a graphic representation has been provided in Figure 5.

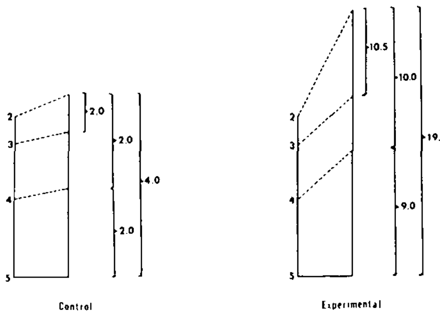

Fig. 5 Diagram representing events in the molar area during the experimental period. Landmarks shown are (2) occlusal plane, (3) alveolar crest at the mesial of the lower first molar, (4) apex of the lower first molar mesial root, and (5) mandibular plane. X represents the beginning of the experimental and Y represents the completion. The figures to the right represent the rates of increase during the experiment (μ/day).

In the control animals the total height of the mandibular body at the area of the first molar (2-5) increased at a rate of 4 μ/day over the 28 day experimental period. Two areas shared in this increase: (a) the height of the fundus from the lower border of the mandible (4-5) increased at a rate of 2 μ/day and (b) the total length of the mandible first molar (2-4) also increased 2 μ/day. It should be kept in mind this increase in tooth length occurred in spite of the attrition that results from normal masticatory function. The distance from the lower border of the mandible to the mesial alveolar crest (3-5) also increased at a rate of 2 μ/day as did the molar crown height when measured from the mesial alveolar crest (2-3).

The experimental animals enjoyed significantly higher rates of vertical growth throughout the molar area. Total height (2-5) increased at a rate of 19.1 μ/day, almost five times greater than the controls. Again the height of the fundus and the length of the mandibular molar were responsible for this increased dimension. The height of the fundus (4-5) increased at the rate of 9.0 μ/day while the total length of the mandibular first molar (2-4) increased 10.0 μ/day. Both of these increments of growth were four to five times greater than the control values. The mesioalveolar crest growth again kept pace with fundic growth increasing at the rate of 9.0 μ/day. Molar crown height as measured from the mesial alveolar crest to the occlusal surface also increased at four to five times the control rate or 10 μ/day.

Angular Measurements (Table III)

Angular measurements were taken to see if the difference in vertical growth between our two groups produced a parallel displacement or rotation of the mandible in its relation to the cranium. The findings are illustrated in Figure 6.

TABLE III - ANGULAR MEASUREMENTS

DATA	DIFFERENCE (mm) (INITIAL VS FINAL)	% CHANGE (EXPERIMENTAL VS CONTROL)
A) Angle: Mandibular Plane to the AB Plane		
Control	-0.8°	260%**
Experimental	$+1.3^{\circ}$	
B) Angle: Occlusal Plane to AB Plane		
Control	$+0.3^{\circ}$	100%
Experimental	$+0.6^{\circ}$	
C) Angle: Mandibular Plane to the Occlusal Plane		
Control	-1.1°	170%
Experimental	$+0.7^{\circ}$	

**Highly Significant (P<.01)

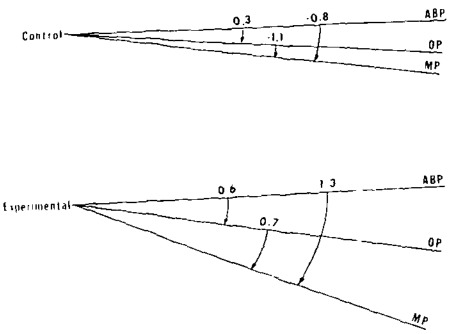

Fig. 6 Diagram of changes occurring between the various reference planes: (ABP) AB plane, (OP) occlusal plane, and (MP) mandibular plane.

The angle MP to AB plane showed a mean decrease of 0.8° in the control group while it increased 1.3° in the experimental group. This difference in behavior is due to the clockwise rotation of the mandible in the experimental group.

The angle between the occlusal plane and the AB plane showed no experimental effect and behaved the same in both groups.

The angle between the occlusal plane and the mandibular planes decreased 1.1° in the controls and increased .7° in the experimental group.

Incisor Changes (Table IV)

Because of the marked experimental changes in the molar area, the incisor teeth were also examined. Our measurements are given in Figure 3.

The bevel angle of the control animals increased about 3.0° in the upper incisor and 1.1° in the lower. In the experimental animals the bevel angle decreased by 1.0° in the upper and 1.9° in the lower. The length of the bevel blade decreased in the control animals at the rate of 5.0 μ/day in the upper incisor and 61.4 μ/day for the lower incisor. The experimental animals showed an increase in the length of the bevel blade at the rate of 11.1 μ/day in the upper and 32.3 μ/day in the lower. Measurements of the width of the pulp chamber of the lower incisor showed a slight decrease in the experimental animals when compared with the controls.

Discussion

Weight Gain

The animals were received in two shipments about three weeks apart. The initial group received was used for the control group. The second group was used as experimental animals. Obviously, each shipment should have been divided equally among control and experimental groups to avoid the ensuing problem of different growth rates. The

TABLE IV - INCISOR CHANGES

DATA	DIFFERENCE (mm) (INITIAL VS FINAL)	RATE (μ/day)	% CHANGE (EXPERIMENTAL VS CONTROL)
A) Incisor Bevel Angle			
Control-Upper	+3.0°	—	130%**
Experimental-Upper	-1.0°	—	
Control-Lower	+1.1°	—	270%**
Experimental-Lower	-1.9°	—	
B) Length Bevel Blade			
Control-Upper	-0.14	-5.0	320%**
Experimental-Upper	+0.31	11.1	
Control-Lower	-1.72	-61.4	150%**
Experimental-Lower	+0.90	32.2	
C) Width of Pulp Chamber			
Control	+0.112	—	180%**
Experimental	-0.092	—	

**Highly Significant ($P<.01$)

discrepancy in rate of weight gain between the groups first appeared in the preexperimental period and continued during the experiment. At the conclusion of our study the average body weight of the experimental group was almost 20% greater than the control average. While this greater gain in body weight certainly substantiated the nutritional adequacy of the liquid diet, it complicated the evaluation of the findings. The use of Metrecal as a suspending agent in the liquid diet introduced a variable which in part could explain the higher weight gain the experimental group experienced. Rats have been shown to have a preference for foods containing sucrose[20] (a major ingredient of Metrecal). This, coupled with the ease of obtaining nourishment, liquid versus solid food, probably resulted in our experimental group ingesting more food. These faults in experimental design add to the difficulty in interpreting the findings.

Skeletal Measurements

Due to the large difference in weight gained between the two groups, it was important to determine if the increased body weight of the experimental animals reflected increased skeletal growth or merely a greater obesity of the animals. The skulls of the experimental animals grew at rates 25% greater than the controls in over-all length and 42% greater in over-all height. Because the attritional effects of the liquid diet would be expected to express themselves more directly in the vertical dimension, the experimental figure for length increase of 25% likely reflects a greater experimental rate of skeletal growth as found in our weight measurements. On this basis the 42% increase in height represents not only the 25% experimental growth increase due to diet and sample difference, but also the effects of the liquid diet on the masticatory apparatus.

Interestingly, when the mandible was studied alone, the increase in over-all length once again was 25% higher in the experimental group. Over-all height, as measured at the condyle, differed dramatically, with the experimental group growing at a rate that was eight times greater than the control rate.

Masticatory Response to Liquid Diet

The purpose of using a liquid diet in the present study was to eliminate the need for mastication thereby decreasing or eliminating occlusal contact of the molar teeth. Because of the marked increase in vertical craniofacial dimensions experienced by the experimental animals, we feel this objective was achieved. To better understand this increased vertical response the components of the craniofacial complex were examined. Proceeding in a superior to inferior direction, the following facts were demonstrated. The nasal cavity of the experimental rats grew at one half the rate of the control animals. The distance from the skull roof to the occlusal plane grew at the same rate. This occurred because the maxillary dentoalveolar complex increased at a higher rate in the experimental animals. This increased dimension took place at the expense of the nasal cavity.

In the mandible the distance from the occlusal plane to the lower border of the mandible increased at a rate that was five times greater in the experimental animals. This increased dimension could have been caused by bone apposition at the lower border of the mandible or by an increased contribution of the mandibular dentoalveolar complex. It is our belief that it was the latter factor. Previous work strongly supports our position. Cleall et al.[4] measured rates of bone formation in rats where the maxillary molar teeth had been extracted unilaterally. While they found the lower border of the mandible to be a site of bone growth, they did not demonstrate any change in its rate of growth as a result of the experiment. Many authors[3,7,11,14,15] demonstrated increased rates of alveolar bone growth in the fundus and interradicular bone of the mandibular molars following the removal of maxillary molars from occlusal contact. Their histologic studies showed increased rates of alveolar bone formation two to three times greater than the control.

Radiographic measurements taken from the lower border of the mandible to the mesial alveolar crest and to the fundus show an experimental increase in the present study. We, therefore, conclude that part of the increased vertical dimension experienced by the experimental animals is due to increased rates of alveolar bone formation, a finding in agreement with the above authors. As reported by Schneider and Meyer,[11] function inhibits the full expression of alveolar bone formation; if function is eliminated, this higher potential of alveolar bone formation is allowed to express itself.

An additional factor contributing to the increased vertical dimension found in the experimental animals is the increased length of their molar teeth. In the controls, total molar tooth length increased at a rate of 2.0 μ/day and in the experimental animals it increased 10 μ/day. This difference was due to reduced attrition of the experimental molar teeth. While one could argue that the increased tooth length observed was due to differences in the rate of cementum formation, this has not been substantiated in other studies which found cementum formation to be relatively unresponsive when molars have been removed from function.[11,14,15] Thus, in the present study the fivefold increase in the rate at which the experimental teeth lengthened may in a small part be due to an increased rate of cementum formation; the largest portion of this increase was due to the absence of molar attrition.

In summary, the increased vertical dimensions of the craniofacial complex found in our experimental animals are due to increased rates of alveolar bone formation and to the absence of molar attrition.

The changes we observed in the angular relationship between the AB, occlusal and mandibular planes occurred in such a manner that implies the mandibles of the experimental animals rotated in a clockwise direction. Such a rotation is not unexpected if one considers the increased dentoalveolar dimensions experienced by this group.

Sites of Adjustment

Since both maxillas and mandibles of the experimental animals experienced increases in the vertical dimensions of their molar bearing areas, one could theorize that these teeth infringed upon the freeway space between them. This space represents the distance between upper and lower teeth when the mandible is in its rest position. In man, when the freeway space has been infringed upon, teeth are usually depressed until the original space is reestablished.[13]

This did not occur in the present study as evidenced by the increased craniofacial vertical dimension of the experimental animals, i.e., 42% greater than controls. What did occur was a displacement of the mandible to provide the necessary space. Evidence of this displacement is offered by the clockwise rotation of the mandible as discussed above, plus the relatively larger dimension of mandibular height when measured at the condyle. Experimental rates of growth were eight times larger than control rates. Whether this increased growth occurred at the condyle, lower border of the mandible, or a combination of these will require completion of the histologic portion of this study.

The nasal cavity provided an additional site of adjustment for the increased dimensions of the maxillary dentoalveolar unit. In the experimental animals the vertical dimension of the nasal cavity increased at only one half the rate it did in the control animals. This response was unexpected especially when viewed from the "function matrix" concept of cranial growth which insists on independence of its functional cranial units.[10]

Difference In Response of Molars and Incisors to Lack of Attrition

In the incisal region the experimental group behaved differently from the controls showing a decrease in bevel angle, increase in length of bevel blade, and a reduction in the width of the pulp chamber. All of these provide indirect evidence that incisor teeth erupt at a slower rate when placed on a liquid diet. Interestingly, this is the opposite of our findings in the molar area.

To understand this difference in behavior requires a more complete understanding of how the rat incisors function. To the rodent, incisor function is of prime importance to survival. A rather elaborate mechanism has evolved to maintain an effective incisal edge. In normal function, breakage of the incisal edge occurs. To reestablish a sharp edge the rat resorts to grooming or special attritional activity.[19] Grooming is accomplished when the rat passes its upper and lower incisors back and forth past one another. This restores the edge of the incisor and maintains an optional tooth length which is in harmony with the muscles of mastication. Because of the liquid diet used, we theorize less breakage of the incisor edge occurred resulting in a longer tooth with a sharper, more pointed edge. The resultant long incisor, if left intact, would soon render the tooth useless since it would lengthen beyond the point where it could occlude with its antagonist. In an attempt to maintain the optimal length of the incisor we hypothesize that the experimental animals resorted to increased amounts of special attritional activity which ultimately produced a functional load and a decrease in the rate of experimental incisor eruption. While the lack of mastication due to the liquid diet ultimately caused an increased functional load on the incisor teeth via grooming, its effect upon the molar teeth was the relief of occlusal forces.

Role of Attrition

Initially, this study was designed to examine the dual effect that attrition plays in mastication. Wear provides space and therefore encourages eruption; functional load causes wear but inhibits eruption. From the results of this experiment it is clear that the inhibitory effect of function is by far the more significant factor. It was surprising to see the wide range of effects that a rather simple procedure such as alteration of diet consistency produced. It is felt this study gives a clearer understanding of how the rodent masticatory apparatus functions along with additional information on the adjustive mechanisms involved in maintaining masticatory homeostasis.

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ACKNOWLEDGMENT

The authors wish to express their appreciation to Dr. Warren Wakerlin who constructed the rats' holding device and assisted in the design and performance of our study.

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