Age-related differences in mandibular ramus growth: a histologic study

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Mark G. Hans, DDS, MSD; Donald H.Enlow, PhD; Regina Noachtar

Sicher,[2] in an address before the American Association of Orthodontists in 1946, stated that orthodontists are "the ones who not only talk about growth of the human body, but also try to do something about it." Almost 50 years later, orthopedic modification of facial growth is still a topic of great interest to practicing orthodontists. A review of the literature reveals a general consensus that, while clinicians can use orthopedic appliances such as headgear to modify maxillary growth, the effects of mandibular orthopedic appliances, such as bionators, on mandibular growth are more controversial. One reason for the unpredictable response of the mandible to orthopedic treatment may be related to the complex morphology of the bone. The mandible can be divided into four functional components: the condyle, the ramus, the corpus, and the alveolus. To understand how the mandible grows, each component needs to be studied. After the contribution of each has been characterized, the clinician can begin to determine how best to modify mandibular growth.

The currently accepted concept of upward and

Abstract

Histologic reconstructions of remodeling variations of the mandibular ramus are demonstrated. This is significant because morphogenic relationships between the ramus and corpus establish mandibular arch position. Ground and polished microscopic sections were obtained from the ramus of 30 well-preserved human mandibles, dental age 1 to 13 years. The distribution of the various types of endosteal and periosteal bone tissues and resorptive versus depository surfaces was recorded. Fourteen of the 30 specimens and the majority of the mandibles at all ages examined exhibited the classic pattern of deposition and resorption (Type A or classic pattern) described by Enlow.[1] Nine mandibles followed a second variation (Type B or vertical variation) involving a gonial angle alignment change. Seven followed a pattern of deposition and resorption similar to what Björk might have called a forward rotating pattern (Type C or rotation variation). The differences in these patterns are large enough to suggest that a common description of one pattern of remodeling for all mandibles is incomplete. Unfortunately, the process of mandibular growth and remodeling does not appear to correlate well with dental age and the basis for changes in patterns may be more complex than first imagined. If temporal differences exist, they are not related directly to dental development. In theory, the differences in pattern are great enough to influence the outcome of mandibular orthopedic treatment.

This research was first presented at a meeting of the Midwest Component of the Edward H. Angle Society held in Sanibel Island, Florida, February 1991.

Key Words

Mandibular growth • Age • Bone histology

Submitted: April 1994 **Revised and accepted:** December 1995 Angle Orthod 1995;65(5):335-340.

backward growth of the mandible was first described by John Hunter in 1771.[3] Prior to that it was thought that the mandible grew primarily by deposition of bone at the chin. The concept of upward and backward growth with downward and forward displacement forced researchers to examine the ramus and condylar cartilage to determine why and how changes in mandibular growth or position occur. Research focused on the condyle as the determining factor in mandibular growth. Based on studies of the epiphyseal plates of long bones, early theorists proposed that the condyle acted like an epiphyseal plate for the mandible and controlled growth of the entire bone.[4] However, surgical removal of the condyle in animals failed to produce dramatic changes in mandibular growth.[5] Modern craniofacial biologists rejected the "master center" notion in favor of the concept of the condyle as a "growth site" able to adjust to changes occurring in other parts of the face.[6] Johnston further proposed that the condyle acts as a ratchet to hold the growth achieved by tissue-separating forces that occur at areas remote to the condyle itself.[7] Because the condyle cannot be considered the control center for mandibular development, variations in mandibular shape and size must, in large part, be achieved by remodeling of the ramus as a whole as its osteogenic and chondrogenic connective tissues receive epigenetic signals from other parts of the face and neurocranium.

This shift in emphasis from the condyle to the whole ramus brought into focus the concept of patterns of bony change. Brodie[8] popularized the idea of pattern as it relates to facial growth. He believed that there were unique patterns of facial growth for each individual. Björk's implant studies[9-12] provided further evidence that different individuals exhibit different patterns of mandibular growth. Moss[13] advanced the idea that mandibular growth does not follow a linear pattern and proposed instead that growth follows a logarithmic spiral. A similar nonlinear pattern was proposed by Ricketts,[14] who thought that mandibular growth follows an arc. Both the logarithmic spiral of Moss and the arcial concept of Ricketts suggest that the mandible undergoes changes in size and shape with respect to some temporal sequence.

Biologically, hard tissues such as bone can only grow by apposition, laying down new layers on top of older ones. Two components of appositional growth processes, deposition and resorption, together must account for the dramatic changes in shape and size of the mandible that occur with growth. By analyzing the histologic pattern of the bone surface it is possible to determine whether any given area is of periosteal or endosteal origin. In 1964, Enlow and Harris mapped the histologic characteristics of the entire inner and outer surfaces of a sample of human mandibles.[1] This study resulted in a topographic map of the developing mandible, showing areas where the bone was remodeling out (periosteal deposition) or growing in (periosteal resorption and endosteal deposition).

Given that other authors have proposed that the mandible does not follow one characteristic pattern throughout life, it is likely that the map of mandibular growth varies with the age of the individual. In his original study, Enlow did not attempt to correlate the bony pattern with the age of the specimens. In order for orthodontists to intelligently approach growth modification, the possibility of temporal variations in normal mandibular development must be explored. The purpose of this study is to determine if a temporal pattern of mandibular growth and remodeling exists. To achieve this aim, remodeling fields comprising areas of periosteal and endosteal bone in an age-series of mandibles were mapped along the posterior and anterior borders of the ramus using multiple ground microscopic sections. Because this study was primarily concerned with growth rotations that may occur in the area of the ramus and gonial angle, sections were obtained only from these areas.

Materials and methods

Thirty well-preserved human mandibles, dental age 1 to 13 years, were available for microscopic preparation and study (Table 1). Dental age was determined using the method described by Schour and Massler.[15] Each specimen was aged by three clinicians and agreement among clinicians was within 6 months for all specimens included in the sample. The sample was the same used previously in an age-related study of the developing human maxilla[16] and was obtained by one of the authors (DHE) from a commercial supply house. The specimens were reported by the supply house to be of Old World Indian origin (India). Possible ethnic variations were not addressed in the present study but need to be in future work. Information on gender was uncertain in many cases and no attempt was made to make correlations based on such data.

Sections were prepared every 3 mm along the posterior border of the mandible from the condyle through the gonial angle and along the

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Table 1

Dental age	Mandible Type A n = 14	Type B n = 9	Type C n = 7
1	1	2	0
2	4	2	0
3	1	0	2
4	0	2	0
5	2	0	0
6	2	1	4
7	2	1	0
8	2	0	0
9	0	1	0
13	0	0	1

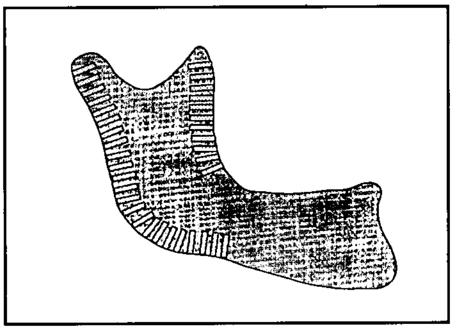

Figure 1

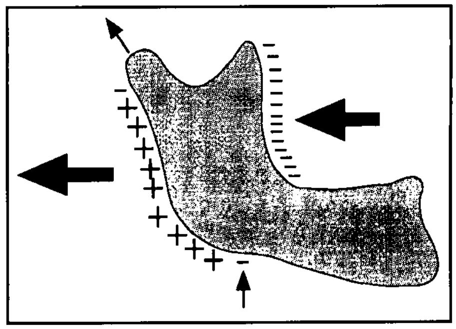

Figure 2

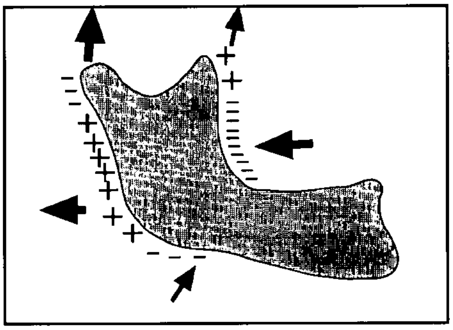

Figure 3

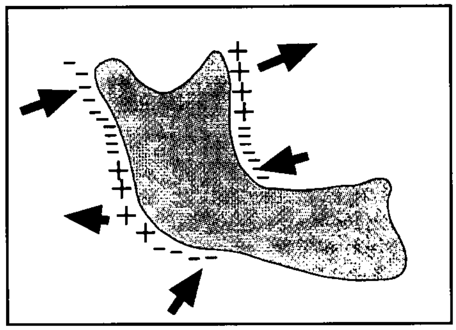

Figure 4

Figure 1
Locations of the sections used for microscopic examination.

Figure 2
Type A–classic pattern, demonstrates remodeling of the ramus leading to upward and backward growth. Arrows indicate vectors of growth movement. Positive sign (+) indicates deposition, negative sign (–) indicates resorption.

Figure 3
Type B–vertical variation, demonstrates closing of the gonial angle and more vertical growth of the condylar head.

Figure 4
Type C–rotation variation, demonstrates forward (counterclockwise) rotation of the mandible.

anterior border from the molar crypt to the tip of the coronoid process. The orientation of the sections is shown in Figure 1. Each cut, undecalcified section was prepared for microscopic examination by previously described methods.[17] Briefly, 1 mm sections of the ramus and gonial angle were obtained by using a flexible diamond disk on a dental handpiece. The sections were then ground on a lap wheel to a thickness of between 100 and 150 microns.

The ground and polished sections were microscopically examined to determine the distribution of the various types of endosteal and periosteal bone tissues and resorptive versus depository surfaces. The patterns were mapped and composite pictures representing the characteristic combinations found for different age levels were prepared. This technique of mapping reveals the manner in which the ramus undergoes progressive remodeling and development through time. The reliability and validity of this technique has been previously described.[1,18,19]

Results

Type A—classic pattern

The most common pattern demonstrated in this sample was the classic pattern for growth of the mandibular ramus described by Enlow.[20] The type A mandible was characterized by deposition on the posterior border of the ramus extending from the gonial angle to just below the condylar head. The posterior border just inferior to the condylar head was resorptive, indicating an oblique upward-backward remodeling growth movement of the condyle. In the area of the gonial angle, depository fields extended around the posterior and inferior surfaces of the gonial angle with a resorptive field at the antegonial notch. The anterior border of the ramus was resorptive along its entire length. A pictorial representation of type A mandibular ramus growth and development is shown in Figure 2. Fourteen mandibles out of the total sample of 30 exhibited this pattern. The age distribution included four at dental age 2, one each at ages 1 and 3, and two each at ages 5, 6, 7, and 8. This pattern produced a strong backward growth vector of the ramus with little forward growth rotation.

Type B—vertical variation

The second pattern of remodeling observed was a variation on the classic pattern and was designated type B remodeling. In type B mandibles, depository surfaces were found on the posterior border of the ramus extending from the gonial angle to the beginning of the condylar neck. The posterior border in the area of the condylar neck was resorptive, indicating an upward remodeling growth movement of the condyle. In the area of the gonial angle, deposition occurred on the posterior border of the ramus and resorption was found on the inferior border of the mandible. Most of the anterior border of the ramus demonstrated resorption except at the tip of the coronoid process where several sections contained depository fields. Nine of the

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30 mandibles followed this pattern. The age distribution included two each at ages 1, 2, and 4; and one each at ages 7, 8, and 9. This type B variation demonstrated a pattern that would result in closure of the gonial angle with an increase in vertical ramus height. This variation is consistent with the vertical changes that are associated with midfacial maturation and accompanying vertical enlargement.

Type C—rotation variation

The final pattern of deposition and resorption observed was designated type C. The type C mandible demonstrated more extensive resorption on the superior aspect of the posterior border of the ramus. There were fields of depository activity superior to the angle of the mandible and approximately equal in height to the mandibular corpus. Like the type B variation, the inferior border of the mandible was resorptive. The anterior border of the ramus in the type C mandible was depository along its superior half and resorptive on the inferior half. Seven of the 30 mandibles exhibited this pattern. The age distribution included two at age 3, four at age 6, and one at age 13. Björk might have called this type C variation a "forward rotating pattern" because the net result of the depository and resorptive fields would cause the mandible to undergo a counterclockwise rotation with respect to the midface. Enlow also described this variation in ramus development in his earlier histologic studies. He concluded that the pattern indicates a mandibular ramus that is remodeling and rotating in a pronounced superior-anterior direction with respect to the mandibular corpus.

A complete listing of the sample broken down by age and remodeling pattern is given in Table 1.

Discussion

The findings of this study will be discussed in light of various theories which have been advanced to explain mandibular growth.

The concept of upward and backward growth of the mandible with downward and forward displacement was clearly demonstrated. However, the complexity of the maturation process is understated by this general concept. All three patterns observed would result in downward and forward displacement of the mandible, but to varying degrees. Enlow's original description of general mandibular growth and remodeling (type A–classic pattern) seems to be the most common. However, two variations (types B and C) showed that the condylar head is rotating forward and superiorly. Both type B and type C variations allow for the change in mandibular form from a horizontal infant mandible to a more vertical, longer-faced juvenile or adolescent mandible. Therefore, a more complete description of mandibular growth would state that the most common vector is upward and backward and at least two alternative patterns allow for vertical change in the ramus with concomitant closure of the gonial angle.

The concept of arcial growth of the mandible proposed by Ricketts as well as the concept of a logarithmic spiral described by Moss are consistent with the vertical component of ramus remodeling seen in our sample and described as type B and C variations. However, the type B and C variations did not consistently follow a temporal pattern (based on dental age) such as that required by the arcial or logarithmic theories. In fact, the results of the study indicate that while mandibular growth proceeds in a series of horizontal and vertical increments, these growth increments do not correlate with dental age. It is possible that individual variations in the timing of the directional changes "evens out" the horizontal and vertical components of growth to an average arc. If this is true, a population mean change might follow an arcial or logarithmic curve. However, an individual's pattern would consist of a series of horizontal and vertical growth increments occurring in a pattern characteristic for that individual, but not consistent for a population. The size of the sample used for this study may not have been large enough to identify temporal changes associated with population-based curves. Because the nature of our analysis required cross-sectional data, conclusions about longitudinal relationships can only be inferred.

Björk's concept of forward and backward patterns of mandibular growth rotation is theoretically possible based on our data. Type B mandibles demonstrated slight anterior rotation of the condylar head along with some deposition at the coronoid tip. However, the degree of deposition at the coronoid process does not suggest that the ramus as a whole was always relocating in an extreme anterior direction. The type C mandibles demonstrated a greater degree of forward rotation of the condylar head with increased vertical growth of the ramus and increased deposition on the anterior border. When deposition was seen on the anterior border of the ramus, the direction of growth was both superior and anterior. Type B mandibles demonstrated greater vertical change and type C more forward rotation of the ramus. Interest-

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ingly, no patterns of deposition and resorption were found that supported the concept of backward rotation of the mandible. It is possible, however, that more distinct and dramatic ramus rotations can occur with greater frequency, especially during vertical enlargement of the nasal airway during a period of rapid growth such as that seen in puberty.[20]

In conclusion, the most plausible explanation of how the mandible changes form encompasses some parts of all of these theories. The developmental process is a long-term composite of horizontal and vertical growth vectors. The general backward remodeling of the ramus with subsequent elongation of the corpus appears to be the more common and basic pattern of ramus growth during the time periods studied. However, differences in mandibular remodeling occur and are related to necessary increases in ramus height as well as closure of the gonial angle. It is likely that the type A, B, and C patterns observed in this study relate to the composite of morphologic requirements placed on mandibular development by eruption of the dentition, differential maturation of the brain, basicranium, pharyngeal airway, and facial musculature, as well as growth of other hard and soft tissues of the head and neck. Such morphologic requirements occur at different developmental time periods, and the variations in mandibular remodeling appear to be a response to the aggregate of these changes.

Limitations of the study

Our results are based on a selected, cross-sectional sample of a primarily dolichocephalic head form population. Some of the patterns identified may or may not apply to dinaric or brachycephalic head forms. In addition, the total sample included only 30 individuals. Although it is unlikely that a larger sample of human skeletal material will be available in the near future, the sample is nonetheless small and does not allow statistical validation of the findings described. The findings are presented in the hope of stimulating theoretical discussion on mandibular growth and should not be considered scientific proof of the supremacy of any single theory.

Conclusions

This study described three growth patterns of the mandible. The differences in these patterns were large enough to suggest that it is not sufficient to describe the complex process of growth and remodeling of the infant mandible to the mature form simply with the statement: "The mandible grows backward and upward and is displaced forward and downward." Likewise, a common description of one pattern of remodeling for all mandibles is incomplete. The process of mandibular growth and remodeling is not simply time-linked and the basis for changes in patterns are not known. If temporal differences exist, they are not related directly to dental age. The differences in pattern were large enough to theoretically influence orthodontic treatment outcomes. Therefore, treatments that are designed to influence growth of the mandible must take into account whether the mandible is growing in a more vertical or horizontal direction during the therapeutic phase. If orthodontic treatment plans are to be designed to "work with growth," then it is important to know both the direction and the velocity of growth that is to be modulated.

The results suggest that mandibular remodeling has more variability during periods of rapid growth. Treatment plans that concentrate on changing mandibular growth could very well be more effective if applied during a time in which growth is occurring with more variation in the pattern. This study represents an initial investigation into the temporal patterns of mandibular growth. Future studies are planned to analyze the important pubertal growth period (ages 12 to 16) to determine if characteristic mandibular patterns emerge. If we, as orthodontists, aspire to "not only talk about mandibular growth, but do something about it," then the basis for the observed differences in growth pattern needs further examination.

Acknowledgments

The authors wish to thank Ms. LaVerne Vogel for her assistance in the preparation of this manuscript.

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Commentary: Age-related differences

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This manuscript addresses some very important questions for the practicing orthodontist. As pointed out by the authors, the literature dealing with the manipulation of mandibular growth is inconclusive. At best, it shows that the orthodontist may be able to affect mandibular growth in some cases. The trick is identifying which cases. Understanding how the mandible grows could help us understand the variability and allow us to predict which cases may be affected.

The manuscript presents some interesting findings that, as the authors state, "stimulate theoretical discussion on mandibular growth." The authors are to be commended for critically reviewing their own work and acknowledging the limitations of the data interpretation. It would be most interesting to examine a larger number of specimens so that statistical analysis could be completed. Without larger sample sizes, there is too much variation in the biological system to allow conclusions to be made in this study.

Another critical point in this type of study deals with the age of the specimen. Whether we correlate bone growth changes to chronological, dental, or skeletal age could result in very different conclusions. Most people believe that chronological age is the least reliable indicator of growth. While dental age may be somewhat better, it is also highly variable. In our longitudinal clinical trial of 300 eight-year-old children, we are following dental and skeletal ages and examining the relationship with craniofacial growth. In the baseline group of eight-year-olds, dental ages varied between the extremes of 5 to 15 years. We are in the process of examining the skeletal ages of these children. The whole point of this is that a randomly selected sample shows a great amount of variation. Gender, race, and perhaps even skeletal age, should be considered when conducting studies of this type in the future. Then we may be better able to understand growth and its variation.

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