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Some Recent Observations on the Growth of the Mandible*

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THE BEGINNINGS of investigations on the growth of bone may be found in the observation by Belchier (1736) that madder root would stain bone red. Some three years later Duhammel confirmed this finding in a paper entitled, "On a Root Which Stains Bones Red." Duhammel's work over the next ten years resulted in a number of concepts which are still accepted as facts. He showed: (1) that only parts of a bone were stained by the dye; (2) that the bones of young animals stained more deeply than those of the old; and by fracture experiments, that (3) only new bone took the dye. After having proved that the deposit of madder indicated sites of *active* bone growth, he checked his experiments with implantations and with wires bound around the shafts of growing bones. From such studies he advanced the thought that bone grows like wood and that the periosteum resembles the cambium layer.

It was almost ten years later that John Hunter joined his brother's school at Convent Garden, and it was not until 1754 that he began his work on the mandible. During the early stages of his investigative career Hunter apparently relied solely on observation for his findings. It is therefore doubly remarkable that he was able to point out that there is destruction of the alveolar process following extraction; that absorption of the roots of the deciduous teeth takes place; and the fact that in the succession of molars, deciduous and permanent, each seems to erupt and to bear the same relation to the ramus. It was Hunter who first insisted that resorption was as characteristic of bone growth as was deposition, and that the concept of interstitial expansion was untenable. In 1764 Hunter had recourse to Duhammel's staining methods and proved his contentions on the mandible and the femur. In his "Natural History of the Human Teeth" (1771) Hunter described ideal occlusion and the growth of the mandible.

None of Hunter's work was checked until the middle of the nineteenth century, owing to the fact that many of his communications had been lost

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sight of. Among these was a reference to the fact that the mandible grows in length by additions to the posterior border of the ramus and that the anterior border of the ramus is maintained by a corresponding resorption. This condition seemed so bizarre to Humphrys of England that he was led to check it with a different method. He drilled holes in the ramus of the mandible and inserted wire rings, one of which encircled the posterior border and the other the anterior border. Upon killing the animals at a later date he found the posterior ring thoroughly imbedded in bone, while the anterior ring had been sloughed off into the soft tissue. Since this time there has been very little of a contradictory nature to disprove Hunter's original findings. His work on the growth of the mandible might be summed up briefly by saying that the height of this bone was mainly contributed by growth at the alveolar border and that length was gained by additions to its posterior border, with concomitant resorptions at the alveolar border of the ascending ramus.

In 1922 Keith and Campion undertook a study of the growth of the bones of the head, using anthropologic measurements, and while their method led them to certain misconceptions they were among the first to call serious attention to the head of the condyle as an important growth center. In 1924 Brash repeated and enlarged Hunter's work and with certain minor additions the findings coincided in every respect. Brash, however, was even more insistent on the importance of the alveolar border, but failed, apparently, as did Hunter also, to pay very much attention to the condyle.

It goes without saying that all work dealing with bone growth in general would be applicable to the mandible. Thus, microscopy has indicated that the cell is the important unit in bone growth. Studies on the trajectory pattern, as indicated by trabecular arrangement and by the Haversian systems of the compacta, have pointed to a close interdependence between function and form, while transplantations have indicated strong hereditary influences in the definition of pattern. The embryologists, anatomists and the anthropologists have added their contributions to the list until today there is a voluminous literature on this bone, second perhaps only to the femur.

From a consideration of all this material it might seem presumptuous for anyone to seek to add anything new upon this question of the growth of the mandible. And it would indeed be presumptuous, were it not for the fact that every technique of investigation carries with it certain definite limitations. In anthropology, for instance, one must be content with a study of the bones of different individuals, which bones are then averaged as to measurements and the average taken as a norm. From this we can derive only trends or tendencies. In histology one must be satisfied with a glimpse of conditions as they existed at the instant of death and must rely on inference for what has preceded it. One has a similar limitation when he resorts to vital staining and, in addition, this work must be performed on laboratory animals.

Methods and Material

Serial roentgenology eliminates the most serious deficiences of the anthropologic method. Here it is possible to work with very nearly the same accuracy as though one were dealing with dried bones and, in addition, one can study the same bone or aggregate of bones in the same individual. While this is a big step forward, it should be pointed out that one still must be content with rates and tendencies; *sites* of growth are inscrutable in X-ray pictures, as are also the modes of bone growth. These must be inferred from histo-physiologic studies.

The technique given us by Dr. Broadbent has opened up a vast field for exploration and has yielded data previously unobtainable. When combined with vital staining employing alizarine and histologic methods, as developed by Schour and his colleagues, we have a wedding of the two most effective methods.

The promise of results from such a combined attack seemed so great that the author was led to undertake a re-investigation on the growth of the head, only a small part of which will be considered in this presentation. Most of the cephalometric material studied has been loaned by Dr. Broadbent from the files of the Bolton Fund and the author would like to take this opportunity to express publicly his gratitude for such great generosity. The alizarination has been done and continues to be done by Dr. Schour and Dr. Massler in the former's department. This work is conducted, not only on lower forms, but also on monkeys. After each investigator has worked out his particular findings the results are gone over and checked for correctness of interpretations. The results of both techniques of investigation are then correlated with the hope that the pattern of growth is not only described and measured but that the basic mechanisms of bone growth involved in the development of the skull may be elucidated. This report will deal mainly with the cephalometric findings, although certain references will be made to the results of alizarination. The material consists of the serial roentgenograms of twenty-one children from 3 months to 8 years of life from the files of the Bolton Study, and selected series of older children from the files of the Department of Orthodontia, University of Illinois. X-rays were made quarterly during the first year of life, semi-annually until five years and annually thereafter.

Observations on the Human

All are familiar with the sort of an illustration shown in Fig. 1, which purports to indicate the relations of gum pads in the new-born. Brash states, as an explanation for this illustration, "There is, I think, a general impression that the infra-nasal part of the face increases at a greater rate than the nasal part; certainly most published illustrations of the fetal skull lend support to this idea. The reason for this, I believe, is that in the adult skull the teeth separate the alveolar margins, while the new-born is deprived of the thickened alveolar mucous membrane; the bony alveolar edges are thus brought together and the lack of depth in the lower part of the face is exaggerated. But the teeth are merely specialized mucous membrane and it would be as logical to deprive the adult of his teeth and to bring his alveolar margins together as to represent the infants' skulls in this way."

Actually, when we view the headplates of a newborn infant in a relaxed condition (Fig. 2), we find that neither condition noted above is correct. The jaws are wide apart, although the lips are closed, and it is possible in soft roentgenograms to see that the tongue occupies the entire mouth cavity and projects between the alveolar process to rest in back of the lips.

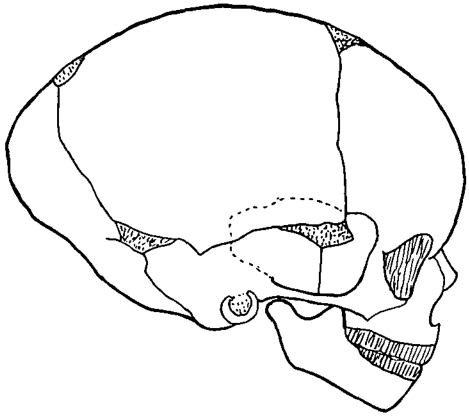

Fig. 1.—Illustration indicating relation of gum pads in the new-born. (After Brash)

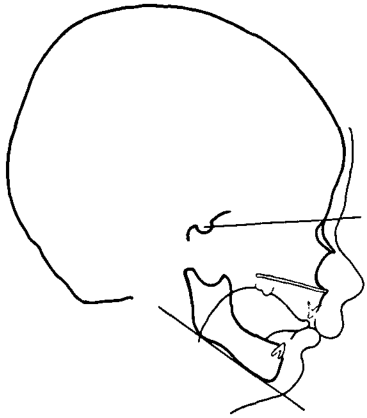

Fig. 2.—Tracing of lateral cephalometric X-ray of 3-month-old infant showing tongue between gum pads.

In an effort to find when and how the jaws are closed, the angle formed by a line representing the anterior cranial base with a line representing the lower border of the mandible was read and tabulated. (Table I) These data reveal that constancy is established after 2 or 2½ years. But cases 1984, 2019 and 2207 show practically the same angles at 3 and 6 months with jaws

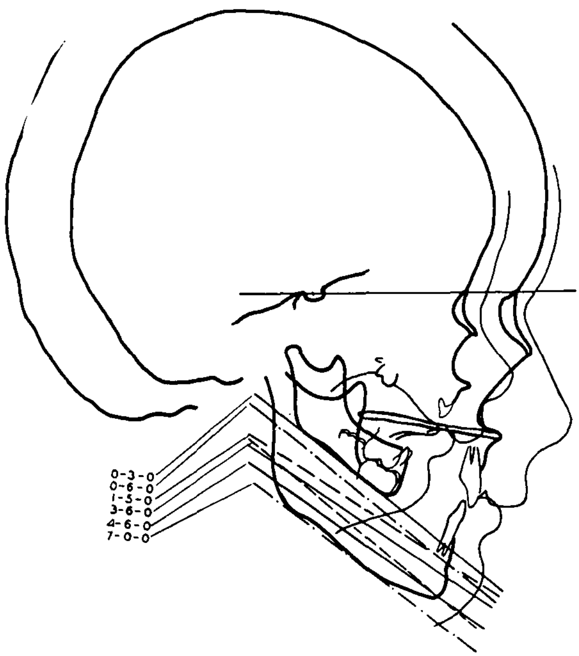

Fig. 3.—Superposed tracings of the same subject at 3 months and at 7 years. Note series of lines indicating stability of relationship of lower mandibular border to cranial base.

apart as at 8 years with jaws closed. Notice in the tabulation that asterisks or plus marks were placed behind some of the values. The asterisk following a measurement in the tabulation indicates that the jaws are apart in the roentgenograms, and it will be noted that all cases, without exception, show this feature up until 9 months or 1 year. At about this level plus marks begin to appear in the table, a symbol to express that the jaws are

TABLE I.—TABULATION OF ANGULAR READINGS OF SELLA TO NASION PLANE WITH TANGENT TO LOWER MANDIBULAR BORDER

Angle S. N. to Mandibular Border

(3 months to 7 years)

Case No.	1893	1897	1932	1941	1984	2005	2009	2027	2035	2070	2165	Mean
AGE												
0-3-0	57.25*			42.75*	37.5*	43.*			45.5*	44.5*	36.25*	43.39
0-6-0	43.25*	51.25*			38.*	38.*	45.25*		46.5*		39.5*	43.10
0-9-0				41.25†	30.25*	36.*	47.*	31.†	51.*			39.5
1-0-0						32.*		33.†	50.5*	33.	32.75†	34.
1-6-0	59.25*	42.75*		31.25*	33.25*	32.*	42.5*	34.		34.5*	30.†	38.1
2-0-0	33.*	46.75		28.5*	32.5*	30.5†	40.5†	31.75	36.25†	35.25†	30.5†	33.97
2-6-0		41.*	30.25	40.*	32.75*	27.5	42.†	31.	37.75†	36.*	30.25†	34.85
3-0-0	39.	41.5	32.25	29.	31.5	30.5*	39.25†	34.	39.	32.75*	32.	34.61
3-6-0	40.25	39.	32.75	30.25	37.5	27.5	41.5	30.25	39.25	31.	32.5	34.70
4-0-0	39.		33.	30.5	37.5	26.75	41.25	32.5	41.75	33.25*	32.75	35.1
4-6-0	40.25	41.25	32.	29.75	35.	28.5	41.	30.	40.25	34.75	33.	34.45
5-0-0	40.25	39.5	32.	29.75	35.	30.	40.	30.25		36.75	31.75	34.52
6-0-0	40.75	37.75	31.		35.75	28.75	39.25	31.5	37.75	34.75	32.5	34.97
7-0-0	40.25	35.75	31.75	30.25	38.	29.25	38.	33.25	37.5	33.25	30.	34.29

(6 months to 8 years)

Case No.	2017	2049	2130	2125	2019	2058	2173	2207	2108	2078	Mean	Total Mean
AGE												
0-6-0	43.*	42.25*	44.*	47.*	38.*	34.5*	50.*	38.*	44.*	45.5*	42.62	42.86
0-9-0	44.*	36.75*	41.*	41.25*	32.*		51.5*				41.08	40.29
1-0-0	44.*		35.25†			34.5*	50.5*	37.75*	44.*		41.	37.5
1-6-0	40.75*	25.†	39.5*	38.5*	38.	43.*	37.†	32.75†	39.5†	39.†	37.30	37.70
2-0-0	45.*	25.†	36.†	38.25†		38.5†	45.25	35.5†	39.5†	39.5†	38.05	36.01
2-6-0	31.5†		35.25†	36.25†	35.5†	45.5*	39.25†	37.5†		42.5*	37.90	36.37
3-0-0		29.†	36.75	36.25†	36.5†		37.5†	38.	38.25†	40.75†	36.62	35.61
3-6-0	34.†	27.†	37.5	37.25	38.	38.5	39.5	38.†	39.5	39.5	36.87	35.75
4-0-0	35.75*	28.75	36.5†	37.25	39.5	40.75†	40.	38.25	37.†	40.	37.37	36.23
4-6-0	37.25†	28.5	37.	38.	38.75	40.25	40.5	39.75	38.	43.5	38.15	36.30
5-0-0	36.25	30.25*	36.5	36.75	38.5	41.5	39.5	39.	37.		37.25	35.88
6-0-0	38.5	30.	36.	35.	39.5	41.75	40.75	36.5	35.5	38.75	37.22	36.10
7-0-0	37.75	31.	35.5	36.5	38.25	40.75	38.	36.	37.5	37.5	36.87	35.58
8-0-0	38.75	32.25	36.5	35.5	38.	39.25	42.	36.	34.	39.5	37.17	37.17

being pushed together by an assistant, as shown by the presence of fingers pressing upward on the chin. Such pressure does not always result in actual closure of the teeth but where it does (2027, 2017, 2049, etc.) it leads to a decrease in the angle below that found in the latest stages. Fig. 3 exhibits superposed tracings of a case at 3 months and at 7 years. The series of lines drawn on the mandible represent the positions of the lower mandibular border in intervening stages. While one or two lines reveal a greater or lesser angle, the parallelism of the lower border or, in other words, the constancy of the angle it forms with the cranial base, is striking.

From the fact that the angle between cranial base and the lower border of the mandible tends to remain constant, and further, since the distance from nasion to the bony chin-point (gnathion) describes a typical growth curve when graphed, it would seem that the body of the mandible is suspended in a position of physiologic rest between the hyoid and skull by an equilibrium of muscular tensions above and below it. Growth, particularly of the alveolar process, together with the eruption of the teeth toward each other, gradually encloses the tongue. This entails no encroachment upon this organ because the anteroposterior dimension has also rapidly increased over the same period by heavy deposition on the posterior border of the ramus and at the tuberosity of the maxilla, with a resulting forward positioning of the face. So much for the maintenance of the mandible's spatial relationships. What of its growth?

Without exception our text-books tell us that the angle formed by the body with the ramus of the mandible begins as an obtuse angle, closes to almost a right angle and again becomes obtuse in old age. This conception has been arrived at by a method that is illustrated in various works on anthropology. It consists of a flat table with a hinged upright leaf and a protractor which makes possible the reading of the angular relation between the base and the leaf. The mandible is placed on the table and the leaf is adjusted to allow the ramus and condyle to touch it. The angle, as registered on the protractor, is then noted. Needless to say, studies of this sort in the past were conducted on the jaws of different individuals. The superposing of tracings of the *same individual* during the growth period discloses conditions that are at variance with previous concepts. Indeed, such superposing is the only method thus far employed that is capable of showing what actually takes place.

The method of superposing tracings as employed in this study is illustrated in Fig. 4. The same tangent to the lower border as used above is taken as the base line. The angle formed by this line with a tangent to the posterior border is bisected to locate the point gonion, the point of surperposition. Further examination of the figure shows that the most posterior points on the condyle fall on a straight line or that the condyle is given off at a constantly higher level but without change in pattern or relationship. If one were to connect with straight lines the most posterior points on the ramus and the condyle, a smaller angular reading with the base line would be obtained as age advanced.

The tracings of the mandibles of six different children are shown in Fig. 5. The first two show a span from 3 months to 7 years and the third from 6 months to 7 years. In these only the first and last tracings are nearly complete, but the intervening stages are shown at the symphysis and at the posterior border of the ramus where the neck of the condyle is given off. The three mandibles in the lower row run respectively from 3 to 9 years, from 5½ to 11½ years, and from 8 to 15 years. Here only the first and last tracings are shown but they reveal, even more definitely, the absence of change in the angle.

Attention should be called to the fact that these cases, like all other normal studies, reveal a strong similarity between the pattern of the first and last tracings, although differences in type are apparent. From this evidence it would seem that the attainment of the adult angle takes place at a

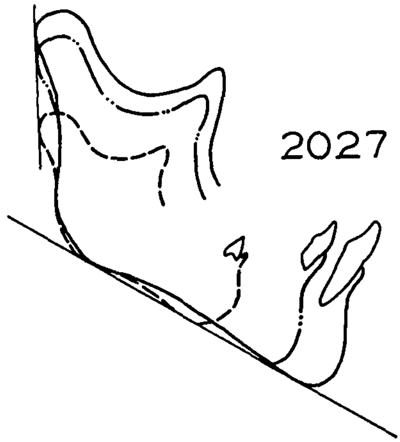

Fig. 4.—Method of superposing mandibular tracings for the study of changes in the gonial angle. Stages shown are 3 months, 2½ years and 7 years.

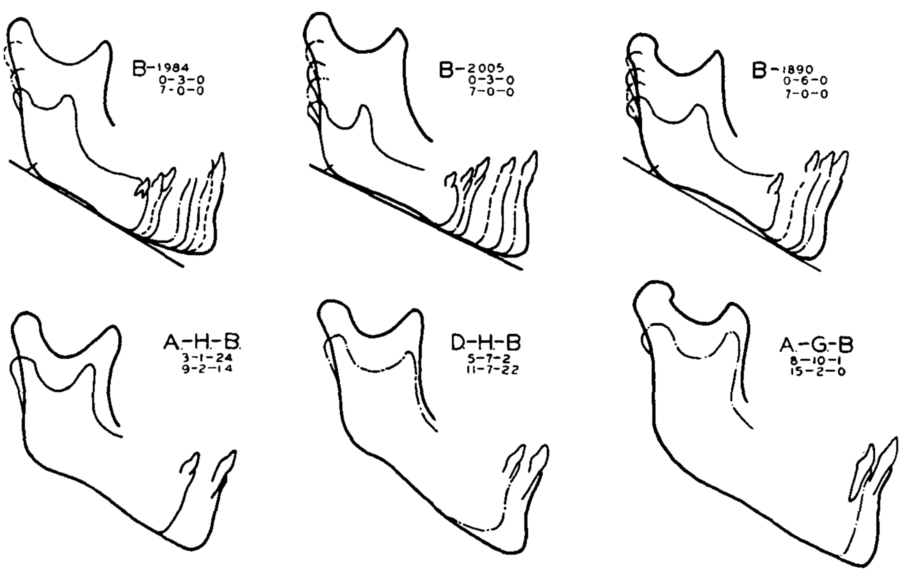

Fig. 5.—Serial superposing of mandibles of six different individuals representing a span from 3 months to 15 years.

much earlier age than has been thought. In some, as in the first case shown, it seems to have been established by 3 months of life, and perhaps earlier, whereas in the third case it has not become stabilized until 1½ years after birth. But from then on, that anatomical portion of the mandible which we designate the angle does not change in form or degree.

Everything thus far noted has pertained to patterns; now, what of rates and sites of growth? When a number of different dimensions of the head are made and tabulated, attention is attracted to the amount of growth that takes place in the length of the body of the mandible.

Figure 6 represents two mean growth curves; the upper is that of the length of the heads of ten children from 3 months to 7 years. The steep rise and geometrical diminution is quite characteristic of neural growth curves. The lower represents the growth of the lower border of the mandible from gonion to gnathion and a striking difference in form is apparent. Whereas the upper shows a strong tendency to flatten out beginning at 5

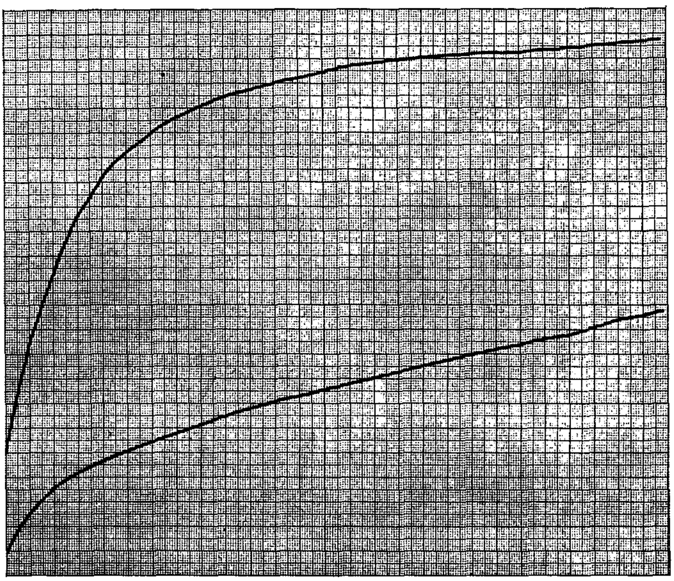

Fig. 6.—Graph showing growth of anteroposterior dimension of cranium (upper) and lower border of mandible (lower).

years, the lower appears as though it would continue steadily along its established path. It has shown no tendency to slow down by the seventh year, and a survey of older children indicates that this steady growth continues with only slight lessening of intensity until the dentition is completed.

The next curve (Fig. 7) represents the anteroposterior growth of the ramus. This measurement is taken at the level of least width which is usually a nearly horizontal line close to the level of the occlusion. This curve again reveals differences when compared to the lower border of the same bone. While it represents a fairly steady rise it will be noted that it is not nearly as steep or, in other words, that this portion of the bone increases its dimension at a slower rate.

According to previous qualitative investigations, there are two processes responsible for this difference, viz. a general and even deposition of bone at the posterior border of the mandible, including the condyle, and a resorption of the anterior border of the ramus. Considering the glenoid fossa as a relatively fixed point in relation to the mandible, it can be realized that such posterior growth would result in a steady shifting forward of the mandible. Second, since such posterior growth on the ramus would lead to an ever-increasing anteroposterior growth of the ascending ramus, this part would ultimately be built out of all proportion to the body of the bone. We are accordingly prepared for the statement that the anterior border is resorbed at only a slightly slower rate than that at which bone is being added in back. This resorption gradually uncovers the succeeding molars to permit their eruption.

Table II is a tabulation of measurements which indicate the relative positions assumed by each molar upon eruption. The distance between the last molar in eruption to the posterior surface of the ramus is measured on a line parallel to the occlusal plane. Dark bars will be noted running across

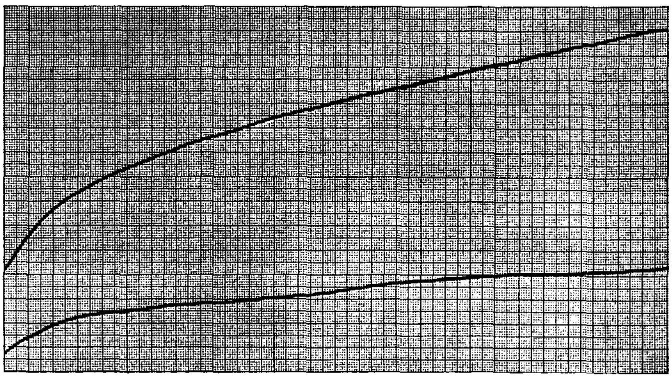

Fig. 7.—Increment growth curves of mandibular length (upper) and anteroposterior width of ramus (lower).

each table. In the first two tables the upper bar represents the first measurement on the mandibular second deciduous molar, and the lower bar that of the six-year molar. It should be pointed out that at least six months elapsed between the taking of the X-rays upon which these measurements were taken, and considerable eruption can occur in this period of time, as we know. In spite of this, a glance at the tables quickly reveals a remarkable closeness of the measurements for these two teeth. The first reads 28 and 28.25, the second 29 and 30, etc. The third table represents the same measurements taken on a group of males in the 6 to 14 year range. Here the upper bar represents the first reading taken on the six-year molar and the lower bar the first reading on the second permanent molar. It should be pointed out that a full year elapsed between all readings in this group. It is readily seen from these tables that Hunter's contention that each molar seems to erupt in the same relation to the ramus is fully borne out.

We next turn our attention to the matter of mandibular height. (Fig. 8) This has been studied as follows: a perpendicular was erected from the lower border of the mandible to the free margin of the alveolar process at the distal of the last molar tooth. Another was erected from the base of the mandible to the tip of the incisors, since in this area it is impossible

Table II.—Measurements of Distance Between Distal Contact Point at Last Molar to Posterior Border of Ramus. Heavy Bars Denote Time of First Measurement on Each Succeeding Tooth

(3 months to 7 years)

Case No.	1893	1897	1932	1941	1984	2005	2009	2027	2035	2070	2165	Mean
AGE												
0-3-0												
0-6-0	21.25											
0-9-0												
1-0-0												
1-6-0	28.^{e}	38.5^{d}		38.^{d}	38.5^{d}	39.5^{d}	44.^{d}	40.^{d}		39.^{d}	39.^{d}	
2-0-0	31.5	39.		40.75	40.	31.^{e}		32.25^{e}	41.25^{d}	40.75		
2-6-0		29.^{e}	31.25^{e}	33.^{e}	30.5^{e}	35.5	36.25^{e}	35.5^{e}	43.	32.^{e}	33.^{e}	31.84
3-0-0	34.	31.5	35.	34.5	32.75	36.5	36.	36.75	34.^{e}	33.5	34.	
3-6-0	34.	33.25	35.75	36.5	34.	38.	36.25	38.25	34.25	35.5	34.5	
4-0-0	37.		36.25	36.75	35.25	38.5	37.	39.	36.25	37.5	34.5	
4-6-0	37.25	35.75	37.	39.	37.	40.	38.75	41.75	37.5	39.	36.5	
5-0-0	28.25^{6}	37.	39.5	39.5	36.5	41.	41.	43.		40.	38.	
6-0-0	31.5	40.	40.5	42.5	28.5^{6}	32.5^{6}	42.	44.5	41.	32.^{6}	28.75^{6}	31.65
7-0-0	32.	30.^{6}	32.^{6}	34.25^{6}	30.5	34.25	35.^{6}	35.^{6}	32.^{6}	33.	32.5	

(6 months to 8 years)

Case No.	2019	2130	2078	2173	2207	2108	2058	2049	2017	2125	Mean
AGE											
0-6-0											
0-9-0											
1-0-0											
1-6-0		38.^{d}	47.^{d}	35.^{d}			36.^{d}		36.^{d}		
2-0-0		39.	31.^{e}	37.		40.^{e}	28.5^{e}		37.5	28.^{e}	31.1
2-6-0	34.^{e}	30.5^{e}	36.25	32.^{e}			32.			32.5	
3-0-0	38.	31.	37.5	33.	32.5^{e}	32.5^{e}		34.25		34.	
3-6-0	38.	33.5	39.	33.5	35.	35.	35.	34.	32.	35.	
4-0-0	37.5	34.	40.	33.5	35.5	36.	35.	35.	32.	36.	
4-6-0	40.	35.	40.75	34.25	36.5	36.5	37.	35.	34.	37.	
5-0-0	41.	36.		36.	38.	37.5	39.	38.	35.	38.	
6-0-0	43.25	38.25	31.^{6}		40.	39.	28.5^{6}	39.5	35.5	28.75^{6}	30.65
7-0-0	32.5^{6}	29.^{6}	34.25	27.5	41.	41.	30.	29.5^{6}	27.6^{6}	31.25	
8-0-0	35.	31.	36.	30.5^{6}	33.^{6}	32.^{6}	32.25	31.	28.	33.5	

Distance of the Last Molar Tooth to Distal Border of Ramus
(6 years to 14 years)

Case No.	255	1681	2471	2600	2798	2384	2037	2032	2234	2216	Mean
AGE											
6-0-0			29.25^{6}				27.^{6}	28.25^{6}			
7-0-0	28.25^{6}	32.5^{6}		32.75^{6}	31.25^{6}	30.75^{6}			30.75^{6}	32.	30.27
8-0-0											
9-0-0											
10-0-0											
11-0-0											
12-0-0			29.5^{7}								
13-0-0	29.^{7}	32.^{7}		33.^{7}	32.^{7}	30.25^{7}	27.5^{7}	27.25^{7}	28.5^{7}	30.5^{7}	29.95
14-0-0											

"d" denotes first deciduous molar
"e" denotes second deciduous molar
"6" denotes first permanent molar
"7" denotes second permanent molar

to locate the alveolar crest accurately. The difference in the technique of taking these two measurements probably accounts for most of the difference in the curves since the incisal curve includes the phenomenon of eruption while that at the molar area does not. Since these curves end at seven years, when both molar and incisor are in place, we would expect the curves to become more nearly parallel.

But this is not the only factor in the height problem. A study of even a short series of X-rays reveals the fact that the occlusal plane moves steadily downward until maturity. It also reveals that such a descent is not accompanied, in the normal, by any tipping of the plane. It naturally follows that one of two processes can take place; namely, (1) the mandible must increase

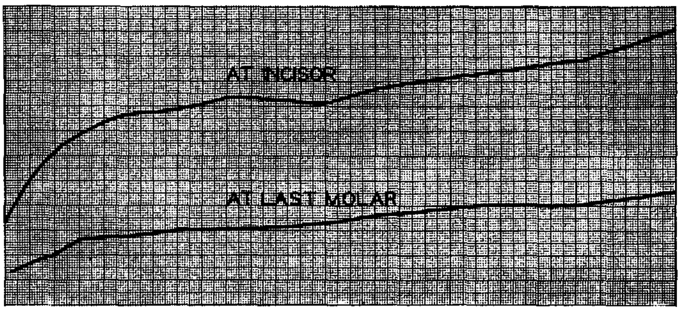

Fig. 8.—Graph showing increase in mandibular height at incisors and at molars.

in height by additions on its lower border and corresponding resorptions on its alveolar edge to permit the plane to descend, or, (2) the condyle must grow upward fast enough to take care not only of the increased height of the body of the bone, but also to accommodate the descent of the occlusal plane. This problem has never received very much serious consideration, although Brash, on the basis of his madderizing experiments, attributes from 70 to 100 per cent of the vertical height of the *body* to alveolar growth, with only 0 to 30 per cent taking place at the lower border. This amount of vertical growth would pull the condyle out of its fossa. It should be pointed out, however, that Brash was investigating the pig, a long snouted animal, where the length increase overshadows all others.

It was pointed out early in this presentation that every technique had its limitations and here we find an example of it. Having determined how much growth takes place along a given line over a given interval of time, we can state our findings in terms of rates and tendencies. But we are still in the dark as to the actual sites where such bone additions are taking place. We must accordingly use a different method for this determination.

Experimental Findings

Obviously, if we are interested in the growth pattern of the human we should select an experimental animal whose pattern lies as close to man as possible. We have used the macaque monkey. A group of these animals have been injected with Alizarine Red "S" according to the technique worked out by Schour and his collaborators. This dye is given by intra-peritoneal or intravenous injections and is deposited wherever active bone deposition is taking place. Its dosage can be so adjusted that a sharp line is obtained and the dye does not disturb the growth of bones. In order to get as wide a range as possible, animals of different ages were used to start with, but our attention has now become focused on the very young. These animals are injected and cephalometric roentgenograms are taken under anaesthesia at periodic intervals. Upon sacrifice, the head skeleton is first examined grossly, after which sections are cut and prepared by grinding in order to measure distances between lines. This work is carried out with the aid of a dissecting microscope.

It is possible to make colored photographs of specimens for projection, but the reproduction of color plates for publication is still prohibitive in cost. Black and white half-tones of colored material leave much to be desired. The author is therefore forced to rely on written descriptions of the findings in this paper. A more detailed consideration of the qualitative data will have to be postponed for the present. Three animals of different ages have been carefully studied thus far. The first of these was in the stage of the complete deciduous dentition, the second exhibited the mixed dentition and the third the adult.

The most striking difference between the three specimens lies in the intensity of the staining reaction. The mandible of the youngest monkey was heavily stained throughout its entire surface. Growth is occurring everywhere and at such a rapid rate that a scrutiny of only the surface fails to reveal a definitive pattern of deposition. Only where the bone is extremely thin, as in the sigmoid notch, are alizarine lines discernible. Growth appears generalized during this stage.

The second animal, which corresponds to a six-year human dental pattern, is quite different. The generalized type of growth has nearly disappeared, bringing into strong relief the *remaining sites* of growth. The most apparent of these is located at the head of the condyle where the red dye is intense. A zone of deposition is present along the entire length of the posterior border of the ramus, the sigmoid notch, and along the alveolar crest. Deposition on the inferior border seems to have stopped and only faint traces are noticeable on the lateral surfaces.

The findings on the adult specimen differ from the second only in degree; that is, the rate of bone growth only is diminished, not the mode. There is still growth at the condyle, the posterior border of the ramus, the sigmoid notch and the free alveolar margin. All are less intense and the lateral surfaces exhibit no trace of stain.

Ground sections cut from various parts of the bone and at right angles to the surface being deposited reveal sharp alizarine lines, corresponding to the injections given. Measurement of the distances between lines should yield data on the rates of growth at various sites. This work is now under way and will be reported at a later date.

Summary and Conclusions

Serial roentgenology as developed by Broadbent eliminates the most serious deficiencies of anthropoligcal methods because it permits accurate study of the same living individual throughout the growth period. However, there is no single method that will yield all of the information we desire and this method is no exception, since we must be content with the growth rates of aggregates and with tendencies. Sites of growth are inscrutable in the X-ray picture. The combination of serial roentgenology and the vital staining technique marks the wedding of the two most effective methods. Each complements the other.

Cephalometric investigations on series of roentgenograms of young males reveal:

(a) That until two years of life the jaws are apart and the tongue occupies the space between them.
(b) The angular relation between the lower border of the mandibles and the cranial base appears to be established by three months of life and perhaps earlier. Prior to and probably after the eruption of the teeth the spatial relationship of the mandible is maintained by the muscle tensions operating upon it from above and below. The tongue is gradually enclosed by the vertical growth of the upper and lower alveolar processes and the eruption of the teeth at the same time that the face is being driven forward by posterior growths against fixed points.
(c) Superpositioning of the mandibles of children from three months of life onward reveals that the angle of the mandible does not change as has universally been taught. The method used in the past for measuring this angle is responsible for this error.
(d) Measurements made from the distal contact points of the molars to the posterior border of the ramus reveal that the second deciduous, and first and second permanent molars all erupt at the same point. This confirms Hunter's contention of 1771. No series had extended far enough to include the third molars.
(e) Measurements on height of the body of the mandible showed a slow and fairly steady increase, but superposing of the tracings of the entire head revealed a lowering of the occlusal plane. The lowering was not marked by any tilting or other change in pattern. This indicates that condylar growth must be equal to the sum of all vertical growth, not only of the mandible but of the upper face as well.

Experimental findings on macaque monkeys were based on a double attack, i.e., a combination of serial roentgenology and periodic alizarine injections. The first revealed:

(a) That the growth pattern of this animal differs only slightly from that of Man.
(b) Alizarination revealed that until the eruption of the first permanent molar, growth was of a generalized type; that is, all surfaces of the mandible were stained.
(c) From the stage of the mixed dentition onward growth was shown to be restricted to definite sites.
(d) The most prominent sites were the head of the condyle, the posterior border of the ramus, the sigmoid notch and the alveolar border. Ground sections of these areas exhibited alizarine lines corresponding to the various injections and held promise that growth rates might be established through further study.

All of the evidence points to a growth of the mandible that is in a downward and forward direction. The forward vector is supplied by bone growth at the back of the ramus, while the downward vector occurs as a result of the upward growth of the alveolar border against a plane that is descending. Since there is no tilting of the occlusal plane and no change in the gonial angle, it follows that the growth of the condyle head must equal the sum of both maxillary and mandibular growths.

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Bibliography

ADAMS, J. W. "Correction of Error in Cephalometric Roentgenograms," *Angle Orthodont.*, 10:3, January, 1940.

BENNINGHOF, A. "Die Architectur der Kiefer und ihrer Weichteilbedeckungen," *Paradentium,* March, 1934.

BENNINGHOF, A. and SEIPEL, C. "Über den Struckturellen Bau des Unterkiefers beim Menschen." Inaugural Dissertation for Doctorate in Dentistry Rheinischen-Fredrich-Wilhelms, Universitat zu Bonn, 1934.

BRASH, J. C. "The Growth of the Jaws and Palate." Dental Board of the United Kingdom, 1924.

——— "Some Problems on the Growth and Developmental Mechanics of Bone," *Edin. Med. Jour.*, 41:n.s. IV, 1934.

BROADBENT, B. H. "A New X-ray Technique and Its Application to Orthodontia," *Angle Orthodont.*, 1:45-66, April, 1931.

——— "Bolton Standards and Technique in Orthodontic Practice," *Angle Orthodont.*, 7:209-33, October, 1937.

BRODIE, A. G. "On the Growth Pattern of the Human Head, from the Third Month to the Eighth Year of Life." Thesis submitted for the degree of Doctor of Philosophy, University of Illinois, 1940.

——— and DOWNS, W. B., GOLDSTEIN A., MYER, E. "Cephalometric Appraisal of Orthodontic Results." *Angle Orthodont.*, 8:266-90, October, 1938.

ELMAN, E. "Studies on the Relationship of the Lower Six-Year Molar to the Mandible," *Angle Orthodont.*, 10:24-32, January, 1940.

FELL, H. B. *Arch. f. exper. Zellforsch.*, p. 390, 1928.

——— and Robison, R. "The Osteogenetic Capacity in Vitro of Periosteum and Endosteum Isolated from the Limb Skeleton of Fowl Embryos and Young Chicks," *J. Anat.*, p. 157, 1932.

——— *Biochem. Jour.*, p. 767, 1929.

GOODSIR, J. *The Anatomical Memoirs of John Goodsir,* William Turner, 1868.

GREGORY, W. K. *Our Face from Fish to Man.* G. P. Putnam's Sons, New York, 1929.

HELLMAN, M. "A Preliminary Study in Development as It Affects the Human Face," *D. Cosmos,* 49:250-69, 1927.

——— "The Face and Teeth of Man; a Study of Growth and Position," *J. D. Res.*, 9: April, 1927.

——— "The Face in Its Developmental Career," *D. Cosmos,* 77:685-99, July, 1935 and 77:777-87, August, 1935.

HOFRATH, H. "Bedeutung der Roentgenfern—und Abstandsaufnahme für die Diagnostik der Kieferanomalien," *Fortschr. der Orthod.*, Vol. 1, 1931.

HUMPHRY, G. "On the Growth of the Jaws," *Trans. of the Cambridge Phil. Soc.*, 1864.

HUNTER, JOHN. *Natural History of the Human Teeth,* London, 1771.

HUXLEY, J. S. *Problems in Relative Growth,* L. MacVeagh, the Dial Press, New York, 1932.

KEITH, A. and CAMPION, G. "Contribution to the Mechanism of Growth of the Human Face," *J. Orthodont. and Oral Surg. and Rad.*, 8:607-33, October, 1922.

MARTIN, R. *Lehrbuch der Anthropologie, in Systematische Darstellung.* 2d. ed., 3 vol. Jena, Fischer, 1928.

SCHOUR, I. "Growth Rhythm and Ring Analysis of the Tooth," *Anat. Rec.*, 67, No. 4, Sup. 3, p. 45-46, 1937.

——— and MASSLER, M. "Rate and Gradient of Growth in Human Deciduous Teeth with Special Reference to Neonatal Ring," *J. D. Res.*, 16:349-50, 4, 1937.

——— and PONCHER, H. G. "The Rate of Apposition of Human Enamel and Dentin as Measured by Effects of Acute Fluorosis," *Am. J. Dis. Child.*, 54:757-76, October, 1937.
——— and BRODIE, A., KING, E. "Dental Changes in a Hypopituitary Condition," A Case Report, *Angle Orthodont.*, 4: 285-304, October, 1934.
THOMPSON, D'ARCY. *Growth and Form,* Cambridge University Press, 1917.
WOLFF, J. *Das Gasetz der Transformation der Knochen,* Berlin, 1892.