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Radiographic Interpretation and Cephalometric Analysis of the Human Fetus in a Posterior-Anterior View: A Pilot Study

O. Richard Infield
Loyola University Chicago

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RADIOGRAPHIC INTERPRETATION AND
CEPHALOMETRIC ANALYSIS OF THE HUMAN FETUS
IN A POSTERIOR-ANTERIOR VIEW:
A Pilot Study

by

O. RICHARD INFELD, D.D.S.

A Thesis submitted to the faculty of the Graduate School
of Loyola University in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE

JUNE

1970

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CHAPTER I

INTRODUCTION AND STATEMENT OF PROBLEM

Numerous studies have been undertaken to describe the growth of the human cranio-facial complex. Most of these works have analyzed the adult or growing skull in longitudinal studies and have been viewed from a lateral direction. Fetal studies have been done to determine the growth patterns of the prenatal skull, but these also used a lateral view.

With the growing interest of modern orthodontics in a posterior-anterior radiograph, it seems a study using a similar view of the human fetus would lend depth to the clinician's understanding of prenatal growth. It is with this in mind, that we present this paper in an attempt to establish some guide lines for the future cephalometric study of the human fetus.

Due to the size of the fetal heads, construction of a special cephalometer was necessary. Provisions were made to facilitate exact 90 degree pivoting of the specimen and headholder thereby enabling confirmation of correct orientation of the posterior-anterior radiograph.

In the process of analyzing this material, it soon became apparent that one of the main problems was simply the definition of the structures seen on the radiogram. Therefore, the content of this paper was expanded to include the identification of these immature structures.

CHAPTER II
LITERATURE REVIEW

A thorough understanding of human growth and development is necessary to satisfy the commitment of the modern orthodontist to competent diagnosis and treatment of his patients. Malocclusion is not merely the irregular arrangement of teeth in the jaws, but is the end result of a complex interplay of forces resulting from heredity, growth, development, hormonal, nutritional and environmental influences.²³ The purpose of this paper is to further expand the boundaries of our understanding in the areas of growth and development.

The human body grows at entirely different rates in its process of development and "normal" growth rate at one phase would be abnormal during another phase. For example, the approximate weight of a fertilized ovum is .005 milligrams (Meyer 1914) and 9 weeks later, at the beginning of fetal life, it weighs approximately 1.1 grams (Streeter, 1920), a rate of weight increase of about 220,000 times. During the following 31 weeks of development, the rate of weight increase is approximately 2,900 times, and from birth to maturity the rate slows down to approximately 20 times.³⁷

Within the various phases, the growth rate varies and is slower at the end of the fetal period than at the beginning. If the rate of growth of the last fetal month continued, the child would weigh 100 pounds at age one year.²⁰

In general, "the law of developmental direction" for all vertebrates proceeds from the head downward, the caudal parts developing slower. This increased rate in the development of the upper part of the body is not confined to embryonic growth, but clearly persists into the advanced stages of fetal life.³⁷

The head itself has a still more complex growth pattern. Growth of the brain case is correlated to the brain itself, but growth of the facial bones varies from cranial growth, even though these bones are in actual contact with the cranial base. The coordinated regulation of parts growing at different rate and direction, together with the modeling of bone by apposition and resorption, is what converts the fetal skull into the configuration of the adult skull.

The greatest change in the proportion of the postnatal skull are those which take place in the dentofacial region, especially the jaws.

The infant skull at birth is divided into 1/8 face, 7/8 skull. As an adult, the face is about $\frac{1}{2}$ and the skull $\frac{1}{2}$.^{3,33,36} The percentage ratio of cranial vault to facial skeleton is illustrated graphically by Scammon's neural (cranial vault) and general (facial skeleton) growth curves from early fetal life to the adult stage.¹⁵

Rabkin³² states that there is a definite morphogenic pattern established early in fetal life and at least by the third postnatal month. (4, 5,6,31,36,41) Broadbent and Brodie doubt this pattern changes much once it has been established. Curtner describes the hereditary influences involved in the morphology of the human face.⁸ He says it is possible to predetermine a child's adult face by superimposing its head film tracing

over that of the mother and/or father. The child's facial pattern will often follow an almost identical cranio-facial pattern of one of the parents.

All of the structures of the human body, including the head and facial area, are based on multigenic complexes. In 1953, Krogman made the following statement: "I, for one, as a human biologist, must react with a sort of awed wonder that there are not more variations or more anomalies merely on the basis of recombinations of genes".²⁴ With this in mind, it seems logical that the jaws, as well as any other individual cranio-facial component, could develop as separate entities with innumerable interrelationships.^{17,40} The "arch length - tooth mass discrepancy" is an example.

It appears that the morphologic traits of individual bones are genetically determined and facial bones do not all grow at the same time or rate.²⁸ The different facial patterns are due to the way the individual bones are related and to the degree of development as they respond to their surrounding environment.^{28,38,39}

Details of cranio-facial growth were described by many authors beginning in 1736 with V. Belehier and H.L. Dhumal in 1740 who worked with a madder diet to describe bone growth in pigs. Craniometric studies of the human began in 1921 with Kieth and Campion²² measuring with calipers and describing the growth of the human cranium and facial complex from child to adult. Hellman¹⁸ did a cross sectional study of numerous American Indian skulls using anthropometric technics to describe growth patterns of the head.

Broadbent introduced a technic in 1931 for the longitudinal study of cranio-facial growth via the use of radiographic cephalometrics.² In this study he demonstrated an orderly, progressive pattern of growth and development. Brodie followed this with a radiographic cephalometric study of his own and determined that, "the morphogenetic pattern of the head is established by the 3rd postnatal month or earlier, and once attained does not change". He divided the face into cranial, nasal, maxillary and mandibular parts and demonstrated a marked parallelism in geometric form and increments. The nasal floor, occlusal plane and lower border of the mandible all maintain a constant angular relationship to the cranial base. The whole face traveled downward and forward "emerging from beneath the cranium".⁵

Many are the studies and vast is the amount of material compiled on growth and development, but little of it deals specifically with the fetal period.

In 1956 seventy six fetuses, age 10-40 weeks, were sectioned sagittally by Ford.¹¹ Through linear measurements, he demonstrated morphological changes in form of height and depth as a result of differential growth rates.

Noback²⁹, also in 1956, studied differential growth analysis of the fetal cranio-facial skeleton. He declared that facial bone dimensions increase at specific rates which have a relatively constant relation to each other. It is generally accepted that cranial growth is largely dependent on the growth of the brain and, therefore, conforms to the neural pattern of growth. This growth is very rapid until age 3 years and then falls off

rapidly to near completion at age 8 years. The facial growth, however, is seen to follow the skeletal growth pattern of the individual.^{1,11, 38}

Scammon and Calkins stated in 1929 that changes in proportions arise through inequality of growth rates that had already been established during the embryonic period.³⁶ Rabkin found it significant that irregularities in jaw relationships can be seen in fetal age groups of 4 to 6 months and the facial features closely resemble physical differences seen in the living.

Levihn,²⁶ in 1966 found that during the latter half of fetal life the upper facial dimension was constant at 41 - 42% of total face height. The fastest rate of growth was observed during the 4th and 5th lunar months of fetal life. He also confirmed the observation of Rabkin that there are variations in facial features that are similar to those seen in postnatal life.

CHAPTER III

MATERIALS AND METHODS

Growth and development of the human cranio-facial complex can be studied in two basic ways: longitudinal and cross-sectional. The longitudinal method can make use of photos, x-rays and mechanical measurement of a living specimen over a period of time -- usually from infant to childhood to maturity. This technic obviously requires many years to complete, but "normal" is more easily verified than in a cross-sectional study.

A cross-sectional study uses many individuals of varying ages and has the convenience of time, since data can be gathered over a relatively short period. The obvious disadvantage is ascertaining the validity of your sample as being a true representative of "normal" at a given age. The source of error can be minimized through the use of many individuals of that given age and then establishing a mean.

For this paper, the author will describe the cross-sectional method and will use oriented posterior-anterior radiographs and cephalometric tracings to study non-living human fetuses of approximately 3 months intra-uterine life to birth. The fetal specimens used were as free from pathology, facial damage and distortion as far as is possible to determine by gross examination.

All specimens were fresh and non-preserved except for cold storage for several days. The age of each specimen can be determined by crown-rump length^{11,36,37} (see Table I - Crown-Rump Chart)²¹ by the appearance of ossification centers^{12,19} and by estimate of the length of pregnancy provided by the physician on the death certificate. With these technics, an accurate determination of the age group can be obtained.

A Weber Radex (Model N) x-ray machine was used to take the roentgenograms. The exposure time varied from 9 - 65 seconds. (See Table II). Milliamps and KVP were held constant at 11 and 55 respectively. The cone of the machine was inserted into a 4 inch inside diameter steel tube with $\frac{1}{4}$ inch walls and 33 inches in length.²⁶ This pipe produced a collimating effect resulting in a field of exposure of 7 inches diameter at a film distance of approximately 63 inches from the anode.

Kodak Ready-Pak-No Screen Medical x-ray film (5 x 7 and $2\frac{1}{4}$ x 3) was placed directly against the specimen to reduce magnification error. Considerable experimentation in exposure dose and film selection and placement resulted in radiograms of very fine quality and definition.¹⁰

Error of magnification was minimized by placing the film directly against the specimen, thus reducing the object-film distance to less than $\frac{1}{2}$ inch and error of magnification to a very small percentage. Therefore, no magnification correction factor was considered necessary.

A headholder similar to those used in conventional orthodontic cephalometry was fabricated to meet the smaller size requirements of a fetal head. The ear rods are both adjustable to maintain a distance of 5 feet

from anode to mid-sagittal plane. The ear-rod supports were mounted on a vertical axis which allowed an exact 90 degree pivoting of the mounted fetal specimen, through the use of a detent. The fetus was oriented to Frankfort horizontal plane in a lateral view and a radiograph obtained. The headholder (with fetus) was turned to engage the 90 degree detent and a posterior-anterior film obtained. In this manner, confirmation of posterior-anterior orientation could be achieved by comparing the lateral radiograph with the posterior-anterior radiograph. (See Figs. 1,2,3) Also, a common Frankfort plane allowed projection of radiographic images of one view to be analyzed in another view thus aiding in identification of the extremely small, immature structures.

The radiographs were traced on thin frosted acetate paper. The illuminated viewing surface was restricted to the size of the film via the use of an adjustable cardboard template. A 3 inch magnifying lens was used to assist in defining the anatomic structures.

Visual examination of fetal skulls provided by Dr. Norman K. Wood, proved invaluable in identification of the osseous anatomy of human fetuses. These skulls (age 45 mm., 65 mm., and 140 mm.) had been cleared with potassium hydroxide and then treated with alizarin red-S to stain all calcified structures. The result was, all calcified structures were crimson colored and suspended in their normal investing tissue previously made transparent with the potassium hydroxide.³⁰

The above specimens proved even more useful when examined radiographically after individual structures were identified with barium sulfate paste.

Review of the various texts proved an aid, but they concerned themselves primarily with adult structures and therefore were of lesser value in identification of incompletely formed and ossified structures.

Macklin²⁷ described a fetal skull in minute detail with accompanying sketches of all components as well as the whole. These drawings, as well as those in Gray's Anatomy¹⁴ and others,^{7,9,25,34,35,40} were used also.

In summation, all of the above described procedures were used and interrelated to arrive at the final results.

Cephalometric orientation was achieved with reliable consistency during the determination of the anatomic structures. Many normally reliable landmarks were completely nonexistent in early skulls, and vague in the oldest (425 mm. - crown-rump) even with clear, sharp films. All visible bi-lateral structures were traced and, where practical, were connected with a horizontal line. In the older specimens, several bi-lateral landmarks were discernible. (See Figs. A-G) These were connected and compared with tracings of the younger fetus. Because of incomplete development in the very young, all convenient points were eliminated except two. These persistent bi-lateral landmarks were joined by a line that was consistently reproduceable in all orientated posterior-anterior radiographs, regardless of age.

All central and vertical structures were traced in a manner similar to the horizontal structures. Again, in the older fetus, several points could be located, but in the youngest only one was consistently definable.

A check on the validity of these base lines was necessary and was accomplished as follows: Wherever development was sufficient to allow it,

lines parallel to the base line were drawn through definable landmarks. These lines were then measured with a caliper for symmetry to establish the validity of the base line. For example, the vertical midline was drawn, then parallel vertical lines were drawn tangent to the lateral borders of the orbits. If this midline equally divided the distance between the lateral borders of the orbits consistently, it can then be assumed this is an accurate definition of the true midline. A total of 18 tracings were so analyzed and this midline was found to be accurate to a high degree.

Reproduceability of the landmarks was confirmed by duplicate serial tracings of a representative specimen of several age groups (95 m., 185 m., 255 m., and 310 m.). One tracing of each of these was done every other day for 7 days supplying then 4 duplicate tracings of each. Then all the tracings of, for example #85, were superimposed for accuracy in tracing and measurement. In all cases the error was within 0.5 mm.

For infants of 150 mm. or greater crown-rump length, support of the body was necessary. This was necessary because distortion by the ear rods, of cranial relationship was evident if the body was unsupported.

TABLE I

Classification of Fetal Age Groups
(Kiebel and Mall)

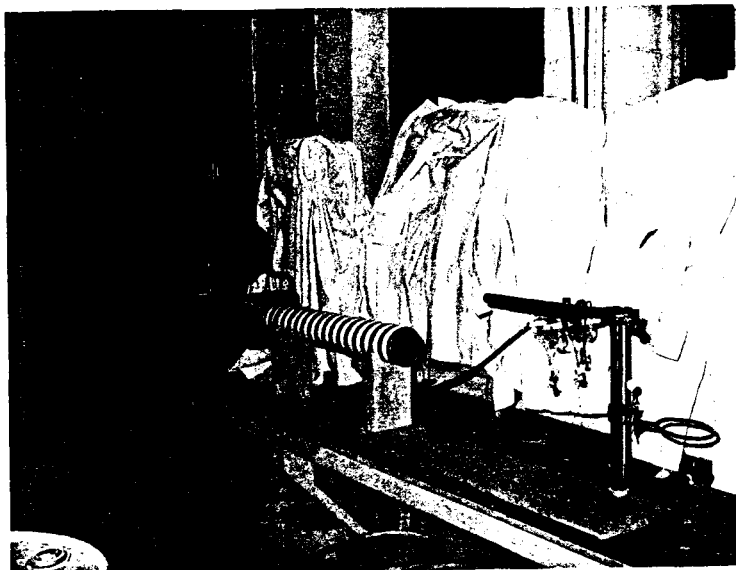
Fetal age groups (weeks)	Lunar month	Approximate crown-rump length (mm.)
12 to 15	4	68 to 111
16 to 19	5	121 to 157
20 to 24	6	167 to 210
25 to 28	7	220 to 245
29 to 32	8	252 to 284
33 to 36	9	293 to 316
37 to 40	10	325 to 336

TABLE II

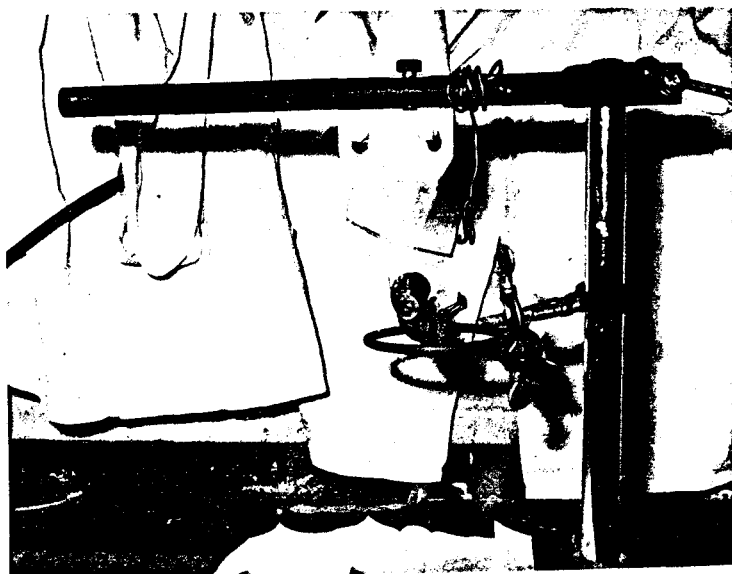
Radiation Dosages

Approximate crown-rump length (mm.)	Exposure Times (Seconds)			
	KVP	MA	Lateral View	P.A. View
68 to 111	55	11	8.0	10.0
121 to 157	55	11	10.0	12.0
167 to 210	55	11	17.0	20.0
220 to 245	55	11	29.0	34.0
252 to 284	55	11	36.0	45.0
293 to 316	55	11	44.0	57.0
325 to 336	55	11	55.0	65.0

Cephalometer Used in Fetal Studies



Headholder with Fetus and Body Support



CHAPTER IV

FINDINGS

A brief description of the individual bones and ossification centers is indicated here to assist the reader in identification of these structures. The dates of ossification given here^{7,14} were determined by the use of alizarin red-S and appear approximately two weeks later on radiographs.

Frontal -- Ossification begins in the 6 - 7th week above the orbits. Several weeks later three more centers appear: 1) in the zygomatic process of the frontal bone; 2) in the nasal spine; and 3) in the area of the trochlear fossa. These last centers fuse in the 7th month. The frontal suture fuses in the 5 - 6th year.

This bone appears early in the posterior-anterior radiograms in the area of the superciliary ridge and progresses medially and laterally, as well as inferiorly to form a distinct outline of the superior portion of the orbits.

Temporal -- Ossification begins: 1) at the root of the zygomatic arch in the 2nd month; 2) in several centers in the mastoid area at approximately 5 months and fuse in the 6th month. (Fig. 3)

This bone appears, lateral to the zygoma, in even the earliest films examined. The zygomatico-temporal suture is clearly seen in all films.

Sphenoid -- Ossification of the greater wing and pterygoid plates begin about the 8th week between the foramen ovale and rotundum. The Post-sphenoid (in front of sella and connected to the lesser wing) begins ossifying in the 8th week also. The lingula at the side of the Post-sphenoid begins ossifying in the 9th week, as do the medial pterygoid plate, hamulus and lesser wing. The Pre-sphenoid begins in the 10th week. At birth (approximately 315 mm. or larger) all of these centers are fused into three parts, i.e. the greater wing with the pterygoid plates (2) and the body with the lesser wing (1).

The greater wings can be seen developing with foramen rotundum in most films. (Fig. 1,2) The lesser wing with the optic foramen can be seen in all films of 200 mm. or greater, appearing on the medial wall and projecting into the orbit.

Maxilla -- Ossification begins in the 6th week above the area of the canine bud. The sinus begins to form in the 4th month.

The infra-orbital rim appears early and changes little with time except for medial extension. The zygomatic-maxillary sutures narrow and become well defined at approximately 200 mm.

Palatine -- Again, ossification begins in the 8th week in the lateral wall of the nasal cavity. Until the 3rd year the anterior-posterior dimension is greater than the vertical dimension, but this reverses as the sinuses develop.

This bone is indistinct in the posterior-anterior view, but usually well defined in the lateral view at all ages.

Zygomatic -- Ossification begins in the 8th to 10th week.

This bone aids in identification of the infra-orbital rim and is well defined by its sutures after approximately 240 mm. Harvold¹⁶ advises using the zygomatic-frontal suture as a cephalometric landmark, but it appears too late in development to be useful in fetal studies.

Vomer -- Ossifies in the 8th week from two centers which unite to one "V" shaped bone by the 3rd intrauterine month.

This is the landmark used in establishing the vertical axis in the cephalometric tracings.

Lacrimal -- Ossifies in the 3rd month in the nasal capsule.

Nasal -- Ossifies in the 8th week from one center on each side of the midline between the two halves of the maxilla.

This is a thin bone and cannot be identified well in the posterior-anterior film. Occasionally the two halves help to identify the midline, however.

These anatomic structures are as shown in Figures 1,2 and 3.

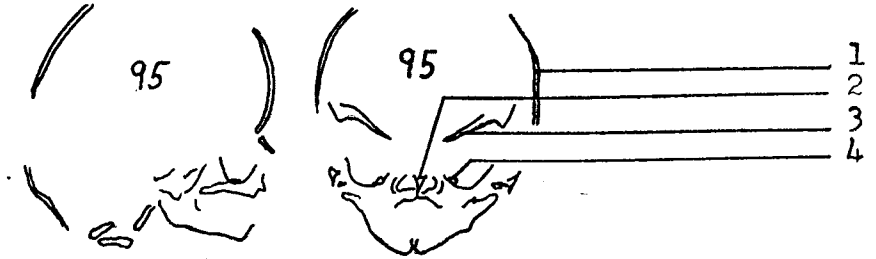


Figure 1

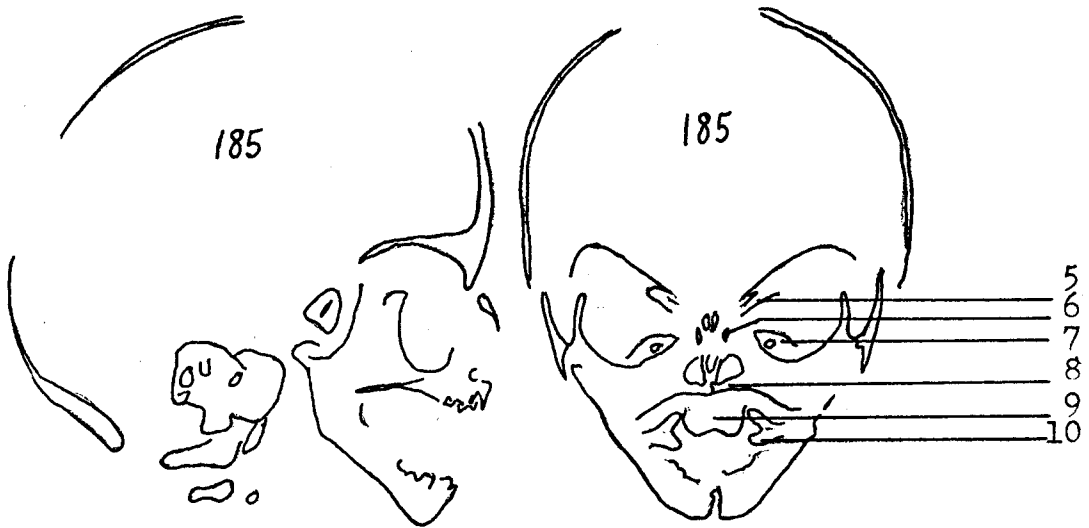


Figure 2



FIGURE 3

Figure 1

1. Parietal Bone
2. Vomer Bone
3. Supra Orbital Rim
4. Foramen Rotundum

Figure 2

5. Lesser Wing of Sphenoid
6. Lacrimal Bone
7. Greater Wing of Sphenoid
8. Palatine Process of Maxilla
9. Basilar Part-Occipital Bone
10. Lateral Part- Occipital Bone

Figure 3

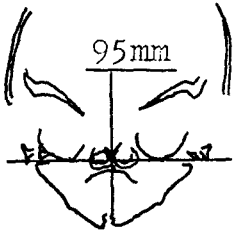
11. Temporal Bone (Squama)
12. Lacrimal Bone
13. Fronto-Zygomatic Suture
14. Lesser Wing of Sphenoid
15. Zygomatico-Maxillary Suture
16. Zygomatic Arch

The cephalometric landmarks consistently reproducible at ages 4 months to birth (86 mm. - 310 mm. crown-rump length) were:

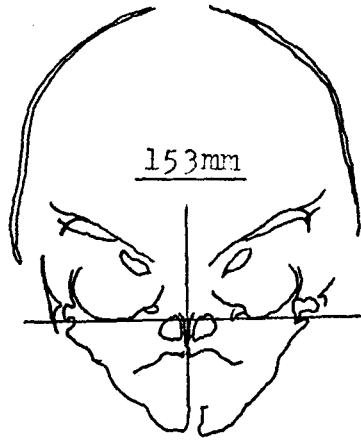
1. The lower border of the orbits.
2. The nasal septum.

The vertical axis is drawn through the nasal septum, 90 degrees from the horizontal, infra-orbital line. For the resultant oriented posterior-anterior radiographic cephalometric tracing, see Figure 4.

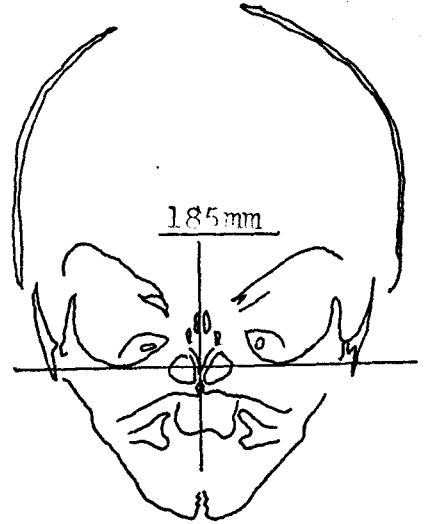
FIGURE 4



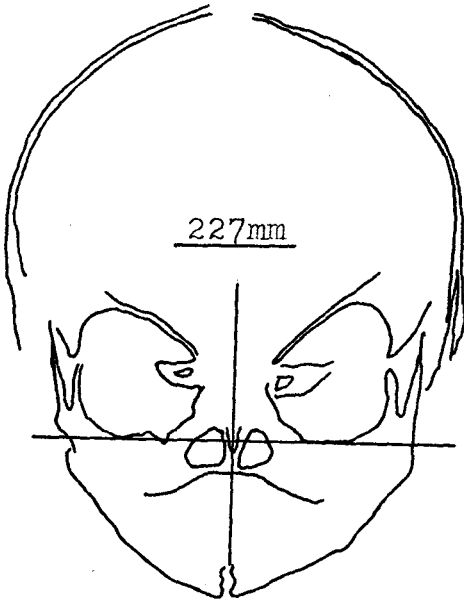
A



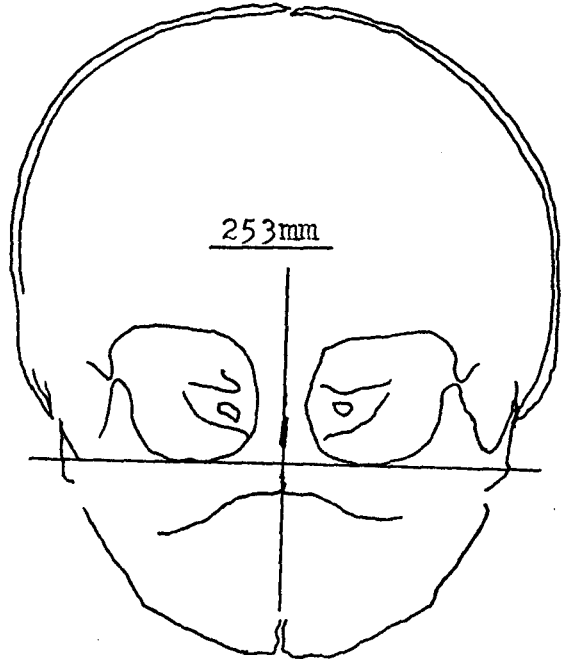
B



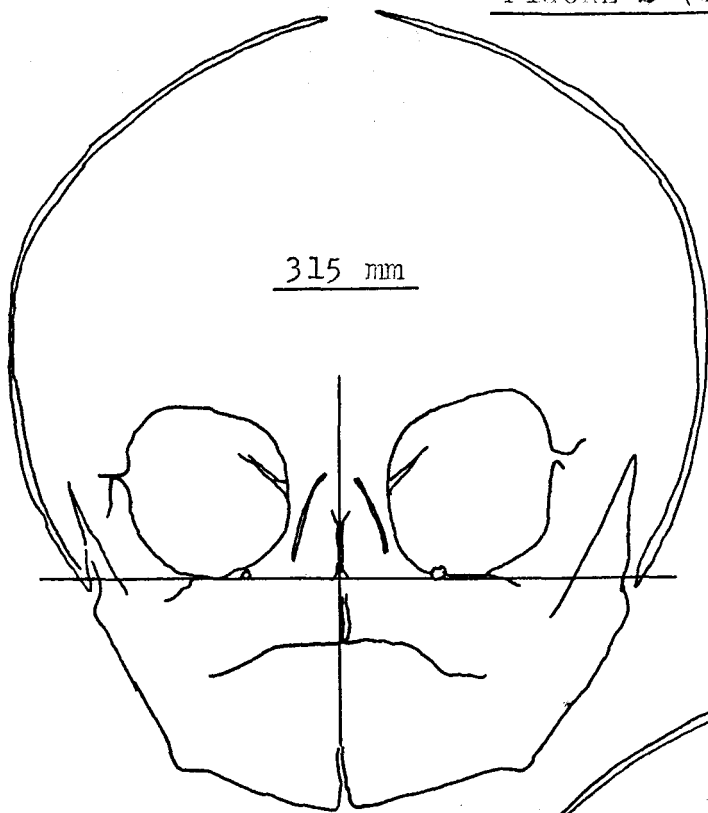
C



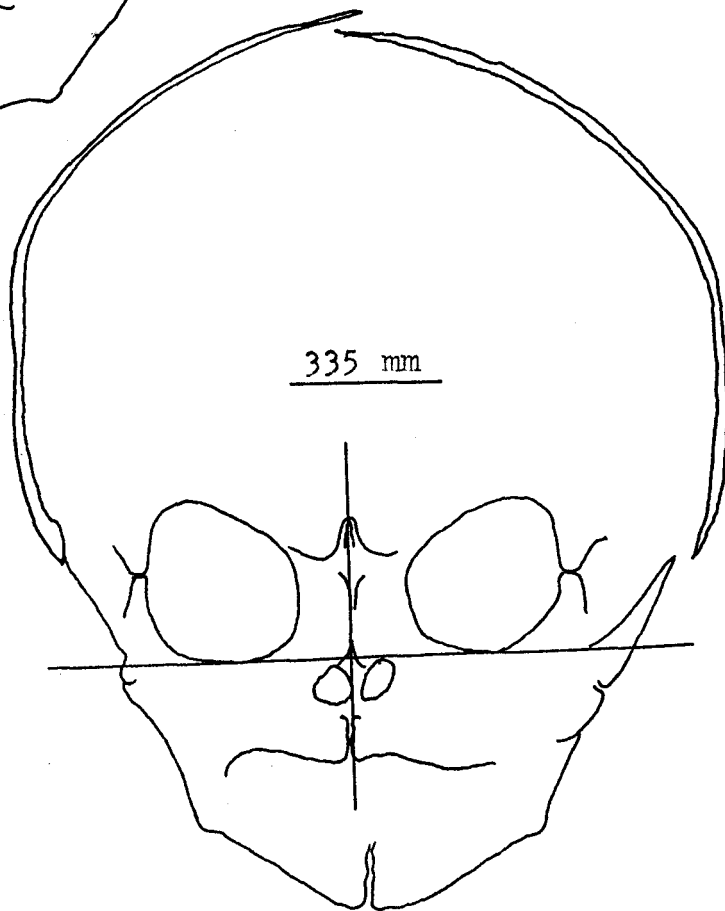
D



E



F



G

CHAPTER V

DISCUSSION

This investigation attempts to define anatomic structures and cephalometric landmarks for future serial study of the growth and development of the human fetal skull as viewed from an oriented posterior-anterior radiogram.

A cephalometer was constructed to simulate as closely as possible the cephalometers used in modern orthodontic practice. The only deviation from this was a reduction in diameter of and distance between the ear rods to accomodate the small skulls. Provisions for turning the sample 90 degrees was provided to facilitate orienting the posterior-anterior view.

Only samples free from distortion, as far as could be determined by both gross and radiographic examination, were used. All fetuses were fresh, non-preserved except for cold storage, therefore eliminating deformation from preservatives such as formalin.

Anatomic as well as cephalometric landmarks were defined in all ages. The earliest ages were extremely small and proved to be a challenge in deciphering.

Identification of the immature anatomic structures seen on a posterior-anterior radiogram was accomplished through the use of several technics which have been described.

Orientation of both lateral and posterior-anterior radiographs of the same specimen helped to give a three-dimension effect, but not as much as had been expected. Structures viewed from the edge, such as the squama of the temporal bone in a posterior-anterior view, were sharp and distinct; but their borders were featheredged, and indistinct in a lateral view.

In the beginning, the position of the mandible was a problem as no standard position could be easily determined. Finally, as experience grew, cotton thread was sewn through the soft tissue of the chin and nose and visual examination of the upper and lower gum pad relationship was used to determine a normal centric. The thread was then adjusted and tied to maintain this relationship while the radiographs were taken. With this procedure, the author feels experience in handling the sample will provide a reasonably consistent position for the mandible. Also, because gonion is close to the condyle as compared to pogonion, gonion placement should change very little because of approximation; as opposed to the relatively large vertical movement of pogonion. When a good maxillo-mandibulo relationship is established, gonion will prove to be a good reference point because it is easily defined in all films.

Only two lines proved to be cephalometrically consistent enough to be used as basic reference points in all ages; 1) a horizontal line tangent to the lower border of the orbits and 2) a vertical line drawn through the nasal septum at a 90 degree angle from the infra-orbital line. Other landmarks were investigated but proved too vague or limited by incomplete development to be consistently reliable.¹⁶

CHAPTER VI

SUMMARY AND CONCLUSION

1. A cephalometer was specially designed to adjust to fetal skulls and maintain orientation in a posterior-anterior direction when pivoted 90 degrees from the lateral projection.
2. Oriented posterior-anterior radiograms of high definition can be obtained with this apparatus.
3. Various anatomic structures can be defined in these radiograms with consistent reliability.
4. Conventional cephalometric tracing procedures can be used to obtain reliable, reproduceable tracings of the human fetus, as viewed in a posterior-anterior radiogram.
5. Conventional cephalometric landmarks are of little value in a posterior-anterior radiograph of a human fetus.
6. Horizontal and vertical base lines were reliably duplicated on these tracings.
 - A. horizontal -- the lower border of the orbits as determined by the infra-orbital rim
 - B. vertical -- midline (as determined by the vomer bone) drawn at a 90 degree angle from the infra-orbital line
7. With these cephalometric base lines, significant numbers of fetal samples can be analyzed to determine direction and rates of growth of the human before birth.

CHAPTER VII

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APPROVAL

This thesis submitted by O. Richard Infield has been read and approved by three members of the Graduate School. The final copies have been examined by the director of the thesis and his signature, which appears below, verifies the fact that any necessary changes have been incorporated, and that the thesis is now given final approval with reference to content, form and mechanical accuracy.

The thesis is therefore accepted in partial fulfillment of the requirements of the degree of Master of Science.

May 11, 1950
DATE

Ronald C. Fitzgerald, B.S., M.S., Ph.D.
SIGNATURE OF ADVISOR