The Angle Orthodontist

VOL. X | JANUARY, 1940 | NO. 1

Correction of Error in Cephalometric Roentgenograms*

J. W. ADAMS, D.D.S., M.S.†
Chicago, Illinois

THE VALUE of all X-ray pictures depends on three major properties. They are (1) the proper contrast in density, (2) sharpness of detail and (3) the degree of distortion of figure. Improved technique and equipment have made possible the control of density and of detail to a very high degree.

The literature reveals that as early as 1897 Rosenfeld wrote on the distortion resulting from varying distances of the tube from the object and the film. Since that time much work has been done by Kohler, Walter, Hammer and Wilsey using geometrical forms and chest structures for their work. These men are generally agreed that since increased power is available better pictures will be taken at distances of 5 to 6 feet rather than from the usual 24-28 inches except in those cases where profound distortion is an aid in diagnosis.

Jewett in working with 100 cases estimated an enlargement of 5% in sella turcica at a 5 foot distance. Mortimer, Levine and Rowe showed that cranial tables were enlarged from .4% to 5.9% with a 30 inch anode-film distance. This was determined by the use of lead wires the actual sizes and position of which could be measured directly. In our own field Broadbent has employed radio-opaque materials in varying ways to check his technique and equipment.

If it were possible to construct an anode that would deliver parallel rays or if the rays were derived from an infinite source our image of outline would be the same size as the object itself and intervening structures would occur correctly in the picture. But since the source of X-rays is a very small area, divergence of rays creates enlargement purely on the basis of successive triangulation. Therefore the enlargement increases as the object-film distance increases. It also follows that the rays closest to the central axis are more nearly parallel and hence give less distortion than those nearer the periphery

---

* Presented at the Twelfth Biennial Meeting of the Edward H. Angle Society of Orthodontia, October 8 to 14, 1939, Chicago.

† Carnegie Fellow in the Department of Orthodontia, University of Illinois. This work has been made possible by a grant of The Carnegie Foundation.

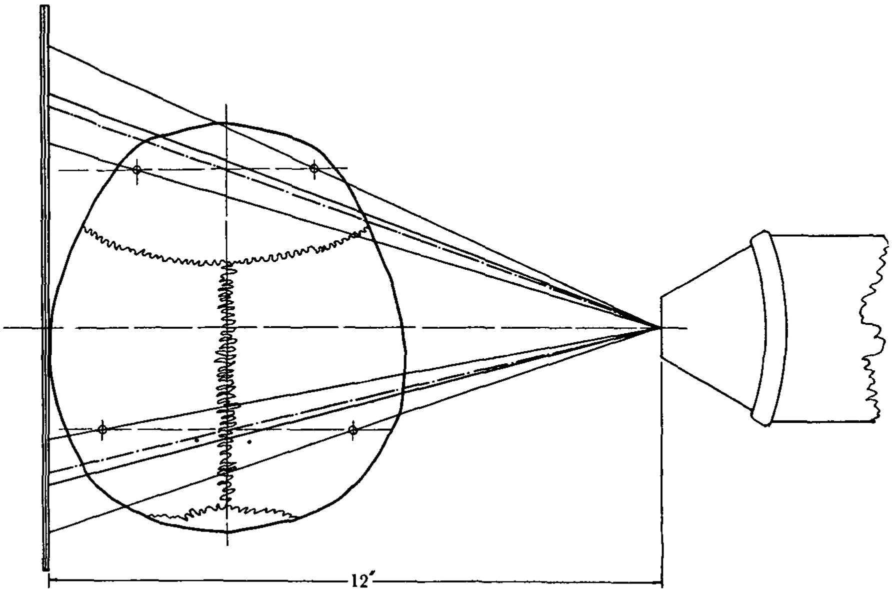

Fig. 1.—Diagram showing the enlargement of outline and images of bilateral structures resulting from the use of a film-tube distance of one foot.

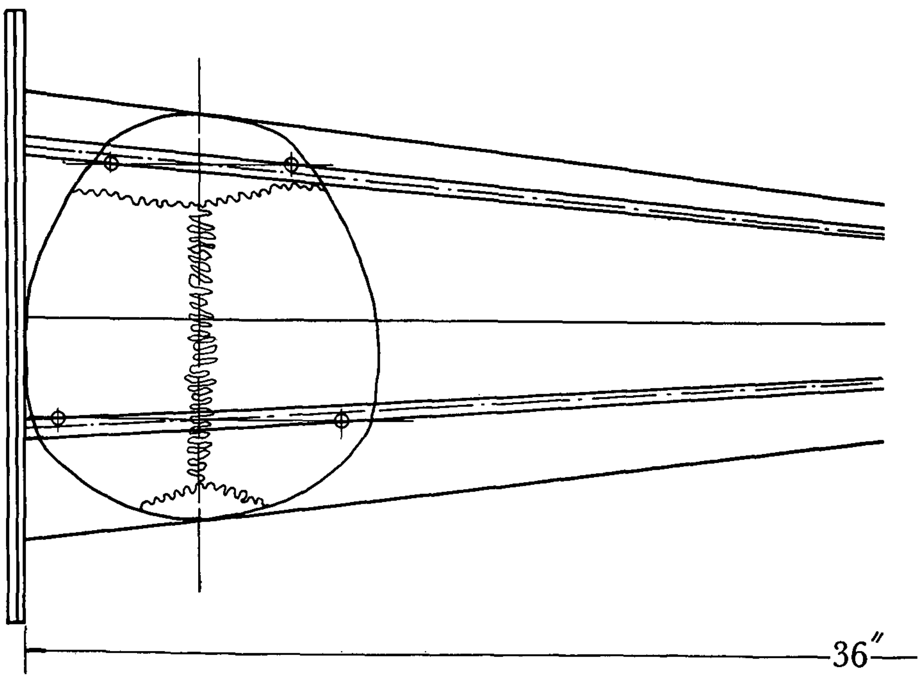

Fig. 2.—Diagram showing the enlargement of outline and images of bilateral structures resulting from the use of a three foot film-tube distance.

of the picture. This has been stated by the roentgenologist in terms of the formula,

$$\frac{\text{object size}}{\text{image size}} = \frac{\text{target-object distance.}}{\text{target-film distance.}}$$

By referring to diagrams we can point out this enlargement and note how it has been minimized in the design of the Broadbent-Bolton cephalometer.

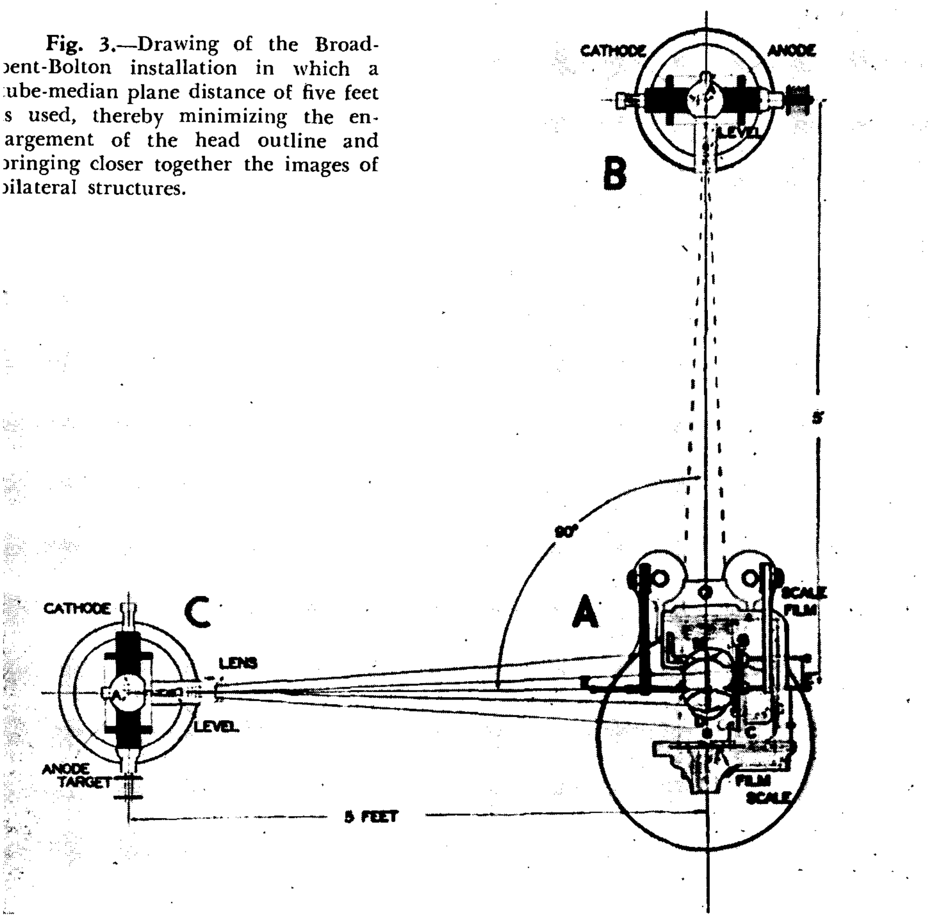

Fig. 3.—Drawing of the Broad-ent-Bolton installation in which a ube-median plane distance of five feet s used, thereby minimizing the en-argement of the head outline and ringing closer together the images of ilateral structures.

(Fig. 1) At one foot distance a skull outline may be enlarged as much as 60% depending on its size. Examination of a three foot diagram such as is seen in Fig. 2 reveals the fact that we have reduced object outline error at least 50%. (Fig. 3) In adopting a distance of five feet from the anode of the tube to the mid-line of the head Broadbent took the most feasible distance. Very little is gained in having the tube six feet or more away because the reduction in error between the five and six foot distances is but .5%. The statement sometimes made, that one gets paralleling of rays at a distance of six feet, is not true.

This principle can be illustrated further by a common experience. When we are in a darkened room with a flashlight and walk away from another individual who is standing still, the shadow projected on the wall decreases in size. Also if we stand still and the other individual moves toward the wall the shadow becomes smaller. Therefore we get the shadow as small as possible by having the individual stand against the wall and moving the source of light as far back as we can.

But there is another matter, aside from a mere enlargement, with which we must deal. This is actual distortion of the image. If we refer again to our first figure we note that the shadows cast by the same landmarks on the left and right sides of the head do not fall on the same spot on the film. In attempting to reduce the error thus introduced we might resort to an averaging of the two readings and assume that such a mean would fall mid-way between the two shadows as though the landmark were a mid-line structure. When we refer to our drawings in figures one, two and three we can see how the increase of anode-object distance tends to reduce this error also.

Fig. 4 represents the true outline of the skull together with the outline of the shadow it casts when employing the Broadbent-Bolton technique. The common point of orientation is indicated by the central black dot which also indicates the axis of penetration of the central ray. An object of this size will present an enlargement or distortion of about 5% in its outline and the variance is due to the distance of the part from the film as well as the distance of the part from the central ray. An example of the first cause for distortion can be seen in the chin region of the frontal drawing while in the lateral drawing the distortion is in direct proportion to the distance of the part from the black dot. The lateral headplate illustrates these two factors further as can be noted in Fig. 8 where the outlines of the two halves of the mandible are seen to cross. The shadow of the left half of the mandible is always more nearly correct since it is closer to the film.

Distortion in lateral headplates was not a significant obstacle in studying relative changes but in such analyses as the deriving of growth rates an attempt must be made at correction. The object of this piece of work was to check the efficiency of scales made to correct such errors of distortion. The idea was conceived by Dr. Allan Brodie and seemed applicable to routine examination of headplate tracings when desired. That is to say, the effort must be made to stay within those limits of error tolerated in the more exact physical fields.

The scales to correct for distortion were made as follows: The metric scale which is routinely clamped on the nasion bar of the cephalometer for lateral pictures, was mounted vertically on the machine in the median line plane with its zero point in the central ray axis. This scale is made of aluminum with indented numerals and millimeter gradations filled with lead so that on X-ray exposure they will show up very definitely. Its numerical scatter is such that when in position its zero is at Frankfort and it is read plus or minus (above and below).

Immediately behind this scale, as shown in Fig. 5, was placed a 12 gauge sheet of lead with a central vertical aperture large enough to permit

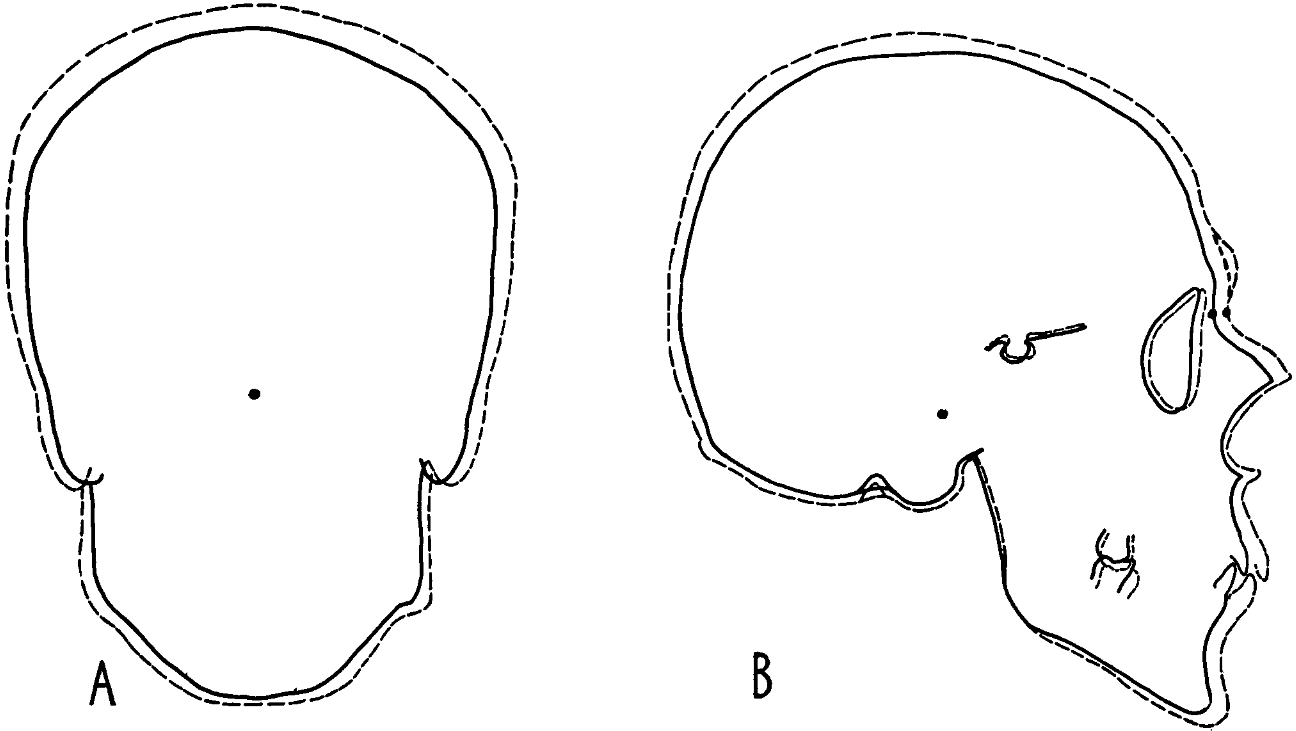

Fig. 4.—Drawings of the lateral and frontal aspects representing the true outlines of the skull together with the outlines of the shadow it casts when employing the Broadbent-Bolton technique. The common points of orientation are indicated by the central black dots which also indicates the axes of penetration of the central ray.

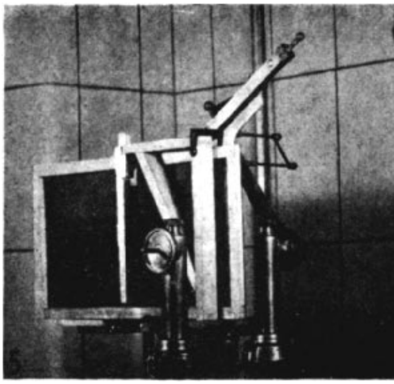 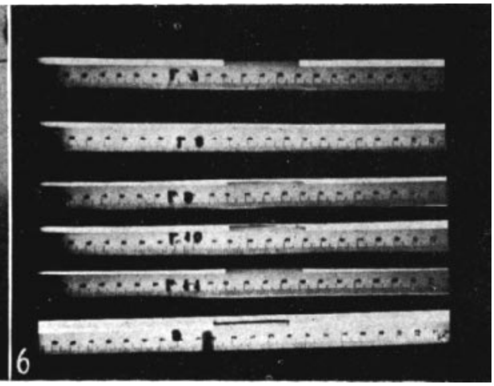

Fig. 5 (left).—A photograph of the framed lead mounted so that the scale is in the median plane of the head-holder. The central vertical aperture is just large enough to permit an image of the scale to be reflected on an X-ray film which is mounted in its regular rack behind the lead plate.

Fig. 6 (right).—The composite X-ray picture resulting from six exposures between any two of which the cassette was slid a little more than the width of the scale. The leaded figures indicate the distance of the film from the median plane of the head-holder where the scale remained stationary.

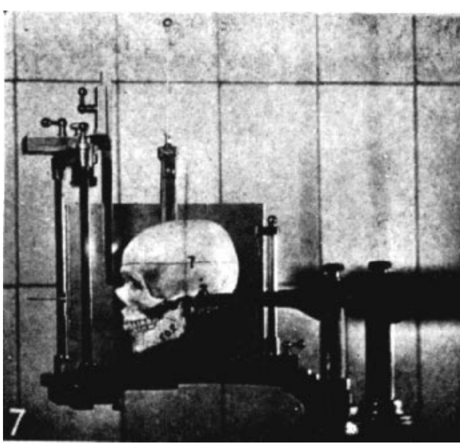 

Fig. 7 (left).—A photograph of one of the skulls mounted in the cephalometer in the accepted manner prior to the taking of a lateral head plate.

Fig. 8 (right).—A photograph of a lateral head plate of a skull showing how radiopaque materials were used to accentuate landmarks. The coiled, angular and curved wires running upward from the mandible were cut after they were waxed into place. Any change in mandibular position showed up in the relationship between the free ends of the wires.

an X-ray exposure of the scale on the film. The film in a cassette was placed in its regular rack behind the lead plate. This set-up was fabricated by Dr. John Spence of the Department of Dental Histology of the University of Illinois.

Starting at 7 cm. from the mid-line of the machine, which distance represents the inside limit of head size, an exposure was made and lead

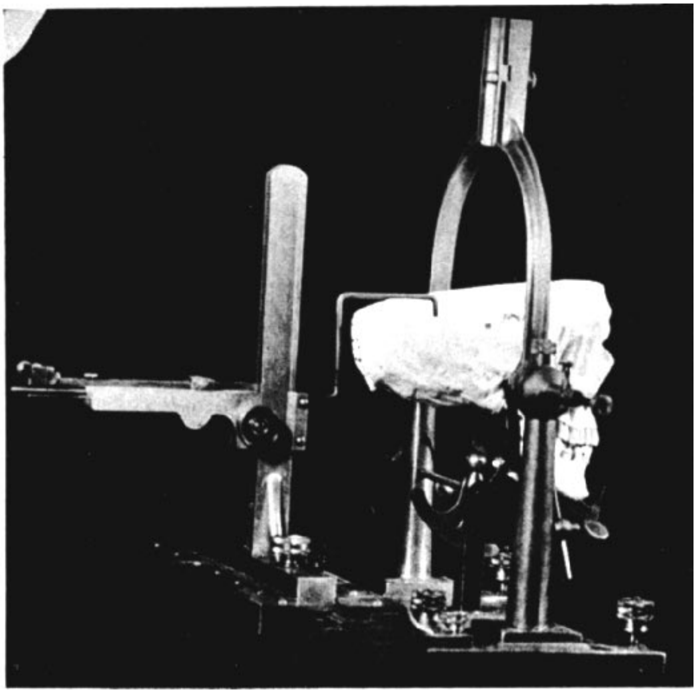

Fig. 9.—Photograph of a skull mounted in the Reserve Craniostat and oriented in the Frankfort. The calvarium has been temporarily removed to measure the interior surfaces and the appropriate anthropometric needle is in use.

markers were added to the scale for identification of the distances. The cassette rack was then moved to a distance of 8 cm. from the median line of the machine, the film cassette was slipped outward a distance which was a little greater than the vertical aperture in the lead plate, new lead identification markers were added and another exposure made. The same operation was repeated at intervals of 1 cm. By such a procedure it was possible to make six corrective scales on one film (Fig. 6) each one with an identification which indicates the distance of the film from the mid-line of the machine. The entire film was processed and the individual scales were then cut out with scissors.

In order to make practical tests (Fig. 7) of the accuracy of the scales five skulls were selected and marked with radiopaque materials such as brass wire, lead discs and foil, so that various anthropometric landmarks could be readily and precisely identified. These skulls were placed in the cephalometer in the accepted manner and headplates such as that shown in

Fig. 8 were made. The various markings are very conspicuous. Tracings were made of these headplates according to the technique described in the literature.

(Fig. 9) The skulls were oriented in a Western Reserve craniostat* in the Frankfort plane and readings of the front half of the skull were made on the vernier millimeter scales which run in three planes of space. By selection of the proper anthropometric needle it is possible to reach any anatomical point, so that it was possible to locate with great accuracy any structure which we desired. In the same manner the posterior half was then surveyed and all points recorded as projections on accurate millimeter graph paper.

TABLE 1.—COMPARISON OF CORRECTIVE SCALE AND STANDARD MEASUREMENT

A composite table of all the linear measurements made on the five skull specimens. The column headed C.S. contains those readings made from the headplate tracings with the Corrective Scale indicated by the distance of the film from the median line. The column S.M. is made up of corresponding readings from the projected images or craniostatic drawings in which a standard metric scale was used.

Specimen Gauge	205		206		207		208		209	
	C.S.	S.M.	C.S.	S.M.	C.S.	S.M.	C.S.	S.M.	C.S.	S.M.
1. Length of Skull	189.00	187.25	169.00	168.50	182.00	183.00	185.00	183.50	167.00	165.00
2. Sella to Nasion	73.00	72.50	62.00	62.50	65.50	65.00	64.00	64.00	54.50	55.50
3. Sella to Bolton	60.50	60.50	57.50	57.00	54.50	55.50	57.50	58.00	45.50	46.25
4. Ptm. Fis. to Bolton	69.00	68.75	62.00	62.00	65.00	68.50	58.00	59.50		
5. Ptm. Fis. to ANS	59.50	59.00	53.00	53.00	36.00	36.00	48.00	47.50		
6. Mandibular Height at Last Molar			28.00	27.75	35.50	35.50	32.00	32.00		
7. Mandibular Height at Incisors	48.00	49.00	47.50	48.00	40.00	40.00	47.00	48.00		
8. Gonion to Gnathion	79.50	80.75	73.50	74.00	76.00	76.50	79.00	80.00		
9. Ptm. Fis. to Key Ridge	26.50	26.50	21.00	21.50	19.00	20.50				
10. A.P. Width of Ramus	30.00	30.50	27.00	28.00	34.00	34.00	28.00	28.50		
11. Sella to Porion	28.00	26.50	30.00	29.50	28.00	29.00	33.00	31.50		
12. Height of Skull from Sella	112.00	113.00	108.00	108.00	110.50	110.50	97.00	97.50		
13. Greatest Skull Width	141.00	139.50	144.50	142.00	153.50	153.00	139.00	137.50	138.00	137.50
14. Bi-Mastoid Width	115.00	116.50	108.00	109.25	107.50	109.00	102.00	100.50	87.00	87.00
15. Bi-Zygomatic Width	132.00	131.00	125.50	127.50	133.25	134.00	123.00	124.00	105.50	106.50
16. Bi-Gonial Width	90.00	89.00	97.50	99.00	101.00	102.50	96.25	94.50		
17. Gnathion to Vertex (Frontal)	215.00	218.75	209.50	206.00	208.50	212.00	196.50	199.00		

In short, all points in which we were interested were plotted in their correct relation and at their correct distances from one another.

The headplate tracings were measured with the correctional scale as indicated by the distance of the mid-line of the skull from the film. The zero point on the scale was kept as close to the porionic axis as possible for increased accuracy, because enlargement in these scales increases as we read toward their upper and lower limits. The enlargement in these scales as in any other X-ray picture is not uniform but rather gets progressively greater as we proceed from the central ray axis. For instance, in the centimeter between zero and one in the average scale there is about .3 mm. enlargement while in the centimeter interval between ten and eleven it is seen to

* The craniostat was obtained through the courtesy of Dr. M. Wilton Krogman.

TABLE 2.—FACIAL ANGLES OF HEADPLATE TRACINGS AND CRANIOSTATIC DRAWINGS

A table showing a comparison of the readings of corresponding angles made with a transparent protractor from the headplate tracings and craniostatic drawings or plotted images.

Specimen	205		206		207		208		209	
	Hdpl.	Cranio	Hdpl.	Cranio	Hdpl.	Cranio	Hdpl.	Cranio	Hdpl.	Cranio
1. BSN	145.00	144.00	147.00	148.00	156.00	156.50	142.50	144.50	23.50	24.00
2. SBN	20.00	20.00	17.50	17.00	13.25	13.00	19.50	18.50	13.00	13.00
3. SNB	16.00	16.5c	16.75	15.75	10.50	11.00	17.25	17.00	10.50	10.75
4. N. ANS. PNS.	82.00	81.50	82.25	82.25	86.00	84.75	85.50	85.00	91.50	90.75
5. PNS. N. NS.	51.50	52.00	50.00	52.50	49.75	49.50	37.50	38.50	46.00	47.00
6. N. PNS. NS.	47.00	46.50	47.00	46.00	45.00	46.00	49.00	49.00	42.50	42.00
7. N. Gn. Go.	58.00	57.00	59.00	58.25	73.25	74.25	61.50	60.75		
8. N. Go. Gn.	80.50	82.00	85.00	84.50	69.00	67.75	81.50	83.00		
9. Go. N. Gn.	41.00	42.00	35.25	35.50	37.75	37.75	36.00	37.00		
10. S. Go. B	50.00	49.00	47.00	47.00	42.00	45.25	42.25	43.75		
11. S. Go. N	39.50	39.00	33.50	33.25	30.25	30.25	32.25	32.25		
12. B. Go. N	89.00	88.00	80.50	80.00	72.25	75.50	74.50	76.25		
13. N. S. Go.	99.00	98.00	101.25	102.50	112.25	112.00	102.00	103.50		
14. B. S. Go.	46.00	46.00	45.50	45.25	44.00	44.25	40.75	41.00		
15. B. S. V.	108.00	105.25	95.00	94.50	114.25	113.00	107.75	106.50		
16. Gonial	135.00	137.00	130.00	131.75	114.00	116.00	130.75	132.75		

be almost .8 mm. It is not the same for each centimeter. Where bilateral structures cast duplicate images, a mean was taken in all cases and listed as a single reading. The measurements on the plotted picture were made with a standard millimeter ruler, scaled to ¼ millimeters. Paired readings, one taken from the X-ray using a correctional scale, and the other taken from the plotted image with a standard scale, were tabulated (Table 1).

When we recorded these paired readings according to specimen it was noted that the differences at no point are very great. In line 3 (Sella to

TABLE 3.—RESULTS OF CHANGES IN PORIONIC AXIS AND MANDIBULAR POSITIONS (LINEAR—C. S.)

A table showing the changes in dimensions brought about by shifting porionic axis and mandibular position as indicated in the column headings. The same specimen was used throughout and a mean of double images from bilateral structures was used. The measurements were made with the indicated corrective scale from the head plate tracings.

	Cranio-static Normal	Normal Porion Centric Occlu-sion	Normal Porion Left Condyle Advanced	Normal Porion Right Condyle Advanced	Normal Porion Protru-sion	Right Porion Centric Occlu-sion	Right Porion Advanced Right Condyle Advanced	Left Porion Advanced Left Condyle Advanced	Left Porion Advanced Protru-sion
1. Length of Skull	168.50	169.00	168.75	168.50	168.75	168.75	169.00	169.50	170.00
2. Length of Sella	9.50	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
3. Sella to Nasion	62.50	62.00	62.25	62.00	62.25	62.25	62.00	63.00	63.25
4. Sella to Bolton	57.25	57.50	57.25	57.50	57.50	57.25	57.25	57.50	57.75
5. Bolton to Pt. Max.	62.00	61.50	61.50	61.75	61.75	61.25	61.50	62.25	62.25
6. Pt. Max. to ANS	53.25	52.75	52.75	52.25	52.25	53.00	52.50	52.75	53.25
7. Ht. of Mand. Last Molar	27.75	28.00	28.50	28.0c	28.50	28.00	28.00	27.75	28.c0
8. Ht. of Mand. at 1 1	48.00	47.50	47.25	47.25	47.00	47.00	47.25	48.00	48.00
9. Go. to Gn	74.25	73.50	75.50	74.00	74.00	74.00	75.00	71.50	77.00
10. Pt. Max. to Key Ridge	21.75	21.25	21.25	21.75		21.75	21.00	21.25	21.00
11. Last Molar to Dist. of Mand.	22.50	24.00		28.00	23.00	28.50	27.25	22.00	23.00

Bolton) the discrepancy is as low as .5% and in no instance exceeds 1.7%. If we recall the relative difference in skull length shown in Fig. 4 it will be noted to how great an extent this error has been corrected. It will be noted further in lines 13 to 16 inclusive where frontal measurements are listed, that the discrepancies are such as to indicate that the scales are not applicable to this view and subsequent work is required on this problem. Certain other differences, though very slight, are no doubt due to human error.

In the case of the angles of the face and the cranium as tabulated in Table 2 no corrective gauge was used, i.e., the same protractor was used for

TABLE 4.—RESULTS OF CHANGES IN PORIONIC AXIS AND MANDIBULAR POSITIONS (ANGULAR)

A table showing the effect on facial angles of shifting porionic axis and the mandible as indicated in the column headings. The same specimen was used throughout and readings were taken from the headplate tracing with a transparent protractor. A mean of double images from bilateral structures was used.

	Cranio-static Normal	Normal Porion Centric Occlusion	Normal Porion Left Condyle Advanced	Normal Porion Right Condyle Advanced	Normal Porion Protrusion	Right Porion Centric Occlusion	Right Porion Advanced Right Condyle Advanced	Left Porion Advanced Left Condyle Advanced	Left Porion Advanced Protrusion
1. Gonial	131.75	132.00	132.75	133.50	135.00	132.50	134.00	133.00	133.50
2. B S N	148.00	146.25	146.75	147.00	147.00	147.00	146.75	147.00	147.00
3. S B N	17.00	17.50	17.25	17.00	17.00	17.25	17.25	17.25	17.00
4. S N B	15.75	16.75	16.00	16.00	15.75	16.00	16.00	15.75	15.75
5. N. ANS. PNS	82.00	82.50	82.25	83.75	82.75	83.50	82.75	82.50	83.00
6. PNS. N. ANS	52.50	50.00	50.00	50.00	50.50	50.00	52.00	50.75	49.50
7. N. PNS ANS	46.00	47.00	47.50	46.25	46.50	46.25	46.25	47.00	48.00
8. N. Gn. Go.	58.25	59.50	58.50	59.00	58.25	60.00	57.75	58.75	58.25
9. N. Go. Gn.	84.50	85.00	86.00	86.00	87.25	84.25	87.25	86.00	85.50
10. Go. N. Gn	35.50	35.25	35.50	35.25	34.75	35.75	35.50	35.50	36.25
11. S. Go. B	47.00	46.50	46.00	46.50	44.75	47.00	46.00	45.50	45.50
12. S. Go. N	33.25	33.50	33.25	33.50	33.50	33.50	33.00	33.25	33.50
13. B. Go. N	80.00	80.00	79.50	80.00	78.75	80.00	79.50	78.75	79.00
14. N. S. Go.	102.50	101.25	101.75	101.75	100.00	102.00	101.75	102.25	101.00
15. B. S. Go.	45.25	45.50	45.00	45.50	47.50	44.75	45.00	45.00	45.75

both tracings and plotted pictures or craniostatic drawings. Here we note that in the enlargement of a headplate the effect is such that all facial angles are opened on an average of 1°. It is least in those in the cranial base and greatest in those involving mandibular points. The explanation is the same. Facial angles are at a greater distance from the central ray.

We are conscious of the fact that at times, even with the most painstaking technique, we get pictures which indicate malpositioning of the head and the mandible. In order to check the results of measuring under such conditions we created this malpositioning in the same specimen by shifting porions 5 mm. and condyles 3 mm. as indicated by the headings. It will be noted in Fig. 8 that various wires were added to increase the accuracy of measuring such as those in the mandibular notches and in the incisal area. We have no doubt in this experiment exceeded any abnormal positioning that occurs in the living where good equipment is used with the proper discipline.

In this phase of the work the error was reduced by establishing mean points in the case of double images and measurements were made with the indicated scale. It will be noted in following the lines across the chart in Table 3 that the error is quite small except in the last two columns of line 9 and in several measurements of the distance of the last molar to the distal of the mandible in line 11.

The drawings from which the data in Table 3 were derived were analyzed from the standpoint of facial angles by means of a transparent protractor. This data is arranged in a table (Table 4) with the variables listed in the column headings. It will be noted that those angles which do not have points in the mandible show a small error while those that do will show an appreciable difference. The greatest discrepancy occurs where a condition of mandibular protrusion was produced.

Conclusions

1. The results of this investigation have led us to feel that we are justified in employing these corrective scales in future cephalometric appraisals. Of course the same end may be attained by the use of mathematical formulae, but when one is taking a series of 50 measurements on every set of headplates this constitutes an enormous task.

2. An examination of the tables in which facial angles from both headplate tracings and plotted images were recorded, indicates that the differences are within the limits of experimental accuracy. Furthermore, a comparison between individuals, as to angles, is quite a different matter than a comparison of a linear measurement.

3. The observations on the shifting of the head and the mandible bear out the fact that we must continue to get proper head positioning in the cephalometer and to make sure the patient is biting properly.

4. It has been brought to mind in many instances in this work as before that there is no substitute for a painstaking technique.

808 South Wood Street

Bibliography

1. ANDREW, F. D. and WARREN, S. L. A Study of the Distortion in Roentgenograms Taken at Various Target Distances. *Am. J. of Roentgenology and Radium Therapy*, 22:332 Oct. 1929.

2. MORTIMER, LEVINE and ROWE. Cranial Dysplasia of Pituitary Origin. *Radiology*, 29:279, Sept. 1937.

3. WILSEY, R. B. The Physical Foundations of Chest Roentgenography. *The Am. J. of Roentgenology and Radium Therapy*, 30:234, Aug. 1933.