A cephalometric evaluation of edentulous Rhesus monkeys *(Macaca mulatta)*: A long-term study

Douglas H. Jaul, D.D.S.,* James A. McNamara, Jr., D.D.S., Ph.D., David S. Carlson, Ph.D.,*** and L. George Upton, D.D.S.******

University of Michigan, Center for Human Growth and Development, and School of Dentistry, Ann Arbor, Mich.

Tooth loss not only decreases masticatory function but may also contribute to excessive residual bone resorption.[1] With over 20 million denture wearers in this country,[2] excessive residual bone resorption may produce difficulties for a significant portion of our population. As a result, much attention has been directed to the problem of residual bone resorption in edentulous individuals. Although some studies of residual bone resorption due to tooth loss have involved the use of experimental animals, most studies to date have involved human subjects who were already wearing dentures or were suffering from periodontal disease.

Methods of measuring the progressive residual ridge resorption associated with tooth loss in patient populations have included the use of casts[3] and pantographic[4] and cephalometric radiographs.[3, 5, 6] Studies have evaluated the relative amount of resorption of the residual ridges,[7, 8] the type and rate of resorptive patterns seen from the time of tooth extraction,[8] and changes in facial height and mandibular morphology, particularly of the gonial region. In addition, the influence of bone density,[9] mandibular contour,[6] the type of extraction procedure,[3] and the use of prostheses[10] on the rate of residual ridge resorption have been examined.

To date, few long-term, serial animal studies have been undertaken which document the rate, location, and amount of residual ridge resorption; nor have studies monitored the changes which occur at the gonial angle, the ramus, or particularly the mandibular condyle. Although investigations by Pietrokovski and Massler[9] and Mitzutani and Ishihata[11] have approached some of these problems using Rhesus monkeys, questions of altered mandibular morphology remain unanswered while patterns of residual ridge resorption have been limited by the design and duration of the experiments.

The purpose of this study was to provide a controlled longitudinal cephalometric analysis of morphologic changes in the craniofacial skeleton of adult Rhesus monkeys following complete removal of the dentition. More specifically, serial cephalograms of adult Rhesus monkeys were made for a period of 234 weeks (approximately 4.5 years) following complete extraction of the dentition to evaluate the rate, location, and magnitude of residual bone resorption, as well as morphologic changes in the gonial region, the ramus, and the mandibular condyle.

MATERIALS AND METHODS

Maxillary and mandibular remodeling changes were studied following full mouth extractions in four young adult Rhesus monkeys *(Macaca mulatta)*. The young adult animals weighed between 5 and 6 kg and had complete permanent dentitions including fully erupted third molars, indicating that they were at least 6 to 7 years of age.[12]

Osseous implants

Twenty-nine tantalum implants[13, 14] were placed in each animal. Four implants were placed extraorally in the right side of the mandible;[15, 16] one in the symphysis, two in the body, and one in the ramus.

*Resident, University of California, School of Dentistry, San Francisco, Calif.
**Associate Professor, Department of Anatomy and Center for Human Growth and Development.
***Assistant Professor, Departments of Anatomy and Anthropology, Center for Human Growth and Development.
****Professor, Department of Oral and Maxillofacial Surgery, School of Dentistry.

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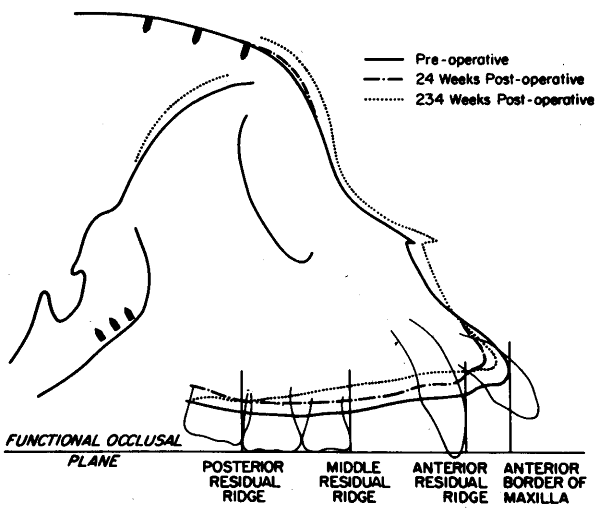

Fig. 1. Cephalometric tracings of the maxillary and cranial base regions of a representative monkey preoperatively and at 24 weeks postoperative and 234 weeks postoperative. Vertical measurements of the maxillary residual ridge were made perpendicular to the functional occlusal plane at three defined points relative to the preoperative position of the dentition: (1) mesial to the canine, *anterior alveolar process height;* (2) mesial to the first permanent molar, *middle alveolar process height;* and (3) distal to the second permanent molar, *posterior alveolar process height.* A horizontal measurement of the *anterior border of the maxillae* was constructed parallel to the occlusal plane.

Five implants were inserted laterally in the maxillary region;[15, 17] one pin was inserted in the bone between the central and lateral incisors, one pin in the palate adjacent to the canine, one pin above the first permanent molar, one pin below the orbit, and one pin adjacent to the zygomatic arch. Three implants were placed in the frontal bone by an extraoral approach. Five implants were placed in the midline of the cranial base on each side of the spheno-occipital synchondrosis by making a small incision through the soft palate and penetrating the posterior pharyngeal wall.[15, 17] The osseous implants provided a reference for superimposing successive radiographs for the purpose of measuring any changes of the craniofacial complex subsequent to complete removal of the dentition.

Extraction

Anesthesia consisted of ketamine 25 mg/kg intramuscularly and pentobarbitol sodium 50 mg/kg intravenously. Two percent lidocaine with 1:100,000 epinephrine was injected locally to promote hemostasis. One side of the dentition of both the upper and lower arches was extracted during a single operation. A mucoperiosteal envelope flap was reflected in one dentoalveolar quadrant. Using a conventional handpiece with a No. 6 round bur, the buccal alveolar bone was removed to approximately 4 mm below the crestal level from the canine posteriorly. Dental elevators and forceps were then used to remove the teeth. Conservative alveoloplasty was carried out at this point, and the wound was irrigated and closed with 3-0 chromic gut sutures. This procedure was repeated in the opposing quadrant in a similar fashion. To allow for proper feeding of the animals during the immediate postoperative period, extraction of teeth in the opposite side of the two arches was not undertaken until 2 weeks later. The monkeys were fed Purina monkey chow ad libitum and fresh fruit daily.

Cephalometrics

Each monkey was monitored with lateral cephalograms at a control stage before any surgical procedures were performed. Following the surgery, the monkeys were again radiographed using a cephalostat especially designed for primates[15] over a period of 234 weeks. Radiographs were made postoperatively at successive intervals of 2, 6, 24, 48, 72, 96, 120, 144, 168, 192, and 234 weeks.

Kodak Type M* industrial film was used to enhance visualization of detail. To reduce the relative magnitude of any tracing error, the lateral cephalograms were enlarged three times on Kodak Translite film* before tracing on 0.003 inch acetate. This enlargement procedure allowed for tracing and direct quantification of very small changes in dimensions which normally might be masked by tracing error. Skeletal changes were measured by tracing the outlines of the maxillary, frontal, and cranial base tantalum implants and noting changes between successive cephalograms.[16, 17] Residual bone remodeling was quantified by measuring contour changes in successive cephalograms.

Horizontal and vertical residual bone changes of both the maxillae and mandible were measured relative to the original (preoperative) functional occlusal plane, the orientation of which was established on the tracing of the initial headfilm (Figs. 1 and 2). Four points were established for quantifying skeletal changes in the maxillae (Fig. 1) while seven points were utilized in the mandible (Fig. 2). This provided a method of quantifying bone changes relative to the position of the bony implants in

*Eastman Kodak Co., Rochester, N. Y.

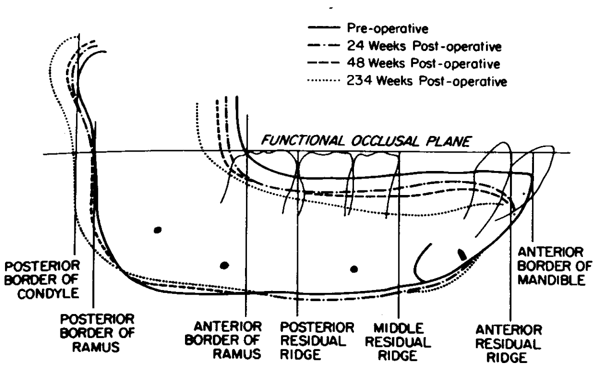

Fig. 2. Cephalometric tracings of the mandible of a representative monkey preoperatively and at 24, 48, and 234 weeks postoperative. Vertical measurements to the mandibular residual ridge were constructed perpendicular to the preoperative functional occlusal plane at three defined points relative to the preoperative position of the dentition: (1) *anterior residual ridge,* mesial to the canine; (2) *middle residual ridge,* mesial to the first permanent molar; and (3) *posterior residual ridge;* distal to the second permanent molar. The *anterior border of the mandible,* the *anterior border of the ramus,* the *posterior border of the ramus,* and the *posterior border of the condyle* were measured serially parallel to the functional occlusal plane.

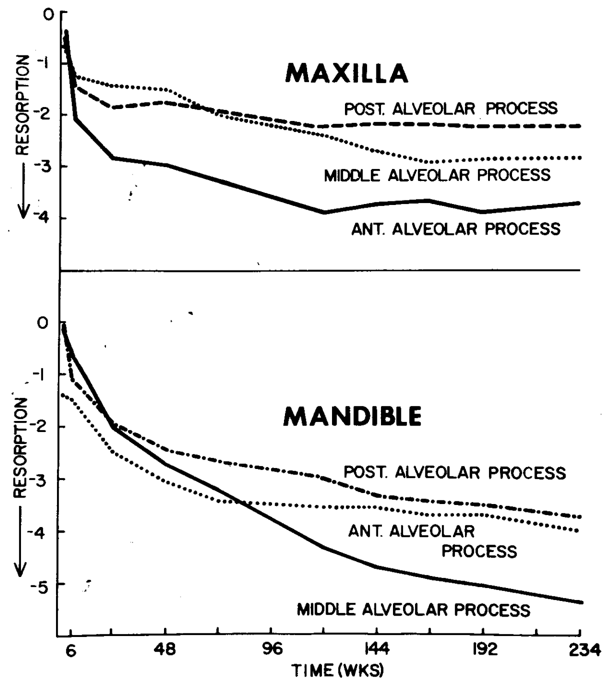

Fig. 3. Graph indicates the mean variation in the height of the alveolar processes of the maxillae and mandible. Negative values indicate an increased distance from the functional occlusal plane, i.e., alveolar resorption.

successive cephalograms. A helio caliper was used to measure successive increments of bone remodeling.

RESULTS

The morphologic changes subsequent to full mouth extractions were monitored cephalometrically using preextraction radiographs as controls. Changes in the mandible and maxillae were arbitrarily subdivided into vertical and anteroposterior adaptations.

Maxillary complex

Residual ridge adaptations. The maxillae underwent marked residual bone resorption in a vertical direction during the first 24-week period following tooth extraction (Figs. 3 and 4). From 50% to 82% of the total vertical ridge resorption (depending on the area measured) occurred during the initial 24-week postextraction period (Fig. 3). Residual ridge resorption continued more gradually through the remainder of the 234-week period in the anterior and posterior regions after the initial 24-week interval. The middle region departed from this pattern and demonstrated relatively large amounts of residual resorption (52% of the total amount resorbed) between 48 and 168 weeks postextraction. The greatest overall reduction in the vertical dimension of the maxillae occurred in the anterior region, followed by the middle region, and the posterior region.

The anterior border of the maxillae was subject to both resorptive and depositional patterns of bone remodeling (Fig. 4). The greatest amount of bone resorption occurred within the first 24-week postextraction period, after which a small amount of bone was deposited at the anterior-most region. This deposition of new bone anteriorly accounted for the replacement of approximately half of the residual ridge originally resorbed during the postextraction period.

Another radiographic finding was the remodeling changes noted in the hard palate. The distance between the superior and inferior layers of compact bone observed in the preoperative cephalogram decreased during the 234-week postextraction period in each of the four animals. The floor of the nasal cavity and the hard palate of the mouth were eventually indistinguishable, appearing as one radiopaque demarcation.

Mandible

Residual ridge adaptations. A marked amount of residual bone resorption occurred following tooth

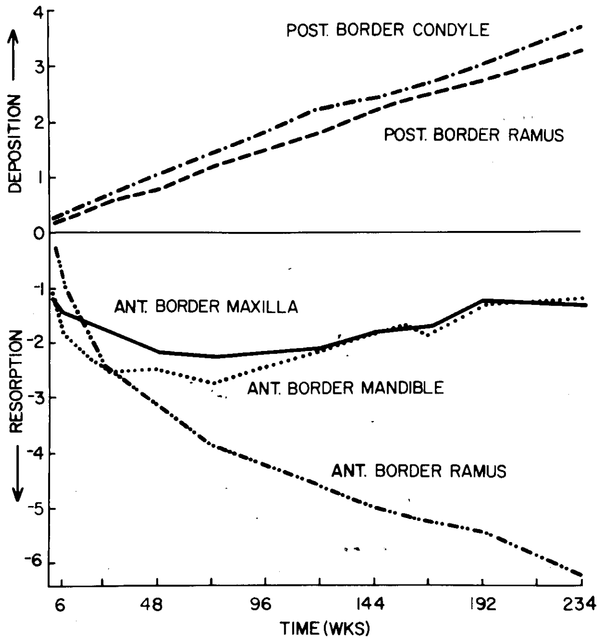

Fig. 4. Graph indicates the horizontal changes in the postion of the anterior border of the maxillae and mandible, the position of the ramus, and the position of the condyle. Negative values indicate bone resorption; positive values indicate bone deposition.

extraction. The greatest rate of mandibular residual resorption occurred during the first 24 weeks postextraction, during which time a reduction of between 42% and 63% of the total vertical height in the mandible occurred (Fig. 3). Reduction in vertical dimension was slower but continuous through the remainder of the experimental period in both the anterior and posterior regions. The middle region of the mandible demonstrated larger amounts of residual ridge resorption (51% of the total amount resorbed) between the 48 and 168 weeks postextraction. The greatest overall amount of residual ridge resorption in the mandible was found at the position mesial to the first molar, while the posterior and anterior regions of the mandibular residual ridge both evidenced a similar, though less pronounced, reduction.

The anterior border of the mandibular residual ridge (Fig. 2) demonstrated two resorptive periods interrupted by a large depositional period within the 234-week postextraction period (Fig. 4). The resorption of the residual ridge evidenced by a reduction in jaw length was uninterrupted for the first 48 weeks postextraction, after which there was a gradual reversal of this trend. Bone deposition at the anterior border continued until nearly one half of the alveolar bone resorbed during the first 48-week postextraction period was redeposited. The depositional trend continued to the end of the 192-week postextraction interval. Between the 192- and 234-week postextraction interval, resorption was again observed. Although two resorptive periods interrupted by a large depositional period were evidenced during this investigation, the mandible exhibited an overall decrease in anteroposterior dimension as a result of the resorptive process. The mandible, however, did not demonstrate as great an average amount of anteroposterior resorption as the maxillae.

Mandibular ramus. Both the anterior and posterior borders of the ramus underwent major bone remodeling, with the anterior border undergoing resorption while the posterior border was depository (Fig. 4). More specifically, the anterior border of the ramus demonstrated a rapid and extensive resorptive change which was continuous for the entire 234 weeks postextraction. By the end of the first 48 weeks postextraction, 50% of the total average amount resorbed during the 234 weeks postextraction was observed for the anterior border of the ramus.

The posterior border of the ramus had a more gradual and less extensive degree of bone deposition, thus resulting in a posterior relocation of the mandibular ramus relative to the corpus. By the end of the 48-week period, only 23% of the total amount of bony apposition which would ultimately be noted had occurred; 50% of the total resorption along the anterior border of the ramus was completed at this time. By 234 weeks postoperatively, approximately 50% more resorption of the anterior border had occurred than deposition of bone along the posterior border of the ramus, resulting in a more posteriorly located but more narrow ramus.

Mandibular condyle. During the 234 weeks following extraction, the condyle demonstrated continued bone deposition along its posterior border. Condylar growth followed a pattern similar to that observed for the posterior border of the ramus; however, the changes at the condyle were usually greater at each interval. The condyle was relocated in both a posterior and superior direction, resulting in an overall upward and backward displacement of the condyle similar to that observed at the posterior border of the ramus.

Gonial region. Continued mandibular remodeling led to an overall posterior and slightly superior relocation of the gonial region (Fig. 2). The gonial angle, measured at the intersection of the mandibular plane and a line tangent to both the posterior borders of the ramus and condyle, changed during the postoperative period, increasing between 0.6 and 2.5%.

DISCUSSION

Alveolar bone remodeling

The results of this study indicated that alveolar bone remodeling occurred in both the mandible and maxillary complex following full mouth extractions. The process of residual ridge resorption was continuous throughout the experimental period except for one interval. The finding that the resorptive process was a gradual, continuous process correlates well with those findings of Tallgren,[8] who noted that the residual ridge underwent continued reduction during 25 years of complete denture wear. A comparison of Tallgren's study of clinical patients with the present experimental study indicates that dentures alone do not cause the continuous loss of alveolar bone seen in patients, but rather that such losses occur normally during the interval following extraction. One can postulate that the loss of normal biomechanical stimuli previously provided by the physiologic function of the teeth and the associated periodontium results in an alteration in the pattern of forces usually applied to the area which, in turn, may lead to an increase in bone resorption.

Rate of alveolar resorption

The results of this study also demonstrate that the rate of aveolar bone loss is not constant, but rather can be characterized by an initial period of rapid bone resorption followed by continued bone loss at a lesser rate. In our study, at least 50% of the total amount of bone resorbed at each measured vertical point on both the maxillae and mandible occurred during the first year of the 4½-year period studied. A similar initial rapid rate of alveolar bone loss was observed by Mitzutani and Ishihata[11] in Rhesus monkeys where 70% to 80% of the total loss occurring over a 2-year period took place during the first 3 months. Although the time intervals considered in these two studies were different, both recorded an initial rapid rate of alveolar bone loss followed by a slower, more gradual rate of loss.

In human patients, Tallgren[8] noted that the reduction of the residual ridge in denture wearers was most rapid during the first year of denture wear. Wictorin[18] noted that greater amounts of ridge resorption occurred when an interval was allowed between the extractions and insertion of the denture than when the dentures were supplied immediately. The advantage of using immediate dentures is further supported by the results of our study which indicated that the greatest rate of bone remodeling occurred within the first year following extractions. The dentures may act to reduce the amount of resorption by partially insulating the residual ridge from functional trauma. Following tooth extraction the empty tooth sockets are filled only by blood clots since bone formation does not occur until much later in the healing sequence. Functional activities may contribute to increased resorption of the unprotected ridge during this period. Since surgical removal of the dentition affects the blood supply of the adjacent alveolar bone which is highly vascular,[19] the ability of the bone to resist pressures within normal physiologic limits may be compromised. Ortman[20] considered the surgical procedure a factor in the rate of bone resorption, since the internal blood supply can be vastly altered by the bone callus.

Location of residual bone remodelling

Anteroposterior adaptations. Some controversy appears in the clinical literature regarding the response of the maxillae to tooth extraction. Heath[21] reported that the anterior aspect of the maxillary residual process was relatively resistant to bone loss following tooth extraction. Tallgren,[22] on the other hand, found that the anterior portion of the maxillae underwent significant resorption following tooth loss. The results of our experimental study support the findings of Tallgren,[22] since a significant amount of resorption at the most anterior aspect of the maxillary alveolar process was observed. This pattern of initial loss in the maxillae was, however, followed by a period of bone deposition tending to reverse but not completely compensate for the initial bone loss. A similar pattern was observed in the mandible. The most anterior point of the mandible underwent an initial resorptive phase, followed by a depository phase which, however, did not replace the amount of bone that had been present prior to the loss of the dentition. The cause of this trend in both the maxillae and the mandible is unclear. Tallgren[8, 23, 24] found significant resorption of the anterior region of the alveolar process, particularly in the mandibular arch in long-term complete denture wearers who had poor denture retention. Based on electromyographic studies, Tallgren[24] hypothesized that the increased activity of the perioral and mentalis muscles in this clinical sample could have resulted in an increased amount of residual bone resorption. This hypothesis is interesting in light of the data reported herein because, if correct, it suggests that different habitual functional activity of the perioral muscles (perhaps a protrusion of the lips) could account for the depository trend along the labial surfaces of the maxillae and mandible.

Vertical adaptations. Differences have been noted in the rate and amount of residual bone resorption both between the maxillary and mandibular arches and within a single arch. Tallgren,[22, 25] for example, found that the amount of residual ridge resorption in the mandible of complete denture patients was at least four times greater than in the maxillae. According to Tallgren,[6] this interarch variability is probably due, in part, to the differences in the shapes of upper and lower arches and their suitability for bearing dentures. Similar variability between the residual ridges of the maxillary and mandibular arches was found in this study, with the mandible exhibiting between 4% and 45% greater bone loss than the maxillary, depending on the region examined. However, the fact that interarch variability was found despite the lack of a prosthesis does not support the notion that the increased rate and amount of mandibular residual ridge resorption is due to a less suitable seat for dentures.

Previous studies of ridge resorption in Rhesus monkeys[9] and humans[5] indicate that the largest amount of alveolar bone loss occurs in the posterior ridge area. Pietrokovski and Massler[9] stated that the alveolar resorption is greatest in the posterior region, owing to the larger root volume and consequently larger socket size following surgery. However, the findings of our studies demonstrate that the entire posterior residual ridge does not lose bone at the same rate. We have divided what is normally termed the "posterior" ridge area into a "middle region," just mesial to the first molar, and a "posterior region," just distal to the second molar (Figs. 1 and 2). Our results demonstrate that both regions undergo significant differences in alveolar bone loss, with the area just mesial to the first molar exhibiting the greatest amount of resorption.

An explanation for both interarch and intraarch variation in the rate and amount of alveolar bone resorption was suggested by Atwood[26, 27] and elaborated upon by Tallgren.[6, 22] Atwood noted that anatomic and functional factors, in addition to metabolic and prosthetic factors, must be considered as probable causes of variation in alveolar bone loss between the arches and within each arch. Tallgren[6] noted that the function of the muscles of mastication has a direct effect on the facial morphology in general and upon the magnitude and direction of forces being transmitted through the arches in particular. Under normal circumstances, compressive stress resulting from jaw closure during mastication is transmitted through the teeth, to the periodontal ligament, and finally to the underlying bone. In the absence of the dentition, however, the compressive forces fall directly on the periosteal envelope of the residual bone, resulting in a relatively greater resorption of residual bone along those regions of the ridge which receive the greatest loads. Therefore, in terms of the data presented herein, the region mesial to the first molar is probably where the monkeys chewed their food most vigorously, leading to a relatively greater amount of compressive force on the periosteum of the residual ridge, a structure not structurally suited to withstand compressive forces, resulting in a relatively greater degree of bone resorption.

Additional morphologic changes of the mandible

Morphologic changes in the form of the mandible which could be attributed to the loss of the dentition were very few. Results of this study demonstrate that the vertical and horizontal components of growth evident at the condyle and the posterior border of the mandible were within the values extrapolated from normal adult female Rhesus monkeys.[16, 28] Thus, the upward and forward position of the mandible during residual ridge contact does not appear to affect the growth of the mandibular condyle beyond its normal level determined for young adult Rhesus monkeys; i.e., any adaptations occurring at the condyle, while maintaining a physiologic homeostasis, did not provide for greater or lesser than normal levels of growth.

The only morphologic change in the mandible worthy of note concerns the overall size of the ramus. Although there was an essentially normal amount of bone deposition along the posterior border of the ramus, there was a proportionally greater amount of resorption along the anterior border, thus leading to a narrower ramus. Studies by Herzberg and Davitch[29] and Trieger and Herzberg[30] on the muscles of mastication in edentulous subjects indicate that distinct changes in muscle function and in biomechanical stresses occur following complete extraction. There appears to be a decrease in the functional forces generated by the temporal and masseter muscles following extraction and a change in the trabeculation of the medullary cavity of the mandible in the ramus, condylar neck, and gonial region suggestive of reduced biomechanical stresses. This is supported by recent histochemical studies of the temporal muscle in human patients with complete dentures,[31] as well as by electromyographic[32] and histochemical and biochemical[33] analyses of the same animals used in this study. Thus, it is probable that the reduction in the size of the mandibular ramus is a result of the reduced activity of the muscles of mastication and concomitant decrease in biomechanical stresses transmitted through their insertions along the ramus.

SUMMARY

1. The rate, location, and magnitude of residual bone resorption, and morphologic changes in the gonial region, the ramus, and the condyle of the mandible were monitored cephalometrically for a period of 234 weeks in four adult Rhesus monkeys *(Macaca mulatta)* following complete extraction of the dentition.

2. Bone resorption in the residual ridges of the maxillae and mandible was most apparent in the first year following extraction. However, it continued at a reduced rate throughout the entire period studied.

3. The residual ridges of both the maxillae and mandible in their anterior-most regions underwent bone resorption during the first 2 years of the study, following which both areas became depositional. It was suggested that this reversal in alveolar bony remodeling may have been a result of behavioral-functional factors related to altered perioral muscle function.

4. The magnitude of residual bone resorption in the mandible was found to be between 4% (just mesial to the canine) and 45% (just mesial to the first molar) and greater in the mandible than in the maxillae.

5. Within the arch, variability in the amount of residual bone resorption was found. For the maxillae, the posterior, middle, and anterior regions, respectively, underwent increasingly greater amounts of resorption. Within the mandible, the posterior and anterior regions lost approximately equal amounts of alveolar bone, while the middle portion of the mandibular residual ridge underwent significantly greater resorption.

6. It was hypothesized that the increase in residual bone resorption in the middle region of the mandible is probably due to relatively greater compressive forces transmitted through that region during mastication.

7. Alterations in the morphology of the gonial region and the mandibular condyle during the experimental period were not pronounced and did not differ from values obtained in normally growing control animals.

8. The mandibular ramus, however, underwent relatively greater resorption along its anterior border than deposition along its posterior border, resulting in a narrower ramus. It was suggested that this was probably due to a reduction in the functional activity of the temporal and masseter muscles.

REFERENCES

1. Lang, B. R., and Kelsey, C. C., (editors): International Prosthodontic Workshop on Complete Denture Occlusion. School of Dentistry, University of Michigan, pp 42-47, 1972.
2. Total loss of teeth in adults, USA. 1960 to 62, National Center for Health Statistics **11**:27, United States Public Health Services, Washington, D. C.
3. Michael, C. G., and Barsoum, W. M.: Comparing ridge resorption with various surgical techniques in immediate dentures. J Prosthet Dent **35**:142, 1976.
4. Wical, K. E., and Swoope, C. C.: Studies of residual ridge resorption. I. Use of panoramic radiographs for evaluation and classification of mandibular resorption. J Prosthet Dent **32**:7, 1974.
5. Winter, C. M., Woefel, J. B., and Igarashi, T.: Five-year changes in the edentulous mandible as determined on oblique cephalometric radiographs. J Dent Res **53**:1455, 1974.
6. Tallgren, A.: Alveolar bone loss in denture wearers as related to facial morphology. Acta Odontol Scand **28**:251, 1970.
7. Atwood, D. A., and Coy, W. A.: Clinical, cephalometric, and densitometric study of reduction of residual ridges. J Prosthet Dent **26**:280, 1971.
8. Tallgren, A.: The continuing reduction of the residual alveolar ridges in complete denture wearers: A mixed-longitudinal study covering 25 years. J Prosthet Dent **27**:120, 1972.
9. Pietrokovski, J., and Massler, M.: Residual ridge remodelling after tooth extraction in monkeys. J Prosthet Dent **26**:11, 1971.
10. Kelsey, C. C.: Alveolar resorption under complete denture. J Prosthet Dent **25**:152, 1971.
11. Mitzutani, H., and N. Ishihata: Decrease and increase in residual ridge after extraction of teeth in monkey (Part I). Bull Tokyo Med Dent Univ **23**:157, 1976.
12. Hurme, V., and Van Wagenen, G.: Basic data on the emergence of permanent teeth in the Rhesus monkey *(Macaca mulatta)*. Proc Am Phil Soc **105**:105, 1961.
13. Björk, A.: Facial growth in man, studied with the aid of metallic implants. Acta Odontol Scand **13**:9, 1955.
14. Björk, A.: The use of metallic implants in the study of facial growth in children: Method and application. Am J Phys Anthrop **29**:243, 1968.
15. McNamara, Jr., J. A.: Neuromuscular and Skeletal Adaptations to Altered Orofacial Function. Monograph No. 1. Craniofacial Growth Series, Center for Human Growth and

Development, The University of Michigan, Ann Arbor, Michigan, 1972.
16. McNamara, Jr., J. A., and Graber, L. W.: Mandibular growth in the Rhesus monkey *(Macaca mulatta)*. Am J Phys Anthropol **42**:15, 1975.
17. McNamara, Jr., J. A., Riolo, M. L., and Enlow, D. H.: The growth of the maxillary complex in the Rhesus monkey *(Macaca mulatta)*. Am J Phys Anthropol **44**:15, 1976.
18. Wictorin, L.: Bone resorption in cases with complete upper dentures: A quantitative roentgenographic photogrammetric study. Acta Radiol (Stockh) (Suppl) **228**:1, 1964.
19. Duterloo, H. S., Atkinson, P. J., Woodhead, C., and Strong, M.: Bone density changes in the mandibular cortex of the Rhesus monkey *(Macaca mulatta)*. Arch Oral Biol **19**:241, 1974.
20. Ortman, H. R.: Factors of bone resorption of the residual ridge. J Prosthet Dent **12**:429, 1962.
21. Heath, M. R.: A cephalometric study of the middle third of the adult human face related to age and the loss of dental tissue. Arch Oral Biol **11**:677, 1966.
22. Tallgren, A.: The effect of denture wearing on facial morphology: A 7-year longitudinal study. Acta Odontol Scand **25**:563, 1967.
23. Tallgren, A.: Changes in adult face height due to aging, wear, and loss of teeth and prosthetic treatment. Acta Odontol Scand **15**:1, 1957 (Suppl 24).
24. Tallgren, A.: An electromyographic study of the behavior of certain facial and jaw muscles in long-term complete denture wearers. Odontol Tidskr **71**:425, 1963.
25. Tallgren, A.: Positional changes of complete dentures; A 7-year longitudinal study. Acta Odontol Scand **27**:539, 1969.
26. Atwood, D. A.: A cephalometric study of the clinical rest position of the mandible, Part II. The variability in the rate of bone loss following removal of the occlusal contacts. J Prosthet Dent **7**:544, 1957.
27. Atwood, D. A.: Some clinical factors related to rate of resorption of residual ridges. J Prosthet Dent **12**:441, 1962.
28. Carlson, D. S., McNamara, Jr., J. A., and Jaul, D. H.: Histological analysis of the growth of the mandibular condyle in the Rhesus monkey *(Macaca mulatta)*. Am J Anat **151**:103, 1978.
29. Herzberg, F., and Davitch, V.: Bony trabecular changes in the human mandibular ramus from prenatal period to adulthood. Anatomical Record **144**:129, 1968.
30. Trieger, N., and Herzberg, F.: Change in the trabecular pattern of the mandibular ramus in a "Macaca Rhesus" monkey experimentally rendered edentulous. J Dent Res **49**:645, 1970.
31. Ringqvist, M.: Size and distribution of histochemical fiber types in masseter muscle of adults with different states of occlusion. J Neurol Sci **22**:429, 1974.
32. McNamara, Jr., J. A., Carlson, D. S., and Upton, L. G.: A long-term study of neuromuscular adaptations in edentulous Rhesus monkeys *(Macaca mulatta)*. (Submitted for publication).
33. Maxwell, L. C., McNamara, Jr., J. A., Carlson, D. S., and Faulkner, J. A.: Characteristics of fibers of masseter and temporalis muscles of edentulous Rhesus monkeys *(Macaca mulatta)*. (Submitted for publication).

Reprint requests to:
Dr. James A. McNamara, Jr.
Center for Human Growth and Development
The University of Michigan
1111 E. Catherine
Ann Arbor, Mich. 48109