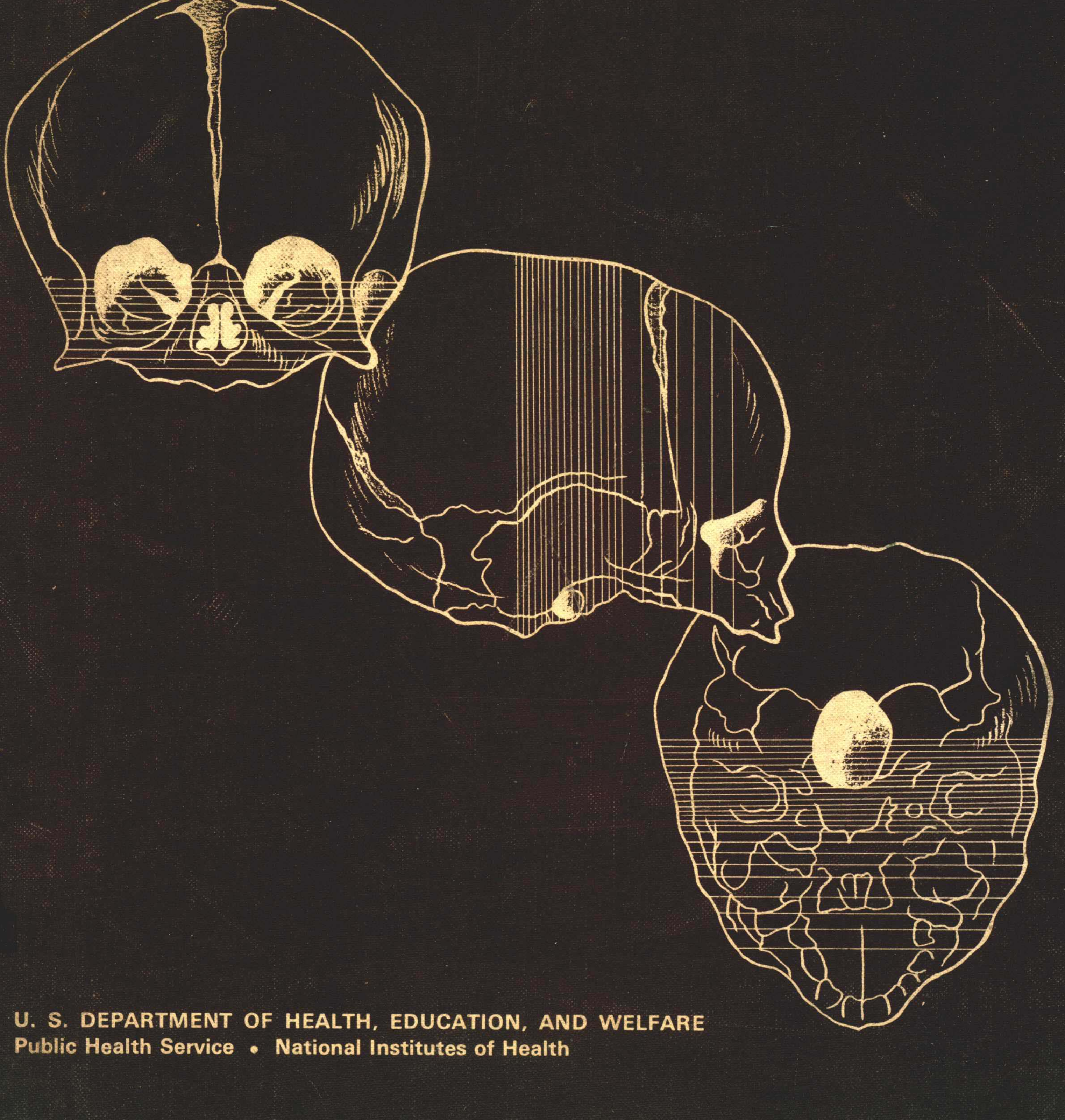
THE CRANIUM OF THE NEWBORN INFANT

AN ATLAS OF TOMOGRAPHY AND ANATOMICAL SECTIONS



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AN ATLAS OF TOMOGRAPHY AND ANATOMICAL SECTIONS

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Preface

This project, sponsored by the National Institute of Dental Research, was generated by the association within the Clinical Center, National Institutes of Health, of Robert H. Pierce, a Clinical Associate in the Diagnostic Radiology Department, of Michael W. Mainen, a Clinical Associate in the National Institute of Dental Research, and James F. Bosma, of the NIDR Section on Oral and Pharyngeal Development. To this association, Robert Pierce brought an interest in tomography acquired as a protege of Galdino E. Valvassori, of the Department of Radiology, University of Illinois Eye and Ear Infirmary. In some respects, this study is a sequel and analogue of *The Interpretation of Tomograms of the Head, An Atlas* by M. L. Daves and E. Loechel (1962), which was also produced intramurally at the National Institutes of Health.

Acknowledgments

Appreciation is expressed to the various individuals and organizations whose assistance has made this project possible. The specimens of infant crania were selected from the collection in the University of Maryland Department of Anatomy, by the arrangement of Frank Figge, and from the collection of the National Biological Laboratory, by arrangement of George Halpin.

The figures and text have been reviewed at considerable effort by Galdino E. Valvassori, of the Department of Radiology, University of Illinois (Chicago) College of Medicine, by Frederick N. Silverman, of the Division of Radiology, Children's Hospital Medical Center, Cincinnati, by Edmund S. Crelin and E. Leon Kier, of the Human Growth and Development Study Unit and the Division of Neuroradiology, Department of Diagnostic Radiology, respectively, Yale University School of Medicine.

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CHAPTER 1

Introduction

The cranium develops as a composite of bones which differ in embryologic origin and in mechanisms and patterns of growth and modulation of form. The BASIOCCIPITAL, EXOCCIPITAL, a portion of the SUPRAOCCIPITAL, the BASISPHENOID, PETROSAL and ETHMOID are preformed in cartilage. Growth of the BASISPHENOID, BASIOCCIPITAL, EXOCCIPITAL and the chondral portion of the SUPRAOCCIPITAL is principally at their cartilaginous synchondroses, until the cartilage is replaced by bone and bony fusion occurs. Thereafter, growth is only at their periosteal margins.

The cartilage skeleton of the branchial arches is the origin of the auditory ossicles and the styloid process.

Most of the cranial bones are membranous in derivation. The squamous elements enclosing the brain case, or calvarium, include the ALISPHENOID, the FRONTAL, the SQUAMOSAL and a portion of the SUPRAOCCIPITAL. These bones ossify peripheralward from one or a few centers within membrane units. Growth continues in irregular distribution, alternating with erosion, at most of their sutural approximations, so that they become interdigitated. They are further modulated in form by apposition or resorption at their inner and outer periosteal surfaces. And, like the rest of the skeleton, their internal trabecular arrangement is continuously adapted to physical stress.

Of the membranous bones of the face, the NASAL and LACRIMAL are initially formed and later shaped in manner like the squamous bones of the calvarium. The MAXILLA, PALATINE and MALAR are formed from multiple ossification centers, but late in fetal life become a single bone. These major facial bones, and the MANDIBLE, undergo extensive growth and modulation of form during fetal and postnatal development.

The external margins of the head, and of its oral and pharyngeal cavities, are smoothly contoured and these contours change subtly during fetal and postnatal development. But the components of the cranium change markedly in structure, in their relative size, in their spatial orientation and in the patterns of sutural approximation. The teeth are also in developmental progression.

Radiography, and tomography in particular, give us strategic information about these sequential developments. The radiographic criteria are multiplied by the differences in skeletal structure. Cartilage is conspicuously radiolucent. The cancellous matrix of ossified bones is less radiopaque than the cortex. The paranasal and paratympanic air cells are lucent, and marginned with radiopaque cortex. But the auditory ossicles and the ANNULUS remain relatively dense and radiopaque. The bony labyrinth, of distinctive non-trabecular bone, and the adjacent bone of the petrous pyramid are distinctively dense. Radiographically, the tooth buds afford a variety of criteria, including the radiodense enamel, the less dense dentin and the denser margin of the crypt.

This multiplicity of radiographic criteria gives opportunity for greater discrimination of skeletal development in the cranium than in the limbs and trunk. But, at the present time, we are still largely dependent upon calibrations of development derived from standardized radiography of dental maturation and skeletal epiphyseal maturation in the limbs and/or the trunk. The variety of skeletal changes in the cranium should be calibrated in relation to these other criteria of development.

Such comparisons are needed to distinguish the relative contribution of systemic factors vis-a-vis local determinants of growth and development in the cranium. The calvarium grows and develops rapidly in fetal life in correlation with the rapid growth of the brain. Criteria taken from the OCCIPITAL, SPHENOID and TEMPORAL composites are particularly relevant to development of the brain stem. The facial skeleton grows and develops in correlation with enlargement of the pharynx and the nasal and oral chambers. The development of the portion of the cranium related to the cervical vertebrae and cervical musculature corresponds in general with that of the skeleton of the trunk.

Parallel evaluation of the cranium and of other parts of the skeleton is, at the present time, the basis for the clinical distinction of generalized skeletal disorders from cranial abnormalities. Dyschondroplasia, for instance, is clinically more familiar in the limbs and trunk than in the cranium. But the dyschondroplasias which result in the cranial distortions described by Crouzon and by Apert occur exclusively or principally in the chondrocranium. Likewise, systemic abnormalities of the bony skeleton, such as nephropathic and hypovitaminotic rickets are better defined outside of the head. But metaphysial, or craniometaphysial, dysplasia (Pyle), a failure of the osteoclastic element of modulation of form, is best detected in the cranium. Likewise, the skeletal correlates of hemolytic and iron deficiency anemias may first be recognized in the cranium. The hyperostosis of hypervitaminosis A and the lytic lesions of Gaucher's disorder may selectivity involve the skull. Neoplastic lesions, such as leukemic infiltrations or the metastases of sarcoma may appear initially in the skull.

The cranium is of particular clinical significance as it evidences regional disorders. These disorders are as varied as the developmental components of the head. The brain is liable to the greatest variety of developmental abnormalities. Some of the skeletal reflections of brain disorders are seemingly simple. For instance, the calvarium expands about a meningeal chamber which is abnormally expanded by hydrocephaly or macrocephaly. Reciprocally, microcephaly is associated with microcranium, selectively involving the calvarium. But the distortions of the cranium associated with certain patterns of brain hypoplasia may be more complex. Thus, in "anencephaly" a bifid and hypoplastic brain is only partially enclosed by a markedly hypoplastic calvarium. But the more caudal skeleton, particularly that of the upper extremities, may be overgrown. Nañagas (1925) interprets this juxtaposition of hyperplasia to abnormal hypoplasia as evidence of the caudalward displacement of the cephalic instigation of growth.

Most of the developmental distortions of the facial portion of the cranium are a part of regional abnormalities as arrhinencephaly, or hypoplasia of the eye, or cleft of the palate and/or lip. These are initiated in embryo, and the mesenchyme generating the skeleton participates in the regional disruption. In this process, the variations of the embryonic neural and epithelial elements are probably determinant. Developmental distortions of the rhinencephalon are associated with severe and peculiar distortions of the facial skeleton. In severe arrhinencephaly, with absence of the olfactory apparatus, the nose is hypoplastic or absent and the face develops in relevance to the eyes, mouth and pharynx. In the circumstance of primary hypoplasia of the eyes, the skeletal orbits are small and abnormally shaped. The skeletal abnormalities of cleft palate and/or cleft lip extend to a variable degree and in variable direction to the nasal, orbital and basilar portions of the cranium, to the mandible and to the upper cervical vertebrae.

Those abnormalities which are associated with motor impairment each influence skeletal development in specific and characteristic manner. In primary disorders of the motor unit, the individual's pattern of muscular hypoplasia and fibrosis is associated with hypoplasia and deformation of the skeleton to which the musculature is attached. Analogous skeletal deformation results if the central neurological lesion results in atony. Other patterns of skeletal deformation result if the neurological lesion results in a spastic form of dyskinesia.

In summary, the heterogenously derived cranium is the site of expression of a variety of skeletal disorders, some of which are restricted to this region. The cranium is also the site of expression of a larger variety of regional abnormalities, primary in brain and/or the peripheral innervation including the nose, eye and ear. More incidentally, certain portions of the cranium may evidence disorders which are principally of the motor system. This heterogeneity must be kept in mind as the clinician selects radiographic procedures to elucidate a particular "congenital abnormality" of the head.

This heterogeneity of patterns of abnormalities involving the cranium is being elucidated by clinical experience. It is appropriate to mention the strategic significance of postmortem radiographic and anatomic studies in the circumstance of death of an infant who has demonstrable abnormality of the cranium. Extensive radiographic studies, followed by anatomical dissection, will advance our understanding of these abnormalities.

CHAPTER 2

Material & Procedures

These demonstrations are of portions of 4 crania selected from 25 late fetal or early infantile specimens. Seven of these specimen crania were obtained from the collection of the Department of Anatomy, University of Maryland School of Medicine, from a racially varied population. Eighteen crania were selected from the large stock of the National Biological Supply Company, which had been obtained from sources of India. The specimens from each of these sources were of unidentified subjects, without information about gestational or postnatal age, details of birth, clinical circumstance of death or measurements of the cadaver. Mandibles were included, but no other portions of the skeleton were available.

But, in common with most specimen infant crania, these had undergone postmortem distortion in form and general dimension. Accordingly, qualitative criteria, rather than measurements, were employed for estimation of developmental status. The crania from the commercial laboratory were prepared in routine manner by manual cleaning of detritus and by the spray application of a thin plastic covering. The crania from the Department of Anatomy were manually cleaned and were, in general, anatomically more complete. In most of the crania, the tympanic membranes were complete or nearly complete. Consistently among these specimen crania, the tympanic membrane, MALLEUS and INCUS were retracted from the position in which they are found in infant cadavers or in most living infants.

Specifically, in approximately a diminishing order of significance, our externally evident criteria of gestational term status were:

In the PETROSAL—The carotid canal is enclosed inferiorly. The fossa of the geniculate ganglion is nearly closed. The subarcuate fossa is partially closed at its orifice. The internal acoustic meatus is approximately 5–5½ mm. deep. The petrosquamosal suture is firmly closed by bony approximation, without fusion in its length in the tegmen.

The anterior and posterior portions of the ANNULUS are approximated; it has extended medialward, along the inferior aspect of the PETROSAL, and lateralward, along the superior and anterior aspect of the external auditory canal.

In the BASISPHENOID, the anterior clinoid processes incompletely approximate the midline. The dorsum sellae and the posterior clinoid processes are entirely chondral. The PTERYGOID is visibly fused or nearly fused with the medial pterygoid process.

In the FRONTAL, the roof of the orbit is continuous. The supraorbital fissure is open within the supraorbital ridge.

In the SQUAMOSAL, the mandibular fossa is only slightly concave.

In the PALATINE, the posterior margin of the bony palate is slightly indented or is straight across the midline; there is no posterior nasal spine.

In the MAXILLA, the length of the infraorbital canal is open to the orbit or, in some specimens, it may be enclosed at its anterior orifice. The anterior nasal spine is a distinct prominence.

In the SUPRAOCCIPITAL, the suture between its chondral and membranous portions is open only in its lateral portion.

The posterior margin of the VOMER approximates the anterior-inferior angle of the BASISPHENOID, immediately adjacent to the rostrum.

Radiological Procedures:

The selected crania, with the upper portion of the calvarium removed, were fixed upon ⅜″ (9½ mm) clear plastic by a layer of red orthodontic wax. The cranium rested on the occipital condyles and the margin of the maxillary alveolar ridge. Variably in individual crania, the inferior margin of the tympanic ring approximated this plane. In this position, a line between "basion" and "anterior nasal spine" parallels the surface of the mount.

The tomograms in the coronal and transverse plane were made on a North American Phillips Polytome. A hypocycloidal pattern of tube and cassette motions was utilized with a standard six second sweep 281 cm in length. The depth of focus with this apparatus is 1.2 mm. The peak kilovoltage and milliamperage varied with the specimen under examination. The coronal tomoradiographic sections of Chapter 4 were made at intervals of 5.0 mm anterior to the posterior clinoid processes and at 1.0 mm more posteriorly, to the middle of the foramen magnum. The transverse sections of Chapter 5 were at 1.0 mm intervals. The most inferior section (Figure 5.6) is through the maxillary teeth, the EXOCCIPITAL and the inferior portion of the pterygoid processes and the inferior portion of the PETROSAL. The most superior section is through the orbitosphenoid, the arcuate eminence of the PETROSAL and the superior portion of the nasal chamber.

The sagittal sections of the otic region skeleton (Chapter 6) were made on a Profexray Gyrotome. The tube and cassette were moved in circular pattern with a 3 second exposure. The kilovoltage and milliamperage were varied according to the specimen. Tomoradiographic sections were made at 1.0 mm intervals.

Anatomical Procedures

Following tomography, the calvarium was removed from the cranium and all periosteum and dura were stripped from the bones. Each tomogram was examined for visible features which were sufficiently discrete to define the plane of the section. In some tomograms, a single anatomical detail sufficed to identify a plane; in others, two or more less defined landmarks were required. When the locations of the tomograms were established, these were marked on full-sized photographs of the skull.

The cranium was coated lightly with wax and fixed in a rectangular wooden box. The anterior portion of the cranium selected for coronal sections was embedded in red acrylic, mixed in thin consistency. The mixture of embedding medium was first poured about the periphery of the cranium and then the orbits and the cranial vault were filled. The mass was extensively vibrated so that all accessible interstices were filled. The selected lines of section, marked at intervals of 5 mm on the cranium, were extended as lines upon the enclosing box. The box, block and cranium were then cut by a band saw.

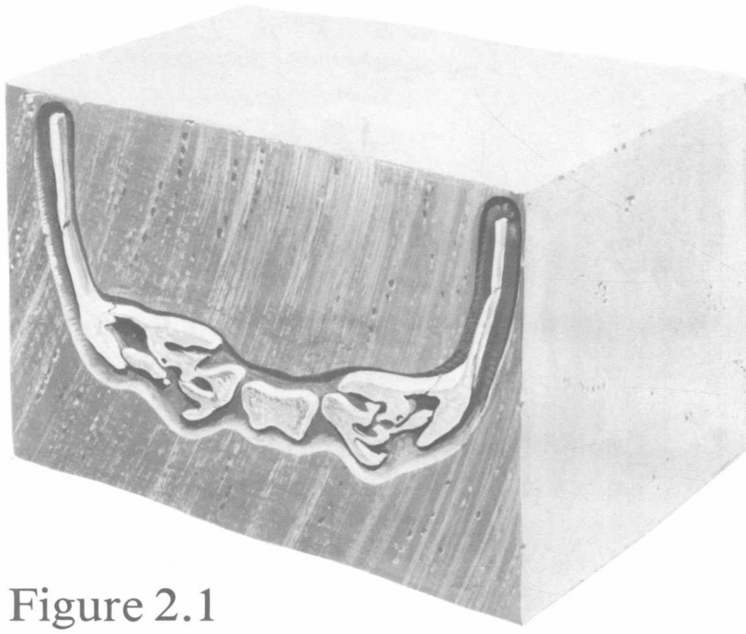


Figure 2.1

Drawing of cranium section embedded in stone. The matrix has been excavated to further expose the specimen.

The portion of this cranium posterior to the posterior clinoid processes was embedded in yellow dental stone. The cranium, in its stone block, was sawn through the posterior portion of foramen magnum. It was then sanded in the coronal plane, in an anteriorward sequence, in 1 mm. gradations. Sanding was done with a motor-driven dental model cutter: a water-cooled rotating abrasive disc which is approximated by the specimen block sliding under manual control on a fixed platform. The stone block provided good mechanical control of the specimen and helped in maintaining stable orientation. As the sanding progressed, the landmarks were sought which identified tomographic sections. The embedding materiel was excavated about the bone on the face of the cut which was to be drawn (See Fig. 2.1). Thus, the anatomical illustrations become somewhat three dimensional, demonstrating the bony anatomy in depth. But this technique of demonstration has resulted in the loss of certain anatomical details, such as the scroll-like portions of the nasal turbinals. The coronal sections of skeleton were prepared and drawn from caudal perspective. The cranium studied in transverse plane was embedded in yellow dental stone. The stone block and the cranium were then sanded in transverse plane, in an inferior-superior sequence. Correspondingly, the successive anatomical illustrations are from inferior perspective.

The crania demonstrated in coronal and in transverse sections were each slightly asymmetrical in relation to the plane of section. These slight asymmetries, estimated at 0.5 to 1.0 mm., were shown in sawn or ground sections and are noted in the comments accompanying the section illustrations. Fortunately, they often demonstrate additional anatomical information.

The cranium selected for sagittal sectional demonstration of the ear area was sawn in the midline and then coronally through the curve of the ALISPHENOID, slightly anterior to the round foramen, and coronally through the EXOCCIPITAL, posterior to the condyloid canal. The block was imbedded in the dental stone, leaving the median section plane slightly exposed. With this plane for orientation, the block and specimen were sanded in a medialward succession, approximating the tomograms at 1. mm intervals, beginning at the head of the MALLEUS and the body of the INCUS.

Relating of Tomographic and Anatomic Sections. The "matching" of radiographic and sawn or sanded anatomic sections offered problems because of the basic differences in the method and anatomic content of demonstration. The radiographic tomograms demonstrate a "slice" or section of significant diameter, with diminishing discrimination of anatomic elements on either side of this. Whereas the anatomic sections are a surface. infinitely thin, except as its margins adjacent to the section are exposed by excavation of the embedding matrix. Thus, relatively lucent structures such as dental crypts or buds, or the various parts of the labyrinth, are often better shown in the tomograms. The sutures which are in cross-wise orientation to the tomographic section are more evident radiographically than in the anatomical section, particularly if the suture is partially fused.

Procedures of Illustrations and Descriptions

The general radiographs and the tomograms were masked at the image margins. They were then logetronically intensified at a variety of discrimination selections and film developing procedures for optimal demonstration of selected details such as foramena, ossicles or elements of the labyrinth within the PETROSAL.

The reference figures of the tomograms consist of line tracings and cut-outs of the radiodense areas in partially opaque overlay sheets.

The drawings of these sections are precisely scaled. In drawing the initial sections, a projection and grid system was employed. Subsequently, the artists depended upon multiple caliper measurements. All sections were drawn in magnification × 2. Drawings of the coronal and sagittal sections, of Chapters 4 and 6 respectively, are printed at this size. Drawings of the transverse sections, of Chapter 5, are printed at ¼ reduction; accordingly, these reproductions are at magnification × 1½.

The *terminology* is that of the Third Edition (1968) of the *Nomina Anatomica* partially adapted toward common vernacular. Bones which are unfused at gestational term are separately designated, using designations which are established in developmental anatomy. Thus, the separate components of the TEMPORAL are named the PETROSAL, SQUAMOSAL and ANNULUS. The OCCIPITAL is composed of the BASIOCCIPITAL, EXOCCIPITAL and SUPRAOCCIPITAL. The SPHENOID consists of the BASISPHENOID, ALISPHENOID, PTERYGOID and, inconstantly, the BONES of BERTIN. The PREMAXILLA is demarcated from the MAXILLA. The INFERIOR TURBINATE is demarcated from the ETHMOID. These separate bones are listed in the Anatomical Index under their general confluence and also singly.

The separate bones are consistently printed in small capitals.

The terms of spatial orientation and direction are interpolated from the mature human, as if the fetus were empirically gifted with the ability to stand in "anatomical position." This usage is incongruous, but it is an empiricism which is essential for effective communication with persons oriented to the anatomy of the mature human.

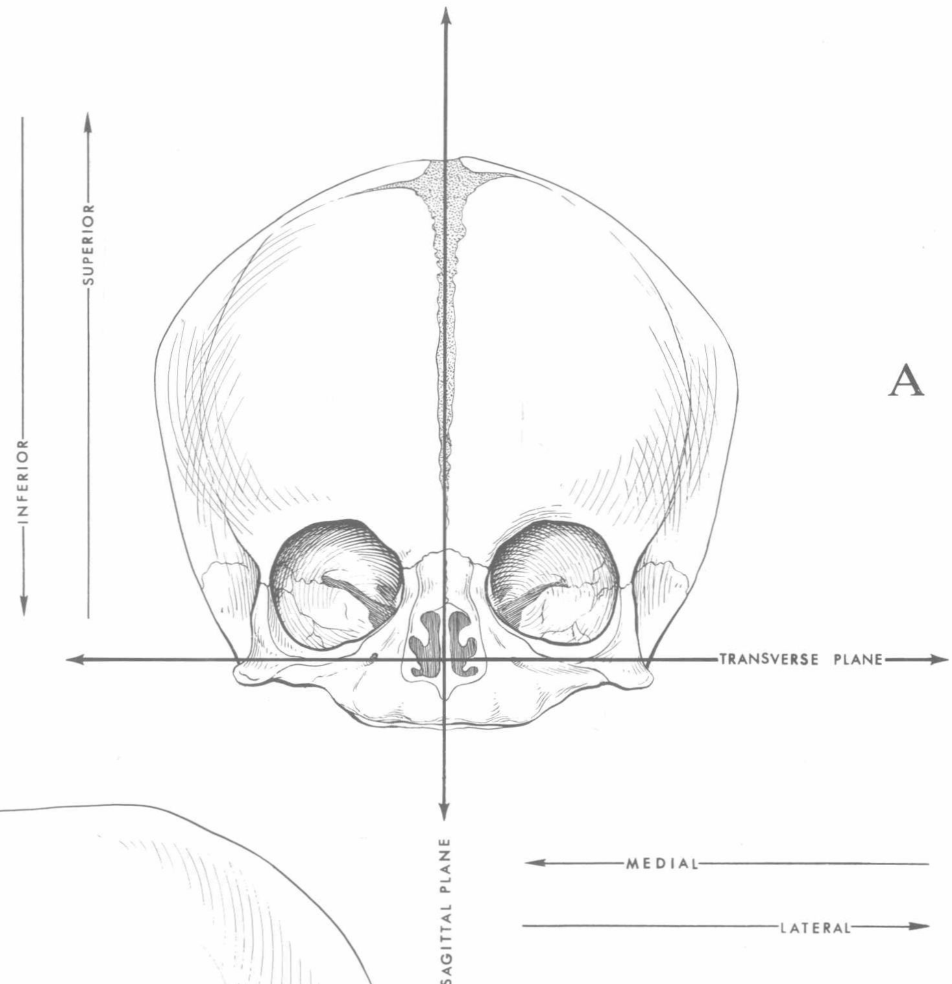
Descriptions of these specimens are in comparison with the anatomical studies of the cranium of the human fetus, term neonate and infant by Crelin (1969), Elias (1971), and in a *Symposium on Development of the Basicranium* (1976). And in comparison with the radiographic descriptions of the cranium of the normal human infant by Caffey (1973), Berkvens (1950), Chusler (1972) and Krogman and Chung (1965).

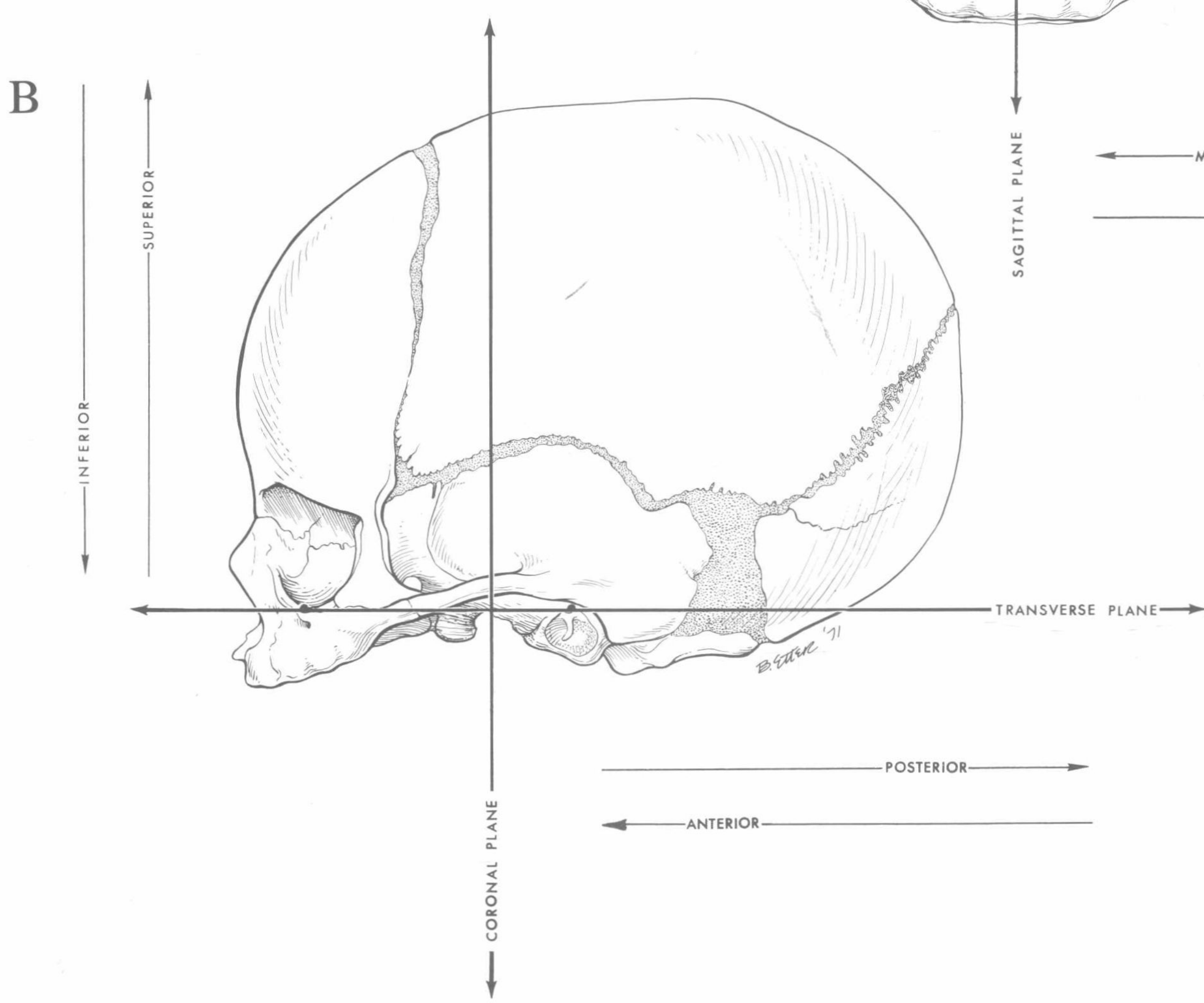
The cranium of the infant has not been described previously in sectional anatomy or in radiographic tomography. But tomography of the adult human cranium, particularly of the temporal area, has been comprehensively illustrated and described by Holvey, Rosenthal and Anson (1945), Petersen and Stoksted (1951), Fischgold, David and Bregeat (1952), Francois and Barrois (1952), Brunner, Petersen and Stoksted (1961), Daves and Loechel (1962), Valvassori (1963), Potter (1971), Binet and Moro (1972), and by Bennett, Brunner and Valvassori (1973).

It is anticipated that the tomographic techniques employes in these studies will be displaced by the techniques of computerized axial tomography which are now becoming available. These new methods, recently reviewed by Ledley *et al* (1974), Gordon *et al* (1975), New and Scott (1975), Robinson (1975), Prewitt (1976) and Webber (1976) effect superior anatomical demonstration with significant economy of radiation. The anatomical portion of this atlas is, thus, a reference in anticipation of these further advances.

Figure 2.2

Schematics of cranium with indications of anatomic directions and planes.
A. In frontal view
B. In lateral view





CHAPTER 3

Drawings of Reference Cranium

This is the reference cranium of our project study. It is estimated at approximately term gestation by most of the criteria noted in Chapter 2.