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A NEW X-RAY TECHNIQUE *and* ITS APPLICATION TO ORTHODONTIA

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DURING the last few years numerous scientific papers have been presented before orthodontic societies by men in the field of physical anthropology. These men have made us realize the value of their precise methods of measuring biological problems and made us hope that we might learn to apply anthropometric technique to our orthodontic practices. Most orthodontists still measure dental and facial deformities very largely by the interrelations of the teeth and jaws both before and after treatment.

Recently we have made a decided advance, by the application of cephalometric methods to record and measure the changes in the jaw in relation to the rest of the head. Careful and detailed analytic studies on this problem bear the names of Todd, Keith, Hellman, Krogman, Lewis, Simon, Dewey, Stanton—and others whose names merit but space does not permit mention. It is in the light of contributions made by these workers to the accumulated common understanding that the method about to be described has been developed. Previous methods use landmarks in the skull of the living child which unfortunately have to be approached through the skin and soft tissues. The uncertainty of such technique led the author to search for a means of recording craniometric (hard tissue) landmarks on the living child as accurately as it is done with a craniostat in measuring the dead skull.

The problem then was first, to design and build a headholder along the lines of the skull holders, and second, to find a means of recording precisely the craniometric as well as the cephalometric landmarks of the face and cranial base of the living head.

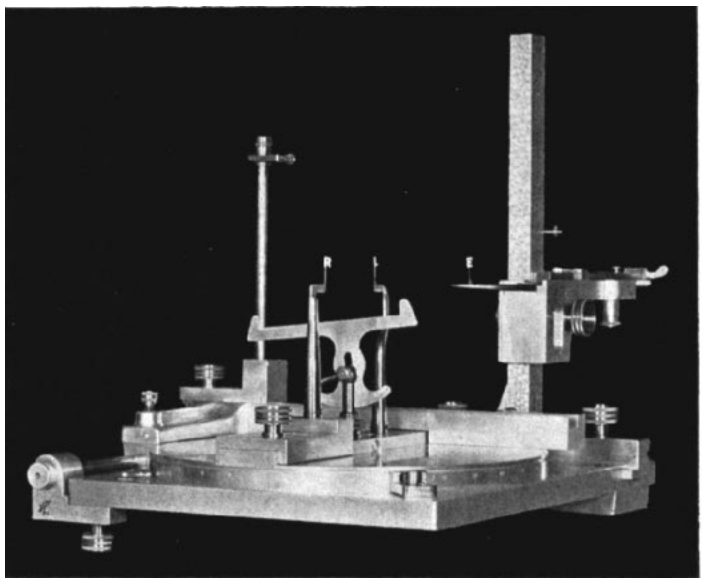

Fig. 1 Special Reserve Craniostat built for roentgenographic studies of skulls.

With the Reserve craniostat as a basis, and with the help of our machinist, the first part of our problem was promptly accomplished. Then the greater problem of registering the internal landmarks of the face and cranial base was solved through the perfection of a roentgenographic technique that records these points accurately on the photographic film. The films, like orthodiagraphic tracings, permit accurate measurement with drafting instruments. Many experiments were made over a period of several years to test its accuracy and to bring this technique to its present state of usefulness. These experiments were first made with skulls on the specially constructed craniostat illustrated by Figure 1.

The skulls were prepared by drilling a minute hole at many of the internal and external cranial landmarks and inserting very small pieces of lead that would register their exact position on the photographic film. Similar bits of lead were placed on dental and facial points. The skulls were then clamped in the instrument with the under surface of the upper side of the

ear holes (external auditory meatus) resting on the supports R and L, Figure 1, and the skull fixed in the Frankfort relation with its left orbital point at E in the horizontal plane when E is level with R and L. The pointer E can be moved vertically, laterally, and antero-posteriorly. The vertical scale V (Figure 2) gives us the distances above and below the Frankfort horizontal in a sagittal plane. The horizontal scale (AH) records the antero-posterior distances in the sagittal plane while the lateral distances in the

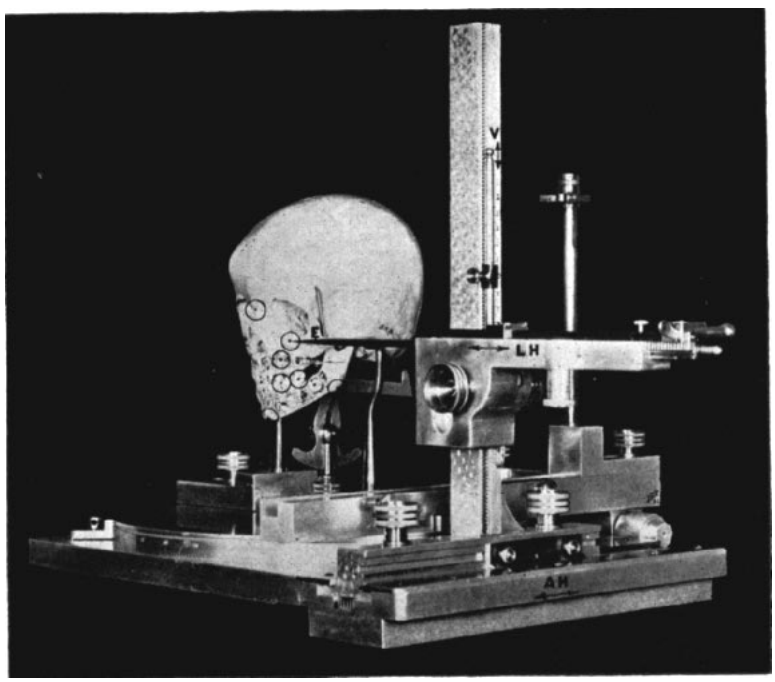

Fig. 2 Skull in the craniostat in the Frankfort Plane. Note some of the sites of the lead pieces have been accentuated and enclosed in small circles for illustration.

frontal planes are registered on the lateral scale (LH) on the upper surface of the pointer carriage. Points in the interior of the skull can be reached with curved pointers (Figure 3) when the calvarium is removed. These readings were then plotted on millimeter cross section paper in frontal and sagittal planes.

After the sites of the lead pieces were plotted in graphic projection in the sagittal plane and their relationships defined by measurement, the skulls were x-rayed for the lateral picture. Each skull was then rotated ninety

degrees and measured in the frontal plane, the graph made, and the frontal x-ray picture taken. Superimposing these roentgenograms upon their respective graphs gave us a measure of technical precision and clearly indicated that a reliable method of recording internal as well as external craniometric points had been successfully accomplished.

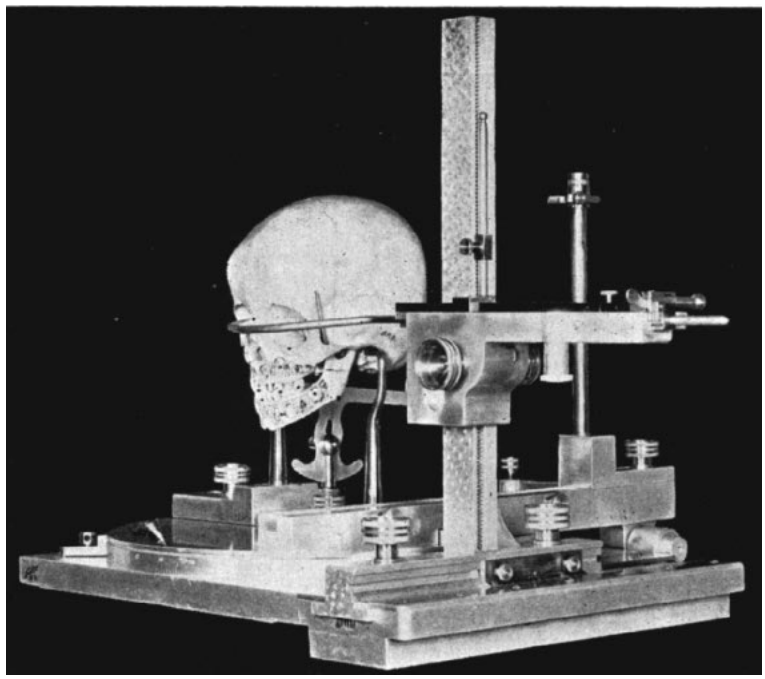

Fig. 3 Skull in the craniostat. Note that the pointer has been moved to Nasion.

The sagittal planes are at right angles to the Frankfort plane and to the Frontal planes, while the Frontal planes are at right angles to Frankfort and parallel to a line joining the tops of the ear posts R and L (Figure 1), i.e. a line passing through the right and left Porion points.

Figure 4 shows the cassette (film holder) in place for the lateral picture. The film is supported in a sagittal plane at right angles in all directions to a line through the top of the right and left ear supports. The distance of the film from the median sagittal plane of the instrument is determined on the lateral scale, and recorded along with the distance of the x-ray source from this plane.

Two relations are necessary to produce two or more identical x-ray

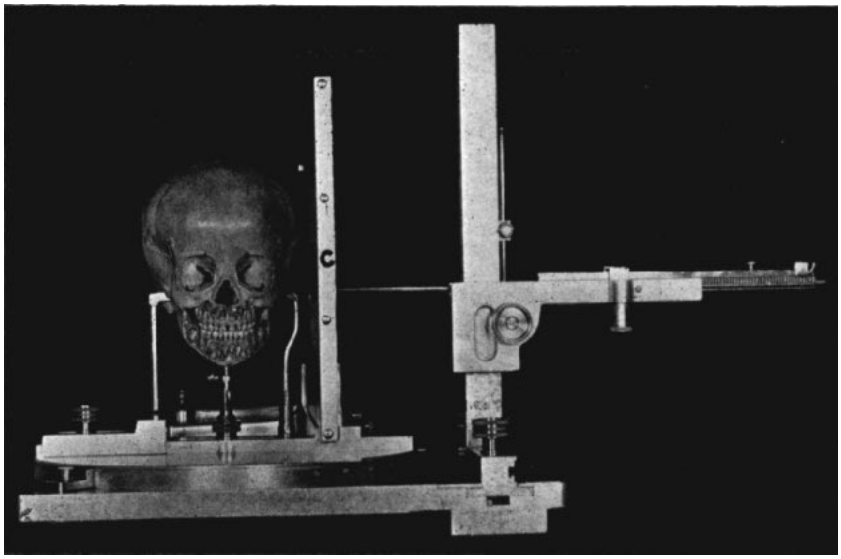

Fig. 4 Skull in the craniostat with the cassette in place for the lateral roentgenogram.

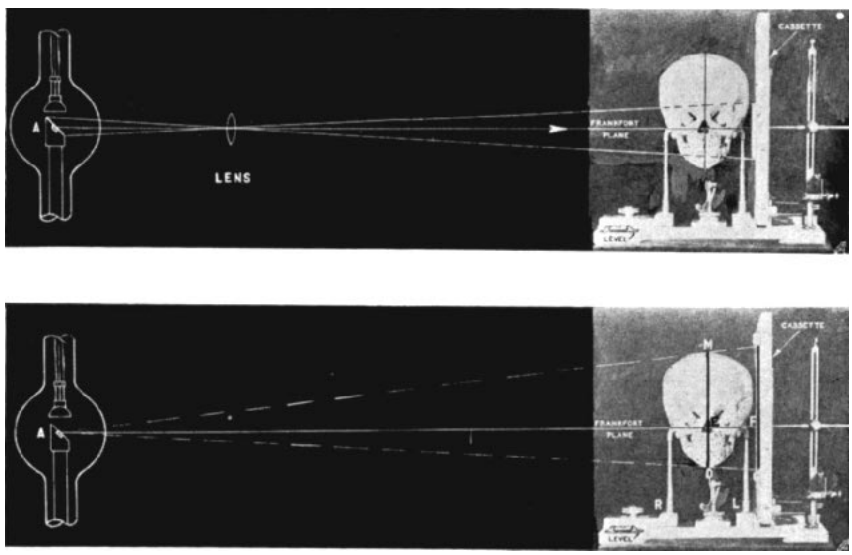

Fig. 5A Diagram of the relation of the Anode Target to the craniostat secured with the aid of a projection lens.
Fig. 5B Diagram of the relation of the Anode Target to the craniostat illustrating the path of the rays and relation of the size of the picture to the skull.

pictures of a skull; first, that of the skull to the instrument; and second, the relation of the source of the x-rays to the instrument. The mechanical adjustments of the instrument makes the placing of the skulls in the Frankfort horizontal very simple and certain.

In order to relate the source of the x-rays at the anode target of the tube to the instrument, advantage was taken of the fact that light generated

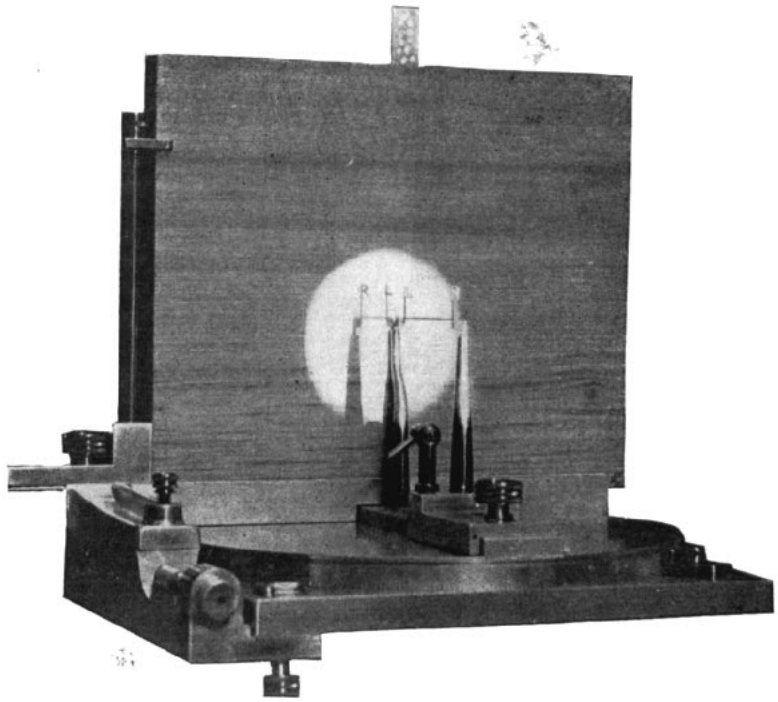

Fig. 6 Craniostat with cassette in contact with left post. Note the white opaque letters R and L mounted on the right and left ear posts and their shadows R and L on the cassette.

by the cathode filament is reflected from the anode target along the path of the central ray when the x-rays are generated. This permitted us to mount temporarily a projection lens (Figure 5A) in front of the x-ray tube with the anode target in the optical axis of the lens. After the craniostat is leveled with a spirit level, the path of the central ray is brought to the level of the Frankfort plane as indicated by the light projected through the lens. Experiments convince us that the most useful pictures were those made when the path of the central ray coincided with the line joining the tops of the two ear supports, and the tube placed 5 feet or more from the middle of the craniostat. This was easily done by measuring the distance

from a point midway between the ear posts of the craniostat and directing the path of the central ray, as indicated by the projected light, toward this point and at the same horizontal level.

The cathode filament is heated in incandescence with a low tension current of about 6 volts from a toy transformer. With a cassette in place in the craniostat (Figure 6) the shadows of the right and left ear supports can be

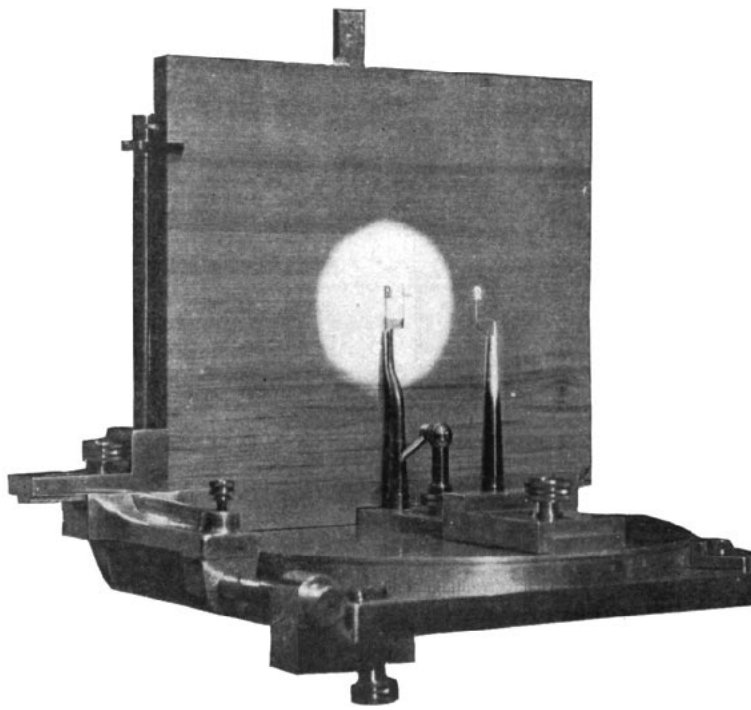

Fig. 7 Craniostat as shown in Figure 6 after being rotated in a horizontal plane until the shadows of R and L and their respective posts coincide. This indicates the desired relation of the craniostat to the path of the ray.

seen on its surface. For illustration small white opaque letters R and L were mounted in identical relation to their respective posts. These throw their dark shadows on the cassette. The instrument is rotated in the horizontal plane until these shadows register one on the other as may be seen in Figure 7. It will be seen that the shadows of the tops of the ear posts coincide and this places them in the desired relation to the path of the central ray and consequently in the proper relationship to the path of the x-rays.

We have demonstrated to our satisfaction that, after dismantling the

apparatus, the skull can be set up anew and pictures taken identical with those previously made in dimensions and in inter-relationship of predetermined points.

The relationships of the sites defined by the shadows of the lead markers, as well as the relationships of the other predetermined points to the projected shadows of the ear posts are dependent upon two factors. These are, first, the target distance at which the pictures are taken and secondly, the dis-

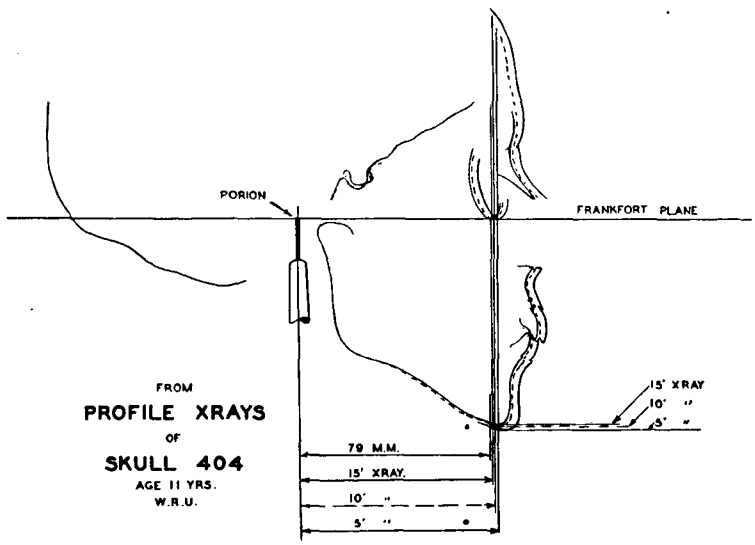

Fig. 8 Tracings of these different roentgenograms of skull 404 WRU superposed in Frankfort horizontal with Porion points in register. Note the increase in size of the pictures as the distance decreases although the position of the film remains fixed.

tance of the film from the median sagittal plane of the craniostat or head holder. Since the x-rays are not parallel as they approach the skull or head but diverge from a common point in the form of a cone, the size of the image on the film is slightly larger than the object projected. When the target distance is lessened and the film remains at a fixed distance from the object the size of the image increases. Figure 5B is a diagram of these relationships, and this effect is clearly shown in Figure 8 by superimposing tracings of three successive roentgenograms of a skull, the Frankfort plane, with Porion, being registered in each tracing. When the target distance remains fixed and the distance of the film from the median sagittal plane increased, a similar change in the size of the image is produced. Since our technique predetermines the target distance, five feet, and the film distance is measured when the picture is taken we can easily compute the actual

dimensions of the face and head with these figures along with those recorded in the finished picture.

If, for example, we want to know the distance MD, (Figure 5B) we measure its shadow BC on the film, and add the scale reading for EF noted at the time the picture was made, to the known target distance AE. With the two altitudes AE and AF and the base BC known, we can figure the other unknown base MD of the triangles ABC and AMD. In our studies of the

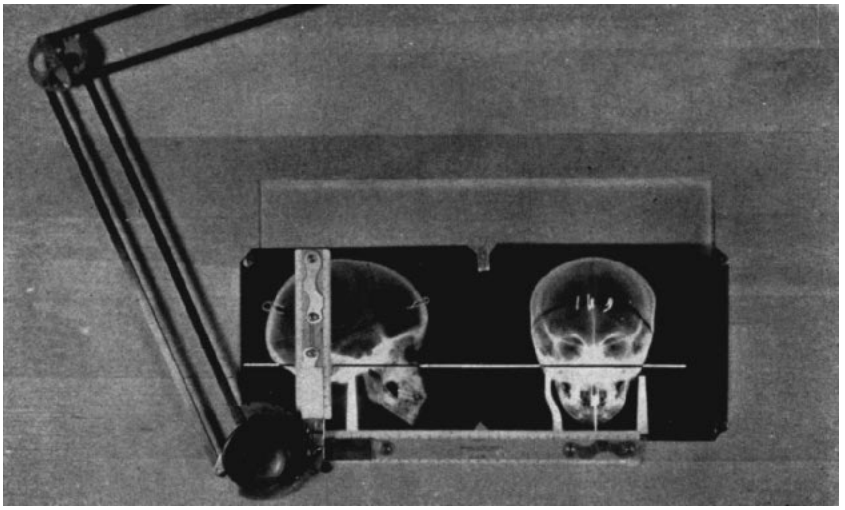

Fig. 9 Frontal and lateral roentgenograms in place for measurement on a transilluminated drafting table fitted with the Universal drafting machine.

development of the face of the growing child it has not been necessary to compute mathematically these many relationships. The variable factors are the same for the same child and subsequent pictures superimposed on the first picture clearly reveal the changes in growth and development and likewise show results of orthodontic treatment.

The roentgenograms are measured with the aid of a Universal Drafting machine fitted with millimeter scales. The lateral view is mounted on the transilluminated drafting table as shown in Figure 9 with the line passing through Porion and left Orbital points parallel to the horizontal scale. The frontal view is then mounted beside its lateral view with a line passing through the right and left Porion points coinciding with the horizontal line projected from the lateral view. The lateral picture is then in Frankfort relation and points may be projected from this view to the frontal view and their positions measured in three planes of space.

The head holder (Figure 10) was designed on the working principles of the craniostat and built for use in conjunction with the standard junior dental chairs. Through the generosity of Mrs. Chester C. Bolton and her son Mr. Charles B. Bolton the head holder and x-ray equipment shown in Figure 11 was built and installed in the Anatomical Laboratory of Western Reserve Medical School, for a study of the developing face of the growing child.

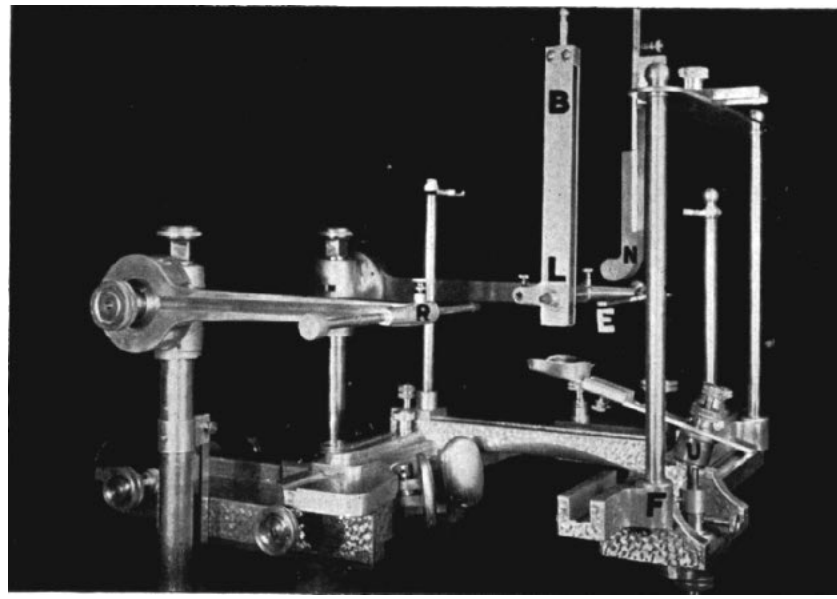

Fig. 10 The Broadbent Head Holder for roentgenographic studies of the living head. Built in the Anatomical Laboratory Western Reserve University for the Bolton Study of the development of the face of the growing child.

The Bolton study has been under way about eighteen months. During this time we have had 1700 children between the ages of nine months and twenty years. Many of these have been x-rayed at six month intervals and will be followed through a five year period. Most of the younger ones are x-rayed every three months during periods of rapid change in dentition.

The head holder is supported on its fixed base A (Figure 11) above a child's size dental chair that has had the usual head rest removed. The chair does not come in contact with the head holder but may be raised or lowered to permit comfortable adjustment of the child's head to the instrument. Like the relation of the skull to the craniostat, the head rests on the uppermost side of the rods that are inserted into the ear holes

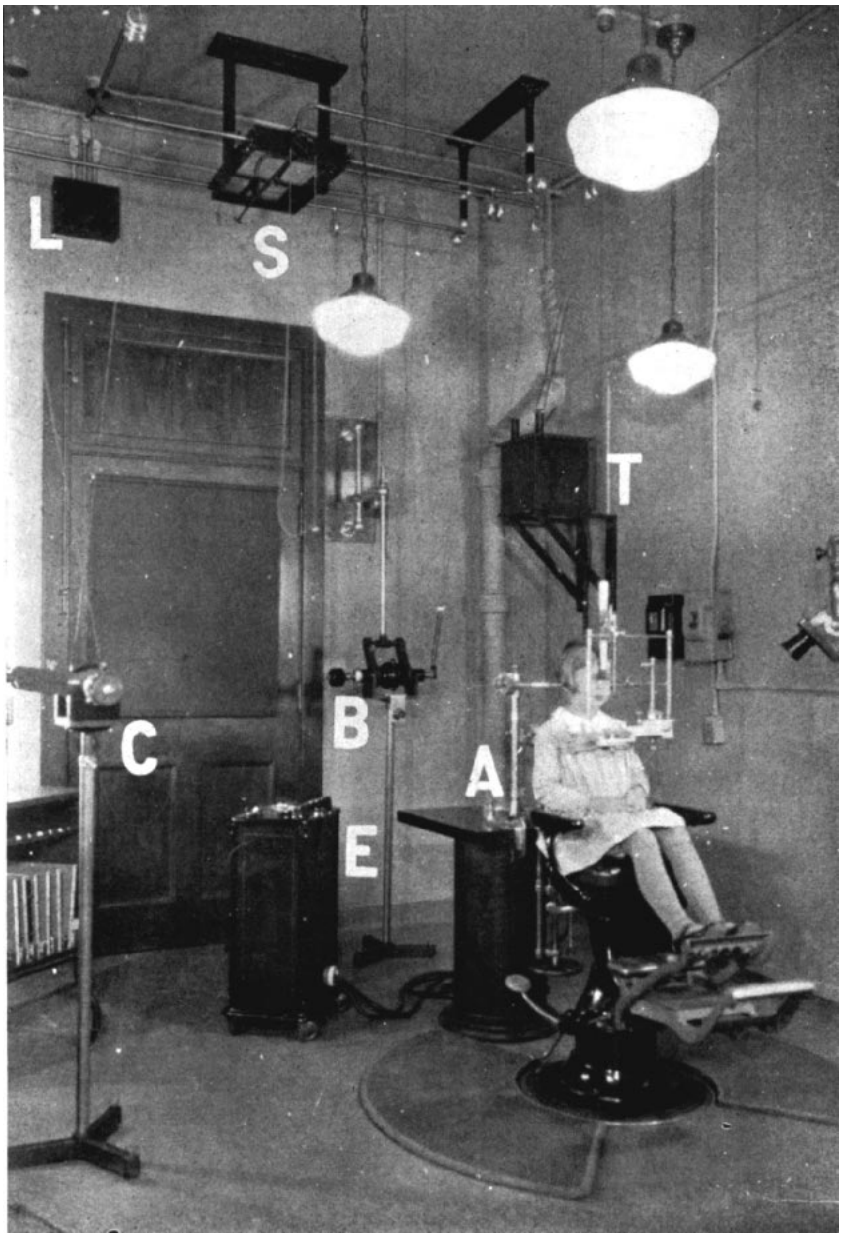

Fig. 11 The Bolton Room in the Anatomical Laboratory of the Medical School at Western Reserve University, Cleveland.

(Figures 10, 12, 13). These rods are calibrated and allow the head to be centered between the ear supports. The left ear support is constructed so that the cassette may be inserted and held close to the left side of the head as in Figure 12 and 13. The distance of the film from the middle of the instrument is read on a millimeter scale at the back of the cassette support.

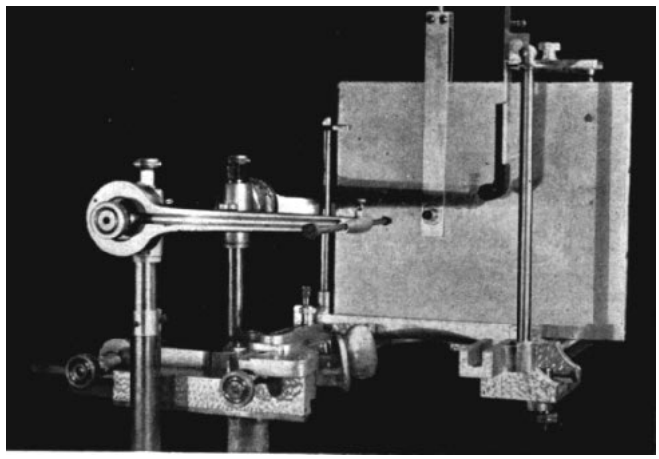

Fig. 12 The Head Holder with cassette in its place for lateral roentgenogram.

After the head has been centered, the chair is lowered or the child instructed to settle down so that the under surfaces of the superior border of the ear holes are resting on the upper sides of the ear rods. Then the head is rotated on this Porion axis by lifting or lowering the face until the lowest point on the inferior bony border of the left orbit is at the level of the top of the ear supports as indicated by the Orbital marker at E (Figure 14). The front attachment F (Figure 10) which supports the frontal cassette and impression tray, also carries a rest for the root of the nose at N (Figure 10). This rest is in the midline of the head holder and may be raised or lowered in a frontal plane and moved toward the ear posts in a horizontal plane by moving the entire front attachment. Placing this rest against the root of the nose clamps the head firmly in the instrument (Figures 13 and 16). Imbedded in the side of the support (N) toward the face, is a small piece of lead, just large enough to register clearly on the films. The exact relation of this lead point to the ear posts is recorded from the millimeter scale on the instrument at the time the first pictures are taken. These readings help in adjusting the head to the instrument when subsequent pictures and models are made. The lead point is used too, when models of

the mouth are made in a known relation to the roentgenograms. The impression and model technique is not a part of this presentation and is described in detail separately. The technique of making the roentgenograms of the living head in the head holder is identical in principle to that just described for the skulls and craniostat.

With the head clamped firmly in the head holder as described above,

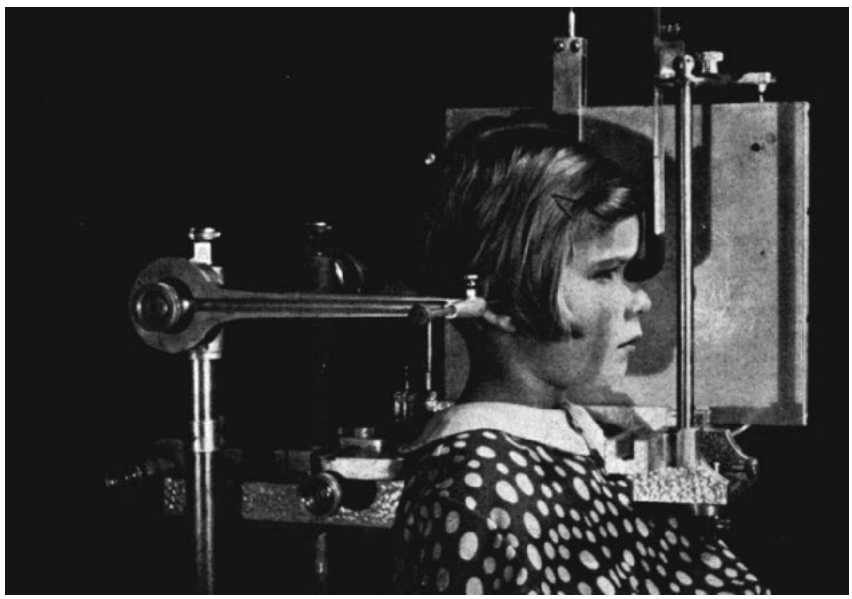

Fig. 13 The child's head adjusted to the head holder. Note the cassette in place for the lateral roentgenogram.

the cassette for the lateral roentgenogram is placed in its support beside the head (Figures 12 and 13) and exposed. This cassette is then removed and another cassette placed in the groove on the front attachment F (Figure 15) and this film exposed for the frontal roentgenogram. After removing the frontal cassette a tray of impression plaster may be placed in the mouth and allowed to set. The universal joint support at U (Figures 10 and 16) is then locked on the handle of the tray T to secure the relationship of the tray to the right and left ear posts and the lead point in N, and consequently to the craniometric points found in the roentgenograms.

The head cannot be rotated on a vertical axis through 90 degrees and therefore we use two x-ray tubes, one for the lateral picture and another for the frontal picture. The illustration (Figure 11) of the Bolton Room shows

these two tubes at B and C mounted on special tube stands, each placed 5 feet from the center of the head holder A at the level of the ear supports. They are controlled by the single control stand E through the ceiling switch S. This switch permits the operator to direct the current from the high tension transformer T to either tube at will. Above the door at L is housed the toy transformer that delivers about 6 volts to each tube, for use in orienting the tubes to the head holder as previously described, for the lateral pic-

Fig. 14 The child's head centered in the Head Holder on the ear rods. Note the lowest point on the inferior border of the left bony orbit is leveled with the top of the ear rods after which the front support for the head is attached.

ture with the craniostat. The back tube B is oriented to the head holder with the path of its central ray in the mid-line of the head holder and its anode target 5 feet from the earpost axis. The central rays of the two tubes are in the same horizontal (Frankfort) plane and at right angles to each other. The resulting pictures register precisely the desired craniometric landmarks of the cranial base and face in three planes of space.

The pictures contain much of the soft tissue detail, especially the facial profile, which has eliminated in our studies the need of photographing the side view of the face. With sufficient illumination it can be seen in the lateral roentgenogram and studied and measured in life size along with the teeth and

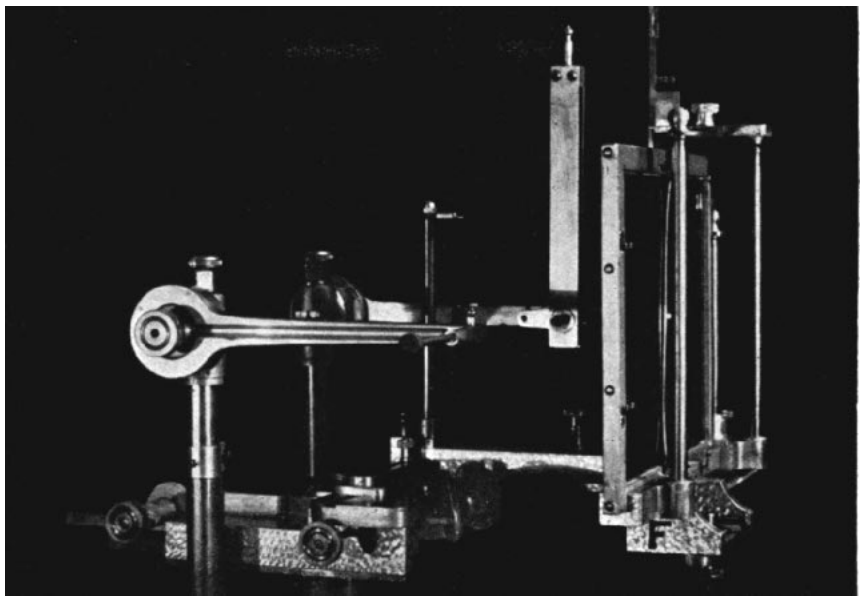

Fig. 15 The Head Holder with cassette in its place on the front attachment F.

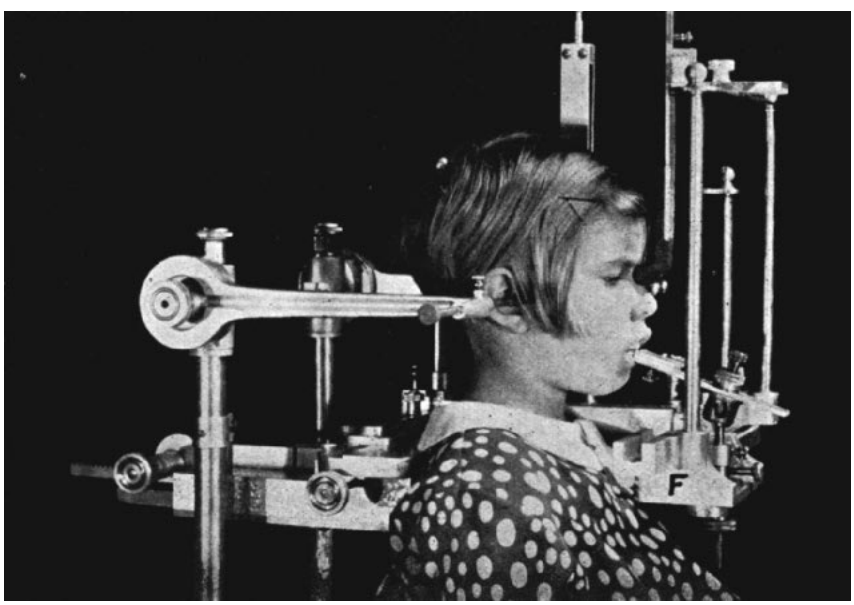

Fig. 16 The Head Holder with impression tray and clamp U in place on the front attachment for securing a model of the mouth oriented to the roentgenograms.

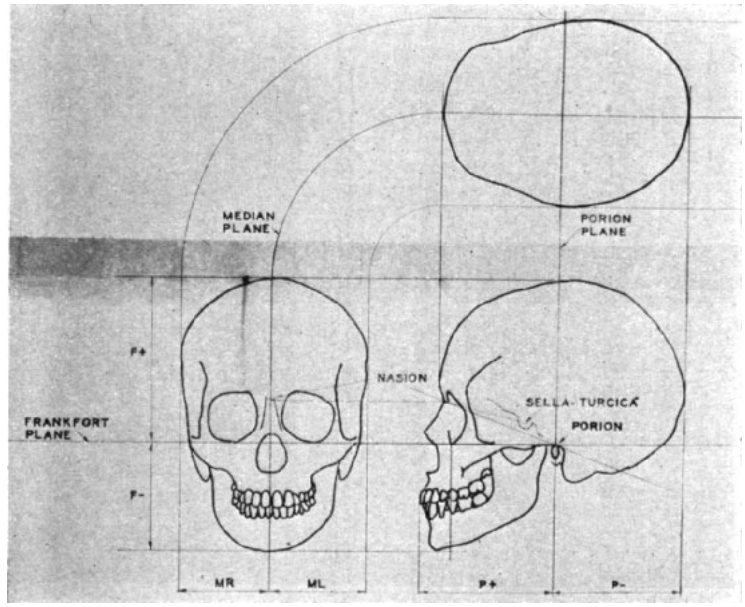

Fig. 17 Diagram of the relations of the lateral to the frontal tracings of roentgenograms made in the Bolton Study for measuring facial development and growth.

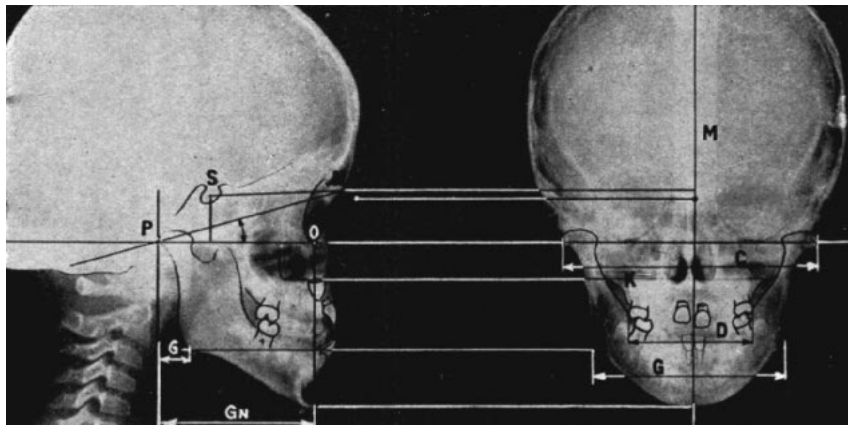

Fig. 18 Lateral and Frontal Roentgenograms of a child with a developing Class III mal-occlusion. Note that this craniometric technique applied to the living eliminates the uncertainty of measuring through soft tissue as it is done in cephalometric methods.

bones that support it. The wide range of half tones in the Diaphax films that represent the hard and soft tissues are easily seen with varying intensities of transillumination, but difficult to show in a single half tone illustration. Tracings are made of these films by three workers and these checked by a fourth person before the figures are accepted for statistical purposes.

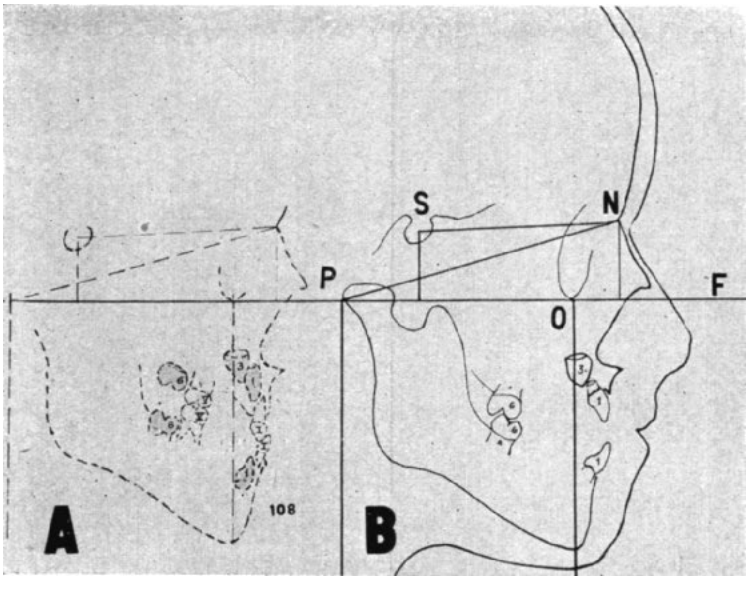

Fig. 19 Tracings from roentgenograms of the same child shown in Figure 18 taken two years apart. Note the relations of the teeth and jaws to the anterior-posterior base planes, PF, PN, SN, and to the vertical planes through P and O.

Figures 17 and 18 show the Frankfort horizontal, the median sagittal plane and the vertical Porion plane as well as some of the other planes which we have found useful in our studies of facial and cranial relationships.

By the end of the first year of our study the subsequent pictures of the same children taken at three and six month intervals, clearly pointed out many significant observations, no traces of which are to be found in the data collected from dead skulls. One very significant fact had an immediate application to the interpretation of the developmental growth of the face of those youngsters whose dentition presented an orthodontic problem. Subsequent pictures at certain ages have revealed areas of non-growth in the cranial base. These areas in which there had been no change permitted us to precisely relate the pictures and measure the changes in the

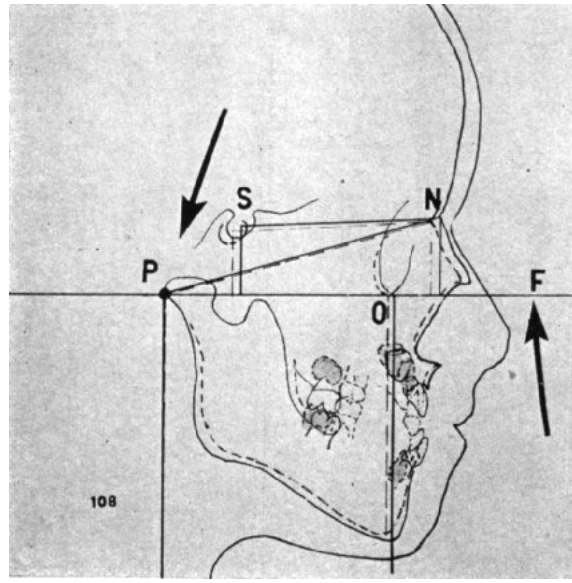

Fig. 20 Tracings A and B shown in Figure 19 superposed in Frankfort relation with Porion (P) registered. Note the amount and direction of change indicated by this common method of superimposing.

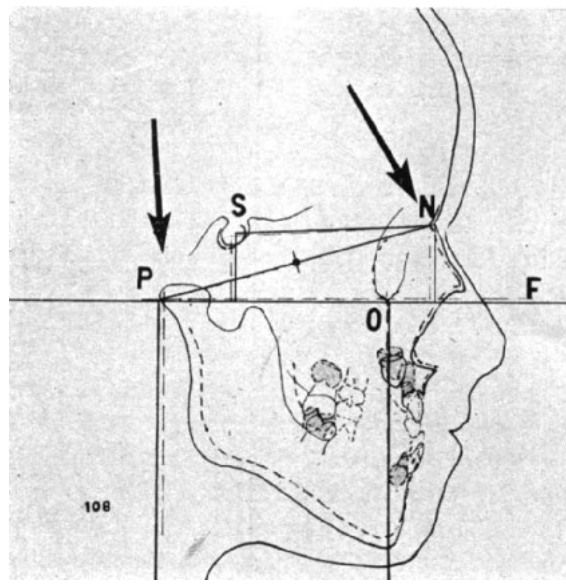

Fig. 21 Tracings A and B of Figure 19 superposed on the Porion-Nasion Plane (PN) with their distances registered at their mid-point. Compare with Figures 20, 22, 23 and 24.

other parts. The next series of illustrations are tracings of two pictures of the same child about two years apart. The tracing A (Figure 19) is from the first picture taken at the age of 6 years and 2 months while the tracing B in solid lines is at the age of 8 years and 5 months. In B will be seen the

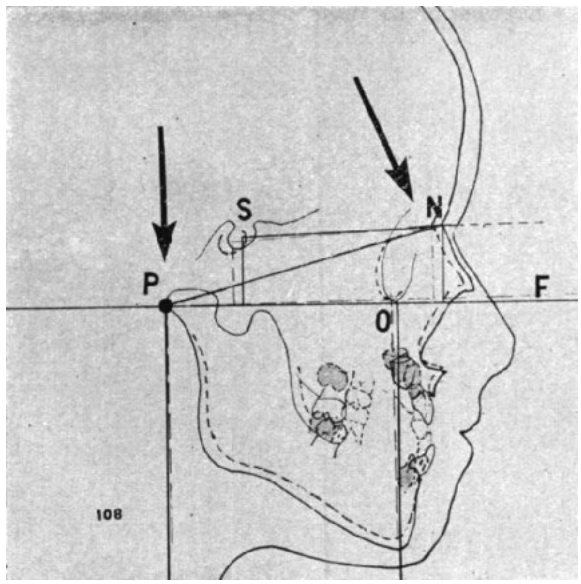

Fig. 22 Tracing A and B of Figure 19 superposed with Porion (P) registered and with Nasion (N) of tracing B falling on a line projected from Nasion (N) of tracing A parallel to the Frankfort plane (F) of tracing A. This is Krogman's method of superimposing tracings. Compare with Figures 20, 21, 23 and 24.

upper and lower incisors and first permanent molars and upper cuspid. These teeth are shown in A along with the second deciduous molars and deciduous central incisors. The deciduous incisors had been shed before the second picture B was taken. In Figure 20 the tracings of this developing Class 111 malocclusion are placed in Frankfort relation with Porion registered. This method of relating tracings is the one most frequently illustrated in our literature. Although these tracings are of the same head and not of skulls of different individuals is it safe to assume that Porion is relatively the most fixed point and that the rest of the face and cranial base are undergoing the changes indicated? Shifting the tracings so that they are superposed along the Nasion-Porion plane (NP Figure 21) with the mid-point of each plane registered, one will secure a somewhat different interpretation

of the changes in which we are interested. The next Figure 22 shows another method of relating these two tracings with Porion registered and Nasion of tracing B falling on a line projected from Nasion in tracing A parallel to the Frankfort plane. Compare this with Figure 20. Reverse this relationship and superimpose Nasion (Figure 23) allowing Porion of tracing B to fall along the Frankfort Plane of tracing A and then observe the effect on the other parts.

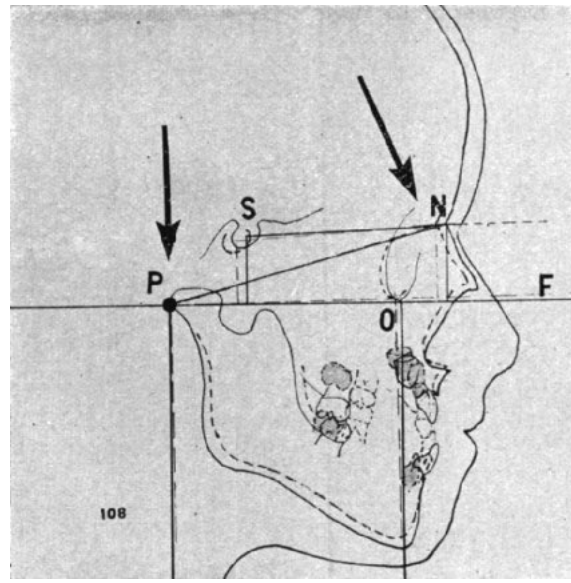

Fig. 23 Tracings A and B of Figure 19 superposed according to Todd with Nasion (N) registered and Porion P of tracing B allowed to fall on the Frankfort plane of tracing A. This method of superimposing is opposite to that of Krogman shown in Figure 22. Compare with Figures 20, 21, 22 and 24.

As valuable as these several methods of superposing orthodiagraphic tracings for measuring facial growth may be, it would seem to the author that the areas in the cranial base that have not changed, offer a more precise basis for relating tracings and consequently a more accurate method of measuring growth and development in the living head. Therefore when we have an unchanged base common to two or more subsequent pictures of the same child, like the area including Sella Turcica and Nasion of this series, we superimpose them on these landmarks. In the last Figure 24, the tracing A and B have been superimposed with their planes SN coinciding. The

relation of N to S has not changed between the time these two pictures were taken and the Figure 24 shows the greatest increase in growth between S and P and along the lower border of the mandible and the posterior border of the ascending ramus.

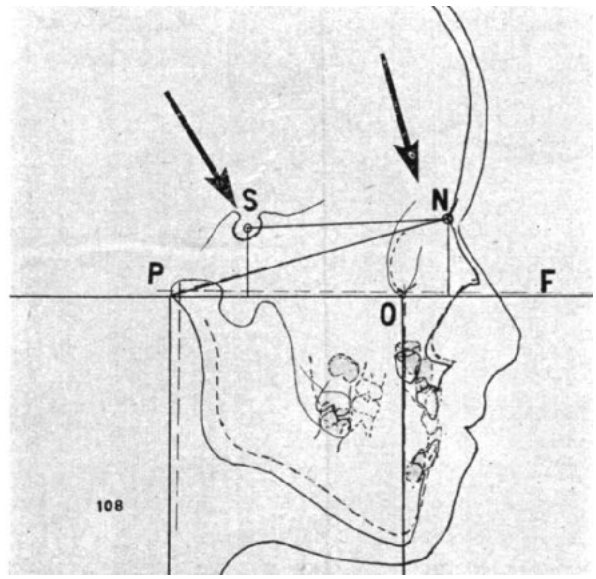

Fig. 24 Tracing A and B of Figure 19 superposed by the authors method of using unchanged areas for superimposing. Note that in both A and B the relation of the Sella Turcica Nasion area has not changed and is therefore common to both drawings. This figure shows these two tracings superposed with Sella Turcica (S) and Nasion (N) registered. Compare this with Figures 20, 21, 22, and 23.

This roentgenographic method has the added advantage of disclosing changes, not only of the teeth that have erupted, but it clearly shows the rate and amount of growth and path of eruption of the unerupted teeth. With the opportunity to record the structural changes along with means of measuring increase in size, we have a morphological as well as a quantitive study. This technique has a direct and immediate application to Orthodontia as a means of measuring tooth and facial changes, while the results of the Bolton Study are adding to our understanding of the principles of developmental growth of the living face which forms the foundation of our specialty.

As a summary of these observations I would emphasize the following:

(1) That the application of precise methods of measurement used by Physical Anthropologists to Orthodontic practice is a decided advance toward a more scientific solution of our orthodontic problems.

(2) By means of a head holder and a standardized roentgenographic technique it is possible to make accurate determinations of changes in the living head that may be due to developmental growth or orthodontic treatment.

(3) Such a technique permits changes in the same individual to be measured and studied. This eliminates the uncertainty of measuring such changes by a comparison of dimensions of different individuals of successive ages.

(4) This roentgenographic technique registers the craniometric landmarks of the face and cranial base of the living head which heretofore have only been measured on dead skulls with a craniostat.

(5) Our present standards compiled from measurements of skulls of children are largely a measure of defective material. A dead child is usually a defective one.

(6) Cephalometric methods of measuring facial changes while a decided advance, do not permit us to record the landmarks beyond the face in the cranial base.

(7) This Craniometric technique has the decided advantage of not having to determine the site of the hard tissue landmarks of the face through the covering of soft tissue of uncertain thickness.

(8) Subsequent roentgenograms have revealed areas in the cranial base that show no change between certain ages. These areas offer a more stable base for relating our tracings and afford a very accurate method of measuring changes in the teeth, jaws and face.