Ontogenic Development of Occlusion *

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Just twenty years ago the late Doctor T. Wingate Todd (1) pointed out to the author that the measurements of skulls of dead children are largely records of defective growth, and in order to secure accurate and useful information about normal developmental growth of the teeth and jaws, it must be done on healthy, living children. This dictated the need for a technique applicable to the living head and initiated experiments from which evolved, through the application of roentgenography (2), the Bolton cephalometer (3). The description of this instrument and the details of the technique (4, 7) have been published elsewhere. This command of registration of the internal as well as external changes in the living head precisely records the progress of developmental growth of the teeth and jaws in relation to the cranial base in three planes of space.

A knowledge of form and structure alone is not enough. It must be accompanied by a clear understanding of the processes of growth and development, i.e., the sequential changes with the passage of time. The X-ray is to gross anatomy what the microscope is to histology; it reveals differentiation of parts and structural and morphological changes can be followed in detail. In proportion to our ability to record and understand the development of occlusion, it becomes more and more the rational foundation for the practice of dentistry, particularly those phases dealing with the maintenance, improvement and restoration of the occlusal function. As dentists, our conception of occlusion is usually the adult normal articulation. Although we fully realize that this adult pattern has been preceded by that of the mature deciduous dentition, yet we continue to ignore the unlimited number of steps in the progressive developmental growth of both the deciduous and permanent teeth. It remained for Doctor Milo Hellman (8) to point out several of the intervening stages of dentition between early infancy and senility. Hellman's stages, based on the erupted pattern of the teeth in the oral cavity, offer a satisfactory set of standards for roughly cataloging skeletal material. Experience in the application of these standards to the growing child indicates that they give only a limited measure of the stage of maturity at which the individual has arrived and practically no indication of the intervening steps between each of his stages and substages.

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Fig. 1.—Standardized lateral and frontal orthodiagraphic roentgenograms oriented for tracing and measuring dento-facial structures. Tracings are shown in Fig. 2.

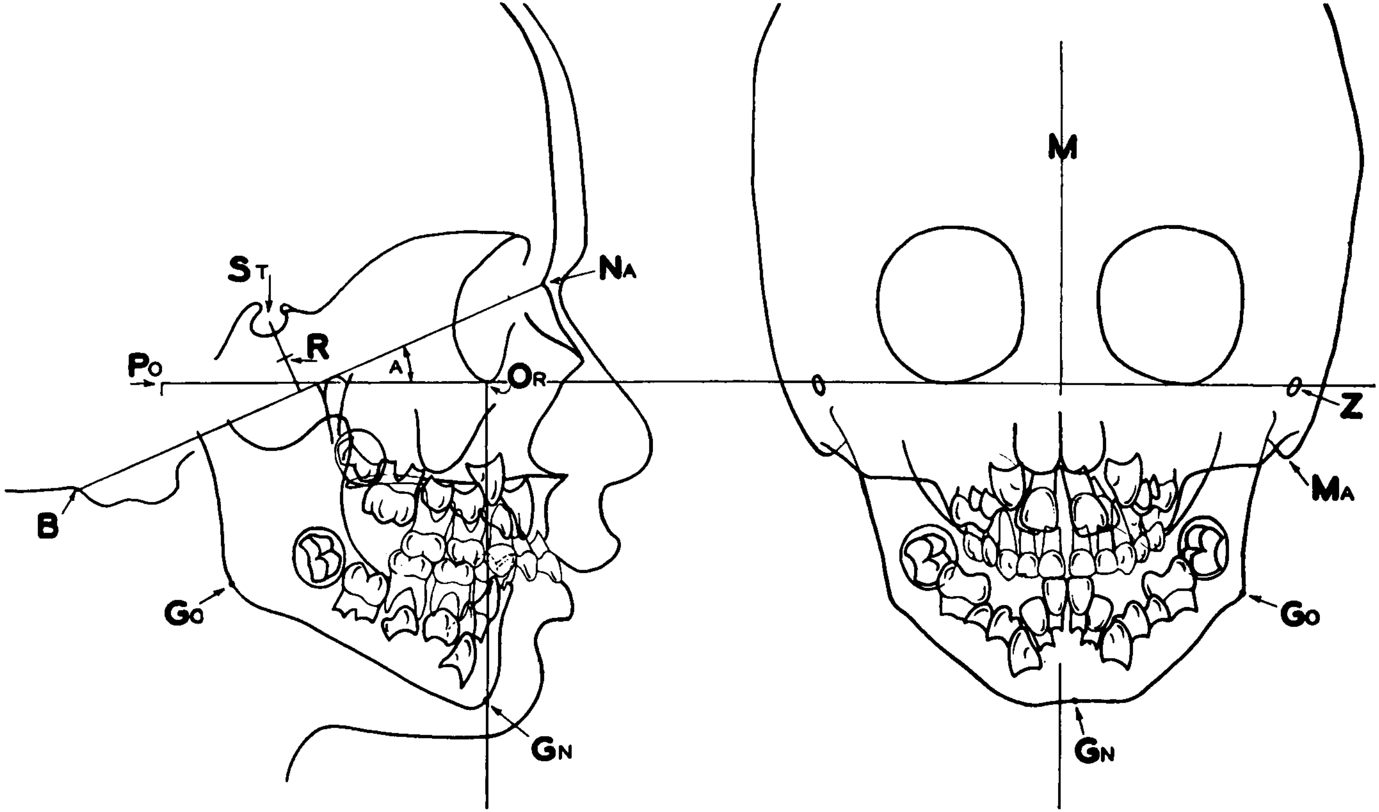
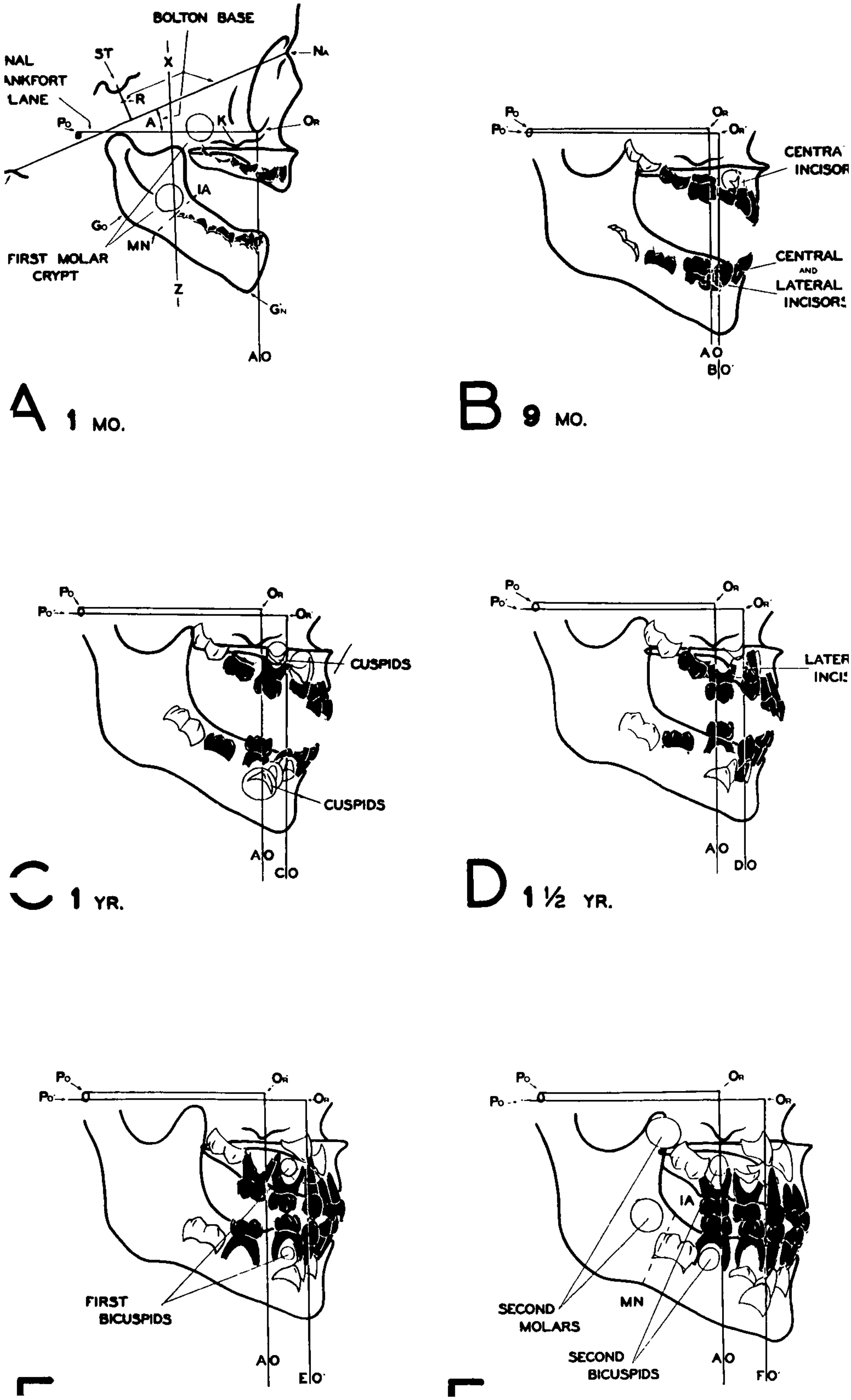


Fig. 2.—Tracings of Bolton roentgenograms shown in Fig. 1 including some of the deciduous and permanent teeth and several of the anatomical landmarks. B—Bolton point. GN—Gnathion. GO—Gonion. M—Median plane. NA—Nasion. OR—Orbitale. PO—Porion. R—Registration point. ST—Sella Turcica. Z—Zygomatic arch.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CUSPIDS
A|O
C|O
C 1 YR.
D|O
D 1 ½ YR.
FIRST
BICUSPIDS
E|O'
SECOND
MOLARS
SECOND
BICUSPIDS
F|O'

Figures 1 and 2 show a typical pair of lateral and frontal standardized cephalometric roentgenograms and their tracings. It is from similar monthly, quarterly, semiannual and annual records made during the past 12 years of 5,000 Cleveland children that the following discussion of the ontogenetic development of occlusion is based. The limited time allotted to this discussion prevents the inclusion of all of the records of these representative individuals. Those chosen illustrate some of the salient features of dento-facial developmental growth progress that aid the clinician (5) in appraising the stage of occlusion at which the child has arrived. Shortly after the birth of the individual we are offered our first opportunity to initiate serial investigations of the development of the teeth and supporting structures.

Figures 3 and 4 are a part of the Bolton records of the same individual at one month through nine years. These are oriented in the Bolton relation, and each contains the original Frankfort and orbital plane of the one month stage. Each subsequent record contains, besides the original Frankfort and orbital plane, the Frankfort and orbital plane of the age at which the individual has arrived.

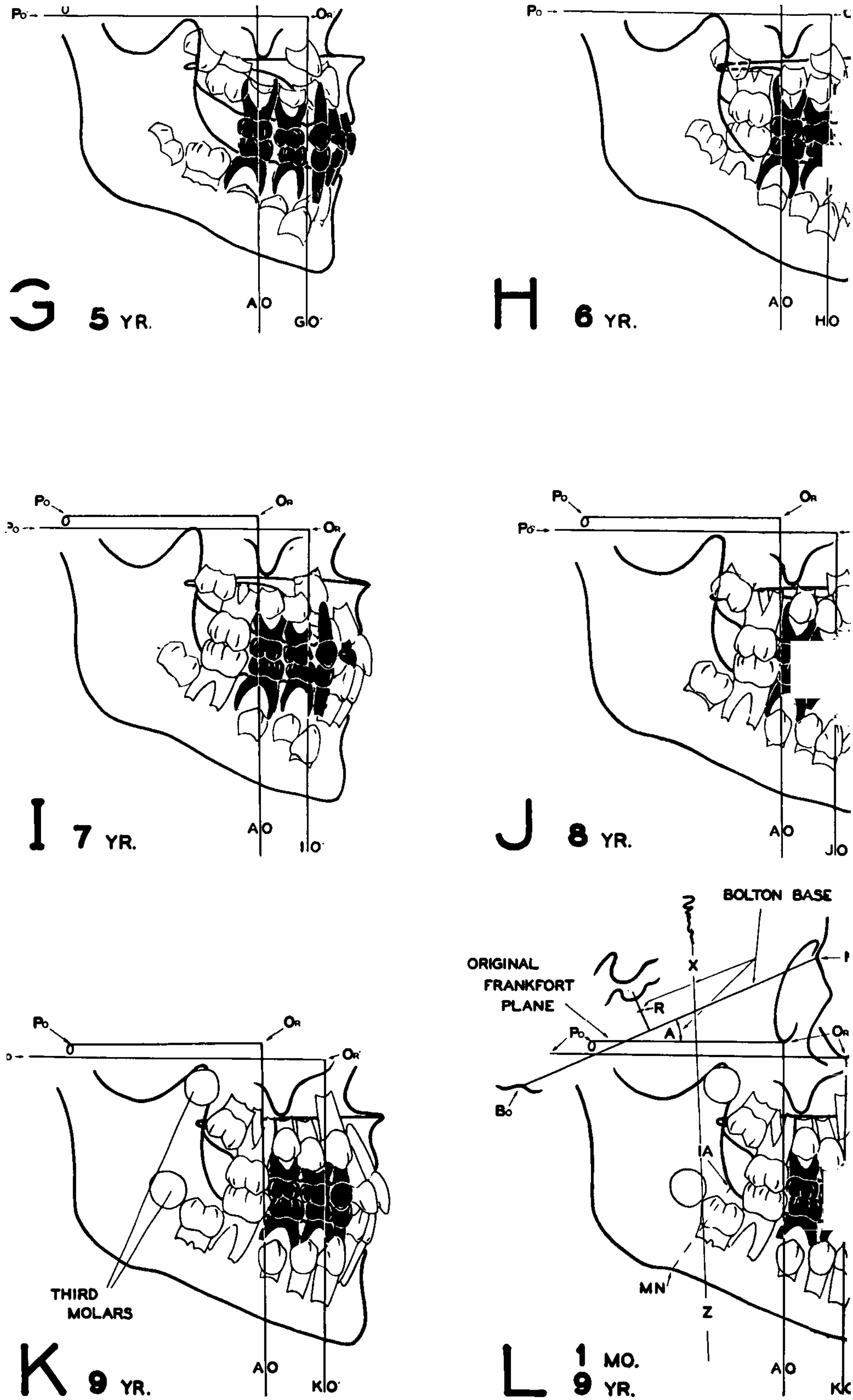
At birth the jaws contain the partially calcified crowns of the 20 deciduous teeth and the clearly defined (roentgenographically)[1] crypts of the first permanent molars. In Figure 3 A, the tracing from the profile roentgenogram of a normal child at one month shows the dental pattern of the deciduous dentition, the arrangement of the dental units very closely approaching their subsequent pattern when these teeth reach their full functional occlusion. They occupy the upper half of the lower jaw and the lower half of the upper jaw. In the lower jaw it is of particular significance to note that the deciduous teeth are in the body of the mandible below and anterior to the crypts of the first permanent molars, while the latter are in the vertical rami above the junction of the body with the rami. The broken line connecting the internal angle *IA* and the mandibular notch *MN* defines the junction of the body with the rami on either side.

The study of the eruption of teeth based on the measurements of skulls of dead children of different ages with unknown health records supplies fragmentary information, while standardized roentgenograms are a comprehensive record of the status and progress of developmental health in the same and different living individuals. Monthly registrations of the same child indicate that eruption in its broadest sense begins with the appearance of the crypt in the bone, includes the migration of this crypt through the bone even before calcification is detected by the roentgenogram and continues to a slight degree after the cutting of the teeth into the mouth.

By nine months, in Figure 3 B, the increase in size of the teeth is ac-

[1] Histological examination will determine the beginning of calcification before the dental X-ray technic will detect it. The dental X-ray technic reveals it slightly ahead of the cephalometric roentgenographic technic. This latter is due to the greater differences in target and film distances.

Fig. 3.—Developing dento-facial patterns of an individual from one month to the completion of the deciduous dentition at three years. IA—Internal angle. MN—Mandibular notch. AO—Original orbital plane. PO-OR—Original Frankfort plane. PO′-OR′—Subsequent Frankfort planes. BO′-CO′ etc.—Subsequent orbital planes. See text for detailed description of the state of dentition.



Po
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AO
GO
H 6 YR.
HO
I 7 YR.
IO
J 8 YR.
JO
THIRD MOLARS
K 9 YR.
KO
BOLTON BASE
ORIGINAL FRANKFORT PLANE
X
R
A
Bo
IA
MN
Z
L 1 MO. 9 YR.

companied by the cutting of the incisors into the mouth and the appearance of the beginning of calcification of the upper and lower permanent centrals and the lower laterals. As Kronfeld (6) first pointed out, the beginning of calcification of the upper laterals does not coincide with that of the lower laterals.

Three months later at one year, Figure 3 C, when the first deciduous molars are appearing in the oral cavity, the roentgenogram reveals the beginning of calcification of the permanent cuspids between the roots of the first deciduous molars. As the deciduous teeth erupt toward the occlusal plane the incisor and cuspid crypts, including their rapidly growing crowns, migrate forward in the jaws at a greater rate than the forward movement of the deciduous teeth themselves. These changes are easily gauged in relation to the relatively fixed Frankfort *PO-OR* and orbital planes *AO*. The inclusion of the subsequent Frankfort plane *PO′-OR′* and orbital plane *BO′-CO′*, etc., at the ages shown, discloses the fallacy of anthropometric technic that uses these migrating landmarks as a basis for measuring dento-facial changes during growth.

At one and one half years (Fig. 3 D) the upper lateral incisors now begin their calcification at sites partially behind the upper centrals and below the upper cuspids. The two year stage is shown in Figure 5 A, of another child, when sufficient calcification of the upper lateral has taken place to permit its location to be determined with greater ease.

Not until two and one half years (Fig. 3 E) do the first bicuspids begin their calcification between the roots of the first deciduous molars. It is significant to note that the site of origin of these teeth is the same as that of the permanent cuspids (Fig. 3 C). This occurs when the individual is cutting the last of the deciduous molars to complete the clinical pattern of the deciduous dentition.

The rapid rate of growth of the jaws continues and by the third year (Fig. 3 F), the crowns of all the first permanent molars are completed, while the lower first molars have migrated from their site of origin in the vertical rami (Fig. 3 A) downward and forward into the body of the mandible from which point they will be seen in the following records to change their course to an upward direction to cut their way into the mouth meeting their upper antagonists at the so-called plane of occlusion. During this eruption these teeth, like all of the teeth in the face, are being carried downward and forward and laterally as the face expands, but at a slower rate than the rate of eruption. Only the central incisors maintain their proximity to the median plane. This age (Fig. 3 F) is also marked by the appearance of the beginning of calcification of the second bicuspids between the roots of the second deciduous molars, and the calcification of the second permanent molars, so that with the completion of the deciduous dentition there are within the jaws the calcifying crowns of all of the permanent teeth with the exception of the third permanent molars.

The pattern of the developing molar series repeats itself with the beginning of calcification of the second permanent molars at identical sites

Fig. 4.—Developing dento-facial patterns of the same individual as shown in Fig. 3 from five years to nine years. See text for detailed description of the state of dentition.

in the maxilla and mandible where, at one month, the first permanent molars originated (Fig. 3 A). With the aid of the Bolton base planes included in each figure it is possible to trace the intricate changes in relative position of each of the teeth as they progress toward maturity. By this time (Fig. 3 F) the pattern of the face as a whole has been consummated, and undergoes little if any change in configuration thereafter.

By the fifth year (Fig. 4 G) the crowns of the permanent upper and

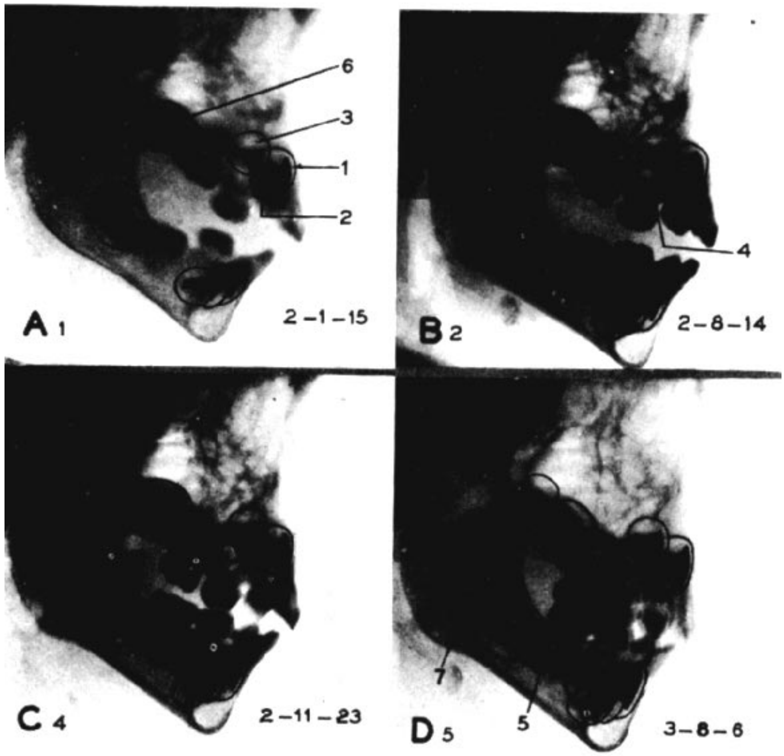


Fig. 5.—Profile roentgenograms of another Bolton record between the ages of two and three and one half developmental years. A—Location of developing upper centrals—1. Upper laterals—2. Upper cuspids—3. Upper six-year molars—6. B—Site of beginning of calcification of upper first bicuspids—4. C—Note the calcification of both upper and lower first bicuspids between the roots of the first baby molars and the appearance of the crypt for the lower second molar. D—Calcification of the lower second bicuspid—5. Beginning of calcification of the lower second molar—7.

lower centrals and lower laterals have been completed. Before the fifth year resorption of the roots of the deciduous incisors has commenced.

In the sixth year (Fig. 4 H) we find the clinical dental pattern at the onset of the mixed dentition with the 20 deciduous teeth augmented by the 4 first permanent molars. Before any deciduous incisors are shed between the sixth and seventh year, the two jaws contain a greater number of teeth than at any other time. The jaws continue their rapid rate of growth to accommodate the fast advancing permanent teeth. As one follows the trend of growth of the dental organs one becomes profoundly impressed by their shifting and tipping as the face expands. Unlike the usual description of tooth eruption by apposition at the root end that is believed to force the crowns toward the plane of occlusion, our studies on the living children clearly disclose that a tooth at various times may progress in three distinctly different ways: first, the growing tooth may remain stationary while its forming end grows away from the incisal or occlusal surface into the bone; second, at another time, it may migrate relatively rapidly through the bone with but little increase in its length; third, the increase in tooth length and the migration of the tooth through the bone may occur simultaneously. These and other developmental growth processes unfolded themselves when the standardized roentgenograms of the same individual were incorporated into the animated motion pictures that have become a most valuable part of the Bolton Study. This visual aid has illuminated many of the heretofore unknown directional paths of eruption not easily discerned in the study of individual charts.

The completion of the deciduous occlusion covers a period of three years. It maintains its occlusal function intact for a like period of time when it is joined by the first permanent molars shortly before the shedding process of the deciduous teeth commences. This shedding covers a period of six years when these teeth are replaced by their permanent successors. If any one period in the development of occlusion is more complicated than another, it is this period of mixed dentition.

The complicated arrangement of the permanent teeth within the bone just preceding the advent of the eruption of the permanent incisors is illustrated in Figure 6. These lateral and frontal views of the skull of a child of five years disclose the closely packed crowns of the 28 permanent teeth and show how filled with teeth the jaws are at this age. The jaws are but shells made up of the external cortical plates divided into numerous crypts, the bony walls of which approximate each other and partition off one tooth from the other. Like the skulls of nearly all dead children available for study, this specimen reveals the lack of proper growth of the maxilla and mandible for a normal child of five years. As a result of the dwarfism in the face, the lower permanent tooth crypts are in contact with the cortical bone along the lower border of the mandible shown at 3 and 6 in Figure 6, and the upper permanent teeth are still above the level of the hard palate. In the frontal view it will be seen that the forming ends of the upper incisors have grown upward above the level of the floor of the horizontal palate into the nasal cavities. Normally, as in Figure 4 G, the vertical dimension of the maxilla and mandible would be sufficient to place the dentition farther away from the floor of the nose above, and the lower border of the mandible below. This skull is a typical picture of retarded skeletal growth.

If an individual has had the good fortune to have enjoyed normal developmental health, then and only then will the bony skeleton of the supporting structures have achieved its destined size and form for its developmental age. Unfortunately there are numerous subclinical handicaps, however slight, that may prevent the expansion of the facial parts to a sufficient degree, so that when the much larger permanent teeth begin their

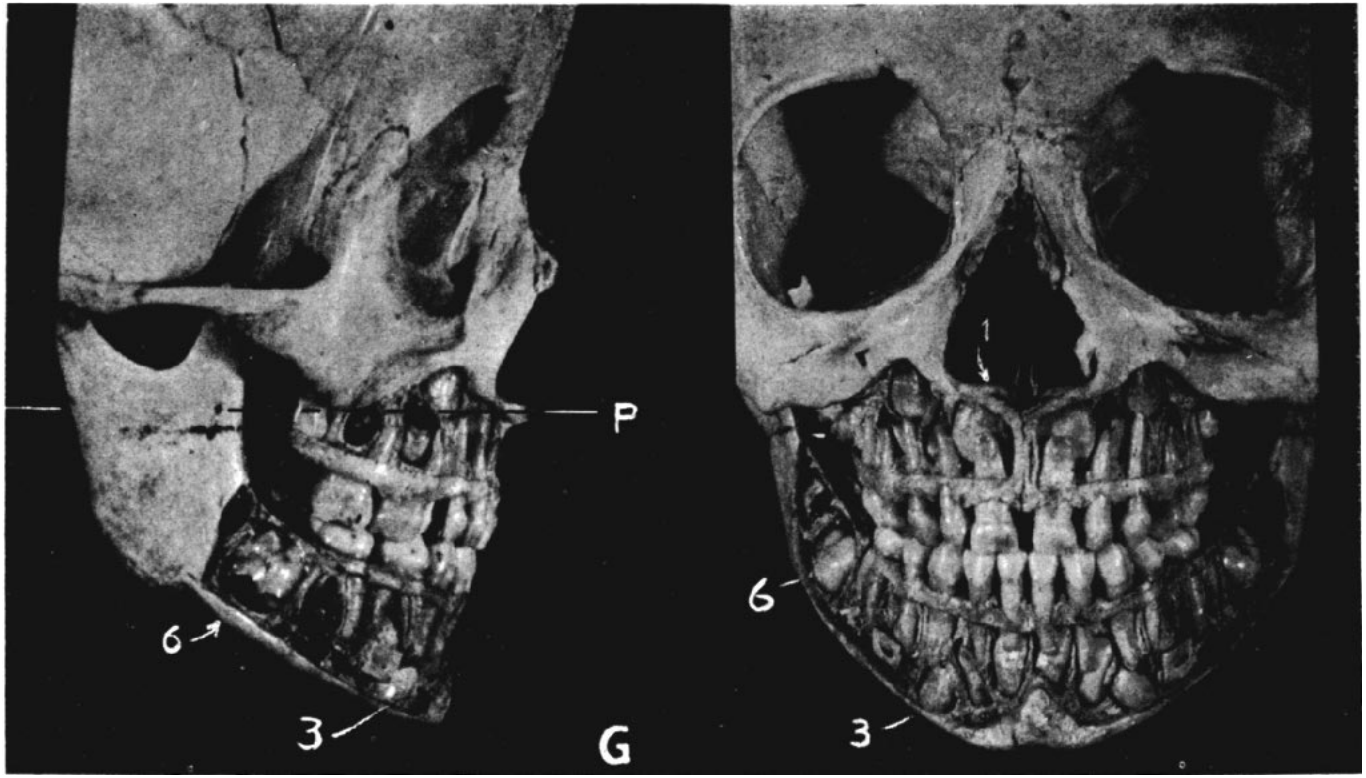


Fig. 6.—Lateral and frontal views in Frankfort relation of a child's skull at five years. Dissection exposes location of the twenty-eight permanent tooth crowns. Note their relation to the deciduous tooth roots and supporting bones. P—Level of the hard palate. 3—Lower cuspid. 6—Six-year molar. 1—Upper central incisor crypt.

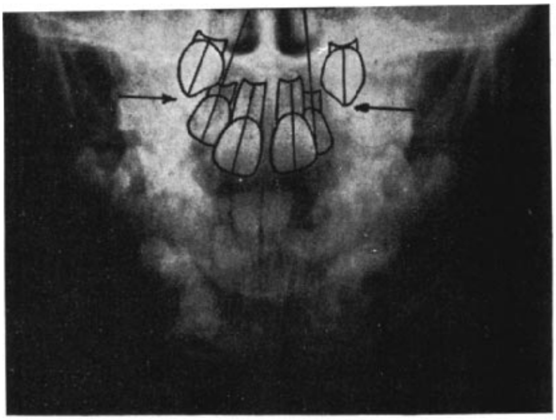
eruption they are forced into malocclusion. Thus, malocclusions appearing in the early mixed dentition are largely symptomatic of past developmental growth defects in the face. If the cause is removed, many of these defects tend to be overcome, unleashing the normal forces of development and permitting the individual to regain much of the lost ground.

Since the advent of orthodontic procedures, the common belief has been that expanding the dental arches by mechanical means more or less insured and maintained normal articulation of the teeth in both dentitions. In children with retarded development the skeletal structures are inhibited in their growth in all three planes of space. Therefore, it does not follow that expansion of the deciduous or mixed dental arches in only two directions can be expected to alter the supporting structures (particularly in the vertical dimensions) except the portions which offer immediate support to the teeth themselves.

Over a period of the past fifteen years the author has accumulated serial records of more than 1,000 orthodontically treated cases. With the opportunity to compare the progress of developmental growth in this series with the serial records of the Bolton Study of over 3,000 non-treated individuals, it is convincing that, granting the correction of the malarticulation of the teeth which is accompanied by some change in the alveolar process, there is little actual alteration in the bony contours. Then, too, the ease with which these articulatory changes are effected is in direct proportion to the developmental health progress of the individual, so that if we as clinicians are to maintain, improve, or restore occlusal function we must be fully cognizant of the limitations placed upon us by the many developmental health factors involved. This brings us to a point where the use of any classification of dental development applicable to the individual for the prognosis, diagnosis and treatment must include several gawky or, as previously termed, "ugly duckling" stages that too often are diagnosed and treated as malocclusions.

Like the layman the clinician has been too apt to conclude that since the deciduous dentition seemed relatively free from malocclusion, the permanent teeth should erupt normally. To avoid this common error the clinician must apply a clear understanding of the developmental growth changes taking place above and below the roots of the deciduous teeth. The command of registration in three planes of space (Fig. 1) shows most of the internal as well as external changes in occlusion of the individual. Any attempt to record and measure a three dimensional object such as our problem includes, with the use of a profile view only, is both irrational and unscientific. Without a record of the lateral growth that is found in the complementary frontal picture, the investigator and clinician alike are leaving too much to the imagination. The frontal roentgenogram permits us to follow the incisor teeth as they wend their devious routes into occlusion. During the eruption of the permanent centrals, particularly the uppers (Fig. 7 I), which shows the beginning of their "ugly duckling" stage, we find in most of the Bolton records a space between these teeth that in many cases persists for three or four years, and may not close until the eruption of the permanent cuspids.

By the seventh year (Fig. 4 I) the crowns of the permanent cuspids have been completed but they have not yet moved far from their site of origin.



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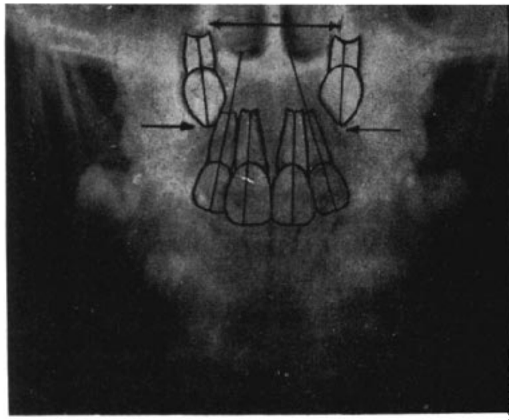

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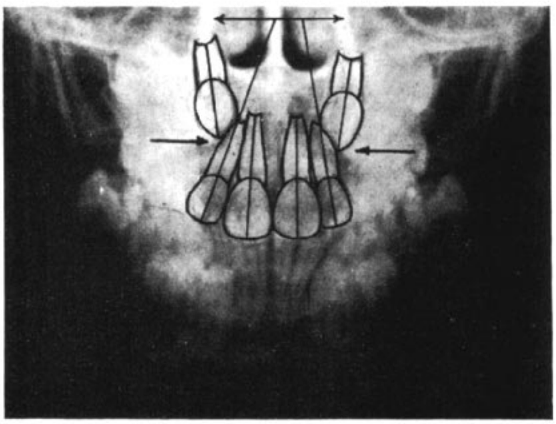

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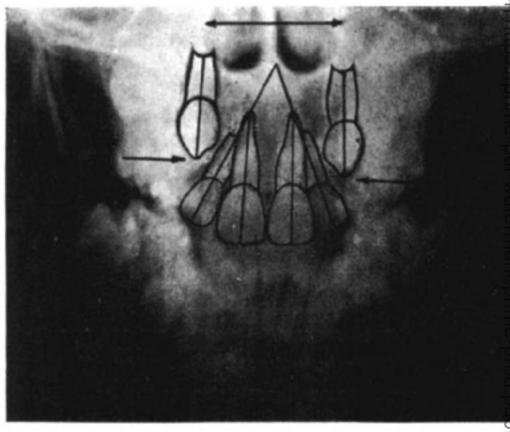

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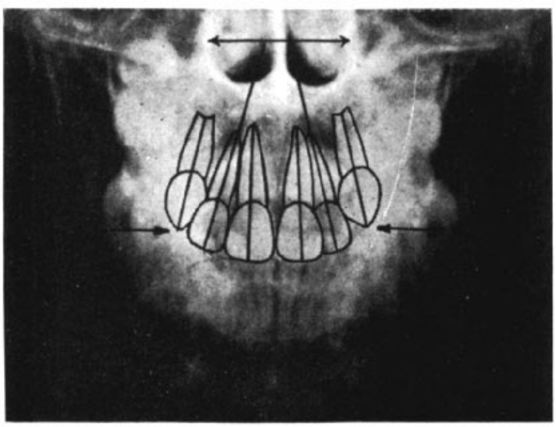

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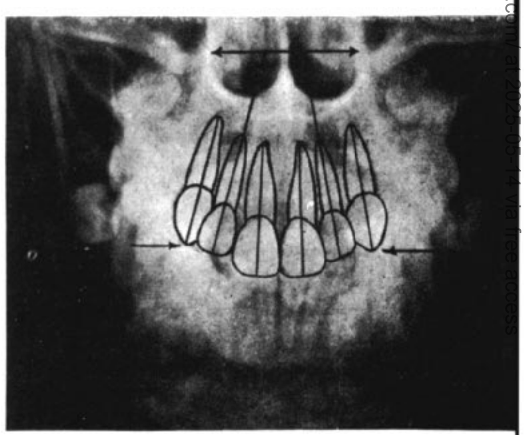

R 14 YRS.

"UGLY DUCKLING"
DEVELOPING DENTAL PATTERNS

In a relatively short time the incisors (see Figs. 4 & 7 J) cut their way into the mouth with the lateral incisor crowns flaring out as they come downward and forward to take their positions in approximal contact at the distal of the centrals. This outstanding "ugly duckling" stage reaches its maximum at about 10 years (Fig. 7 N). The apical ends of all the lateral incisors remain converged until the increase in size of maxilla and mandible is sufficient to permit them to assume the more mature upright pattern.

In following the trend of development of any individual the progress in tooth eruption is predictable with these serial records that measure the increase in dimension of the supporting bones. With sufficient increase in dimension in the subnasal area the upper cuspids move downward, forward and laterally away from the root ends of the laterals when development of the face is normal (see K, N, Q, & R, Fig. 7). Until the cuspids approach their places in the dental arch there is not sufficient space at the apical base to permit the axes of the lateral incisors to shift into the more erect alignment of young adulthood. It is obvious that to correct the "ugly duckling" incisor alignment between 8 and 12 years of age (see Fig. 4 J, K and Figs. 8 N, 9 Q), is fraught with hazards that are greater in the underdeveloped face than in one that is normal for its age. Our large number of clinical records accumulated through this age range have, in all but a few instances, justified the clinical procedure of not encumbering the natural developmental forces with mechanical interference. Semi-annual records are usually sufficient to give adequate orthodontic supervision to the average patient.

Until the last of the deciduous teeth are shed (Fig. 9 Q), the first permanent molars that have up to this time occluded end to end, now join the cuspids and bicuspids and adjust themselves to the normal adult articulation. The cuspids play a great rôle in completing this articulation as they wedge their way between the laterals and the first bicuspids, forcing the first bicuspids distally to compensate for the difference in the mesio-distal diameter between the deciduous and the permanent teeth.

If this process of normal articulation of the crowns of these erupting permanent teeth succeeds in spite of dwarfed facial bones, it creates in the individual the appearance that the teeth and dental arches are too far forward in relation to the cranial base. This condition is commonly referred to as bi-maxillary protrusion. It may be bi-maxillary protrusion in the empirical sense, but from the standpoint of these studies of normal developmental growth of the face it is largely the result of physical handicaps that leave a lasting and permanently dwarfed skeletal structure. In other words the condition and appearance is due more to the retarded facial skeleton than to the dentition being too far forward in relation to the cranial base.

As the face proceeds on its continuous process of increase in size, additional room is gained at the posterior end of the dental arches for the eruption of the second permanent molars (Fig. 9 R). Thus space is created principally by the forward migration of the anterior two thirds of the facial mass and partially by the backward growth of the posterior third of the face. The

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Fig. 7.—Frontal dental patterns from roentgenograms of the same individual showing normal axial changes of erupting incisors and cuspids during the "ugly duckling" stage of developmental growth in the mixed dentition.

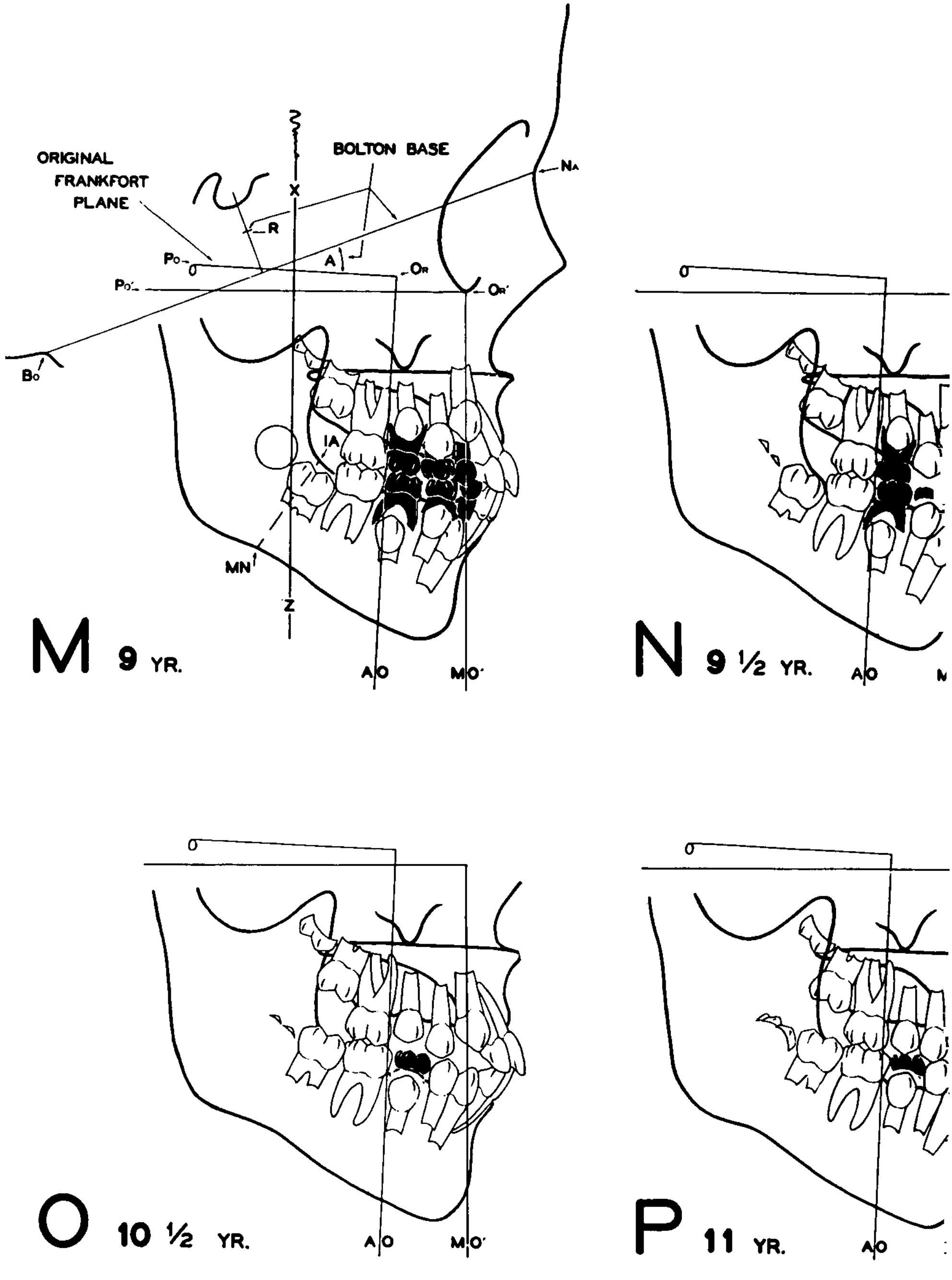

Fig. 8.—Developing dento-facial patterns of an individual from nine years through eleven years. Note the shedding of the remaining deciduous teeth. AO—the original orbital plane at one month. MO′—the orbital plane at nine years.

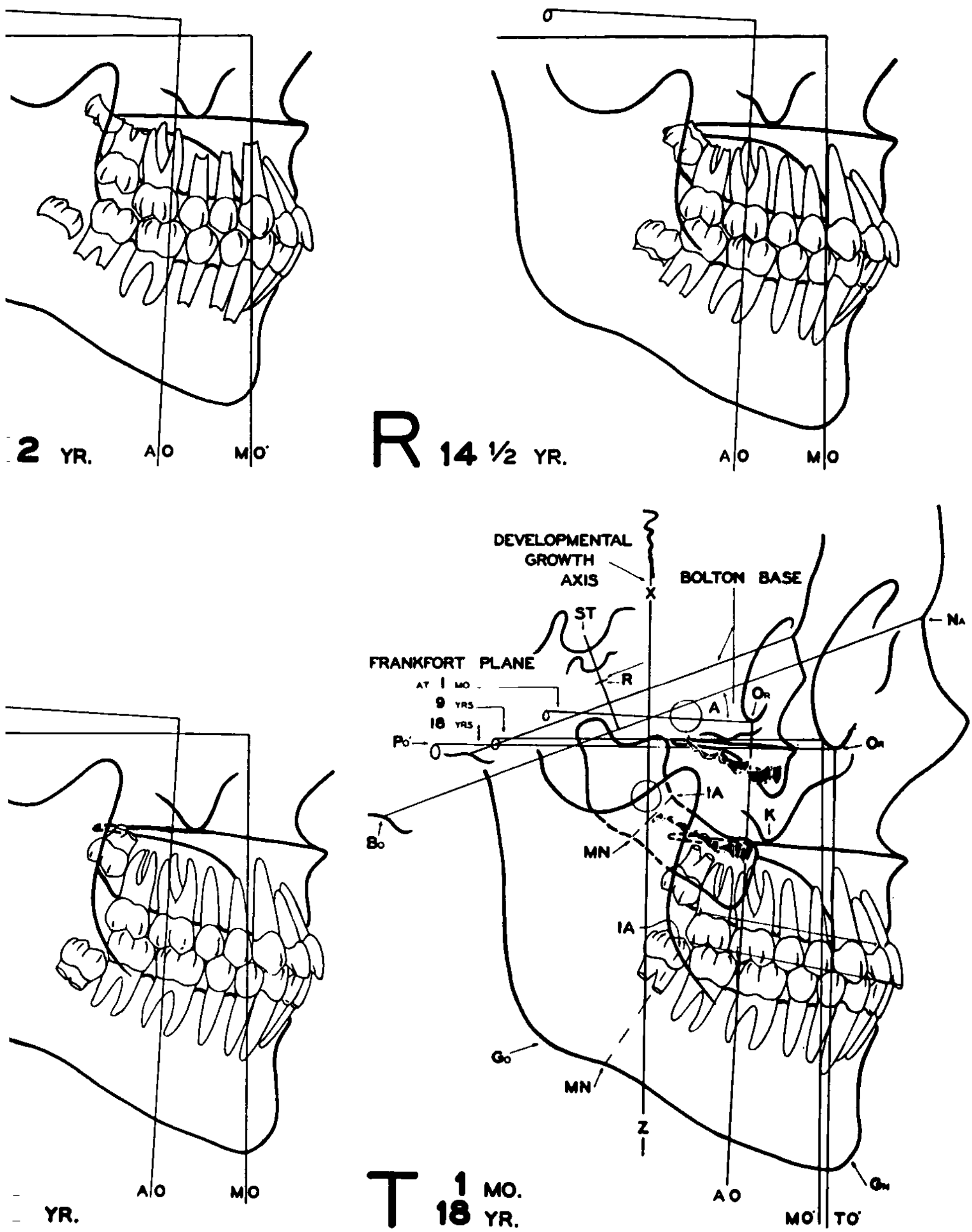

Fig. 9.—Continuation of the developing dento-facial patterns of the individual shown in Fig. 8. MO'—the orbital plane at nine years. TO—the orbital plane at eighteen years. See text for detailed description of dento-facial changes.

zone of least change is along the frontal plane *XZ* (Figs. 3, 9 & 11). This developmental growth axis is comparable to the median sagittal plane from which it is customary to measure increase in lateral dimension. An excellent measure of this process is gained in this individual (Figs. 8 M & 9 T) representative of the growth changes from 9 to 18 years, by noting the relative change in forward position of the bones and teeth to the Frankfort *PO'-OR'* and orbital *MO'* planes of the nine year stage (Fig. 8 M). Before the fourteenth year all of the teeth except the second permanent molars have com-

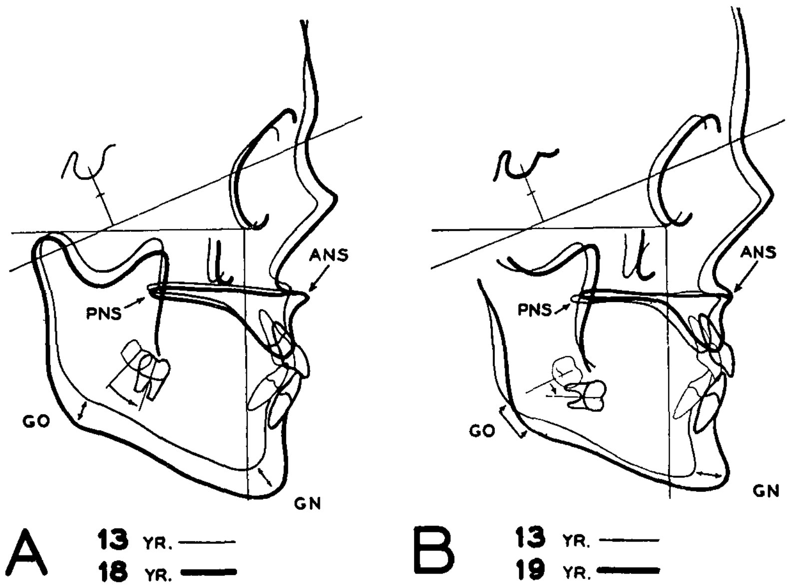

Fig. 10.—Superposed tracings of the same individual through late adolescence, reveal in A—the normal trend of facial development accompanied by normal eruption of the third molar, while in B—the abnormal trend of facial development is accompanied by impaction of the lower third permanent molars.

pleted their root formation and by the sixteenth year the root ends of the second permanent molars are closed.

As the normal face completes its progress toward maturity, room for the third permanent molars becomes available and they, like their forerunners in the permanent molar series, "wiggle" their way toward the occlusal plane cutting into the oral cavity to complete the permanent dentition (Fig. 9 T). About the time that the crowns of the last permanent molars are complete (around the fourteenth year) the handicaps suffered by an individual who has been thwarted in nature's plan to achieve full development of the skeletal structures deny the third molars their scheduled eruption. This failure of the face to provide enough room for the teeth is likewise apparent in the anterior segment of the dental arches for it prevents the incisors, particularly the lowers, from maintaining their normal position in the line of occlusion. Any buckling of the lower dental arch is commonly attributed to the so-called *pressure* of the erupting third molars. Factual evidence collected by the Bolton Study for the past twelve years would acquit the wis-

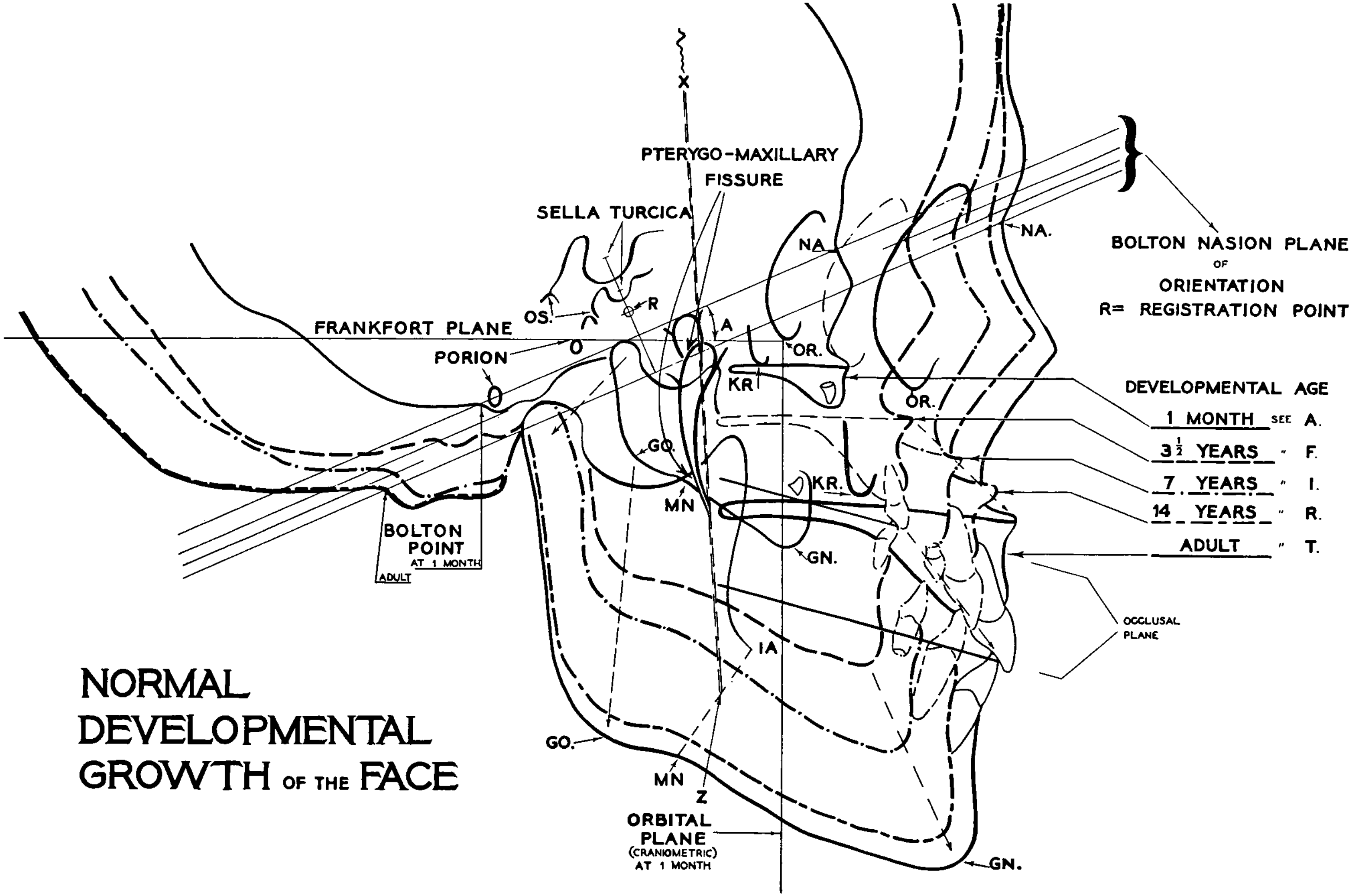

Fig. 11.—Chart of Normal Dento-facial Developmental Growth from the Bolton Study records. GN—Gnathion. GO—Gonion. IA—Internal Angle of the mandible. KR—Key ridge. MN—Mandibular notch. NA—Nasion. OR—Orbitale. OS—Occipito-sphenoidal suture. A, F, I, R, T refer to corresponding developing dental patterns in Figs. 3, 4, 8 and 9.

dom teeth of the aforementioned charges and include them along with the incisors as co-sufferers resulting from the failure of the facial skeleton to attain its complete adult size and proportions. Figure 10 illustrates two cases that show contrasting third molar eruption. "A" contains the first and last records of the same individual at 13 and 18 years of age, representative of the Bolton group of individuals in this age range that have enjoyed excellent facial development, and consequently have room for the erupting third molars. In contrast to this, "B" is a record of aberrant facial development with the resulting third molar impaction.

In the chart of normal developmental growth of the face (Fig. 11), there are registered in Bolton relation the profile outlines of individuals representative of the Bolton groups at the ages shown (7). These ages correspond closely to those of the developing dental patterns of occlusion shown in the previous figures (Fig. 3 A & F, Figs. 4, 7, 8 I and R, and Fig. 9 T). Since the development of normal occlusion in the individual is so greatly dependent on the normal development of the supporting structures, it seems fitting to terminate our discussion of this subject by pointing out, with the aid of this record, how orderly and uniformly the face unfolds. Tracing the direction and amount of change in the various areas included in the chart. we find those landmarks in the median sagittal plane moving in a straight line forward and downward with the exception of nasion *NA* that is above the fixed point *R*. This moves forward and slightly upward. The anterior end of the palate, the incisor teeth and gnathion *GN* move downward and forward to a greater or lesser degree depending upon their proximity to the cranial base. The other landmarks shown, with the exception of the posterior end of the palate, migrate downward, forward and laterally. The posterior end of the palate lies in the zone that divides the anterior from the posterior components of growth. Therefore we find the anatomical landmarks in this zone moving in but one direction, downward. This frontal growth axis that marks the junction of the anterior-posterior components of growth is defined at its superior end by the coronal suture. It passes downward through the pterygo-maxillary fissure at the posterior end of the palate and terminates in the mandible at the center of the line that marks the junction of the body with its vertical rami. The line joining the internal angle *IA* and the mandibular notch *MN* locates the junction of the body of the mandible with the vertical rami. Both porion and gonion are lateral to the mid-plane of the head and move downward, backward and laterally. The Bolton point and the fixed point *R*, lie in the median sagittal plane. The Bolton point that defines the posterior end of the Bolton plane moves downward and backward.

After the pattern of the face is established at the completion of the deciduous dentition, it is significant that, contrary to current belief, there is no marked change in the proportion of the face thereafter. It consists more or less of a proportionate increase in size. Observe that the horizontal palate and the inferior border of the mandible descend, maintaining the same angle to the cranial base plane as is established by three and one half years. Sandwiched between these two boundaries of the supporting structures of the teeth, the developing dental pattern as indicated in the chart by the occlusal plane descends with the same uniformity.

Thus it is seen that an assembly of dento-facial patterns of normal individuals of different ages expresses the same orderly and uniform pattern of growth that is revealed by the serial records in our longitudinal study of the same individual.

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