Diagnostic Neuroradiology

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To our wives

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PREFACE

Neuroradiology has only recently celebrated its golden anniversary. The war of 1898, soon after Roentgen's discovery, saw radiologic methods employed extensively in the localization of foreign bodies, even intracranially. Not until the second decade of the twentieth century, however, were major accomplishments made. Early in this period Schüller, the father of neuroradiology, was at work, and his book of 1912 constituted the first publication of great significance on the subject. During the same period, Forssell and Stenvers also made important contributions to the plain film diagnosis of intracranial disease.

It was just a little more than half a century ago that Luckett and Stewart encountered their famous case of traumatic pneumocephalus, the prelude to Dandy's description of ventriculography and pneumoencephalography. Shortly afterward, Sicard and Forestier devised radiopaque myelography. Some years later Moniz reported his success, by perseverence, with cerebral angiography. In many countries angiography lay dormant, however, for many years until Torkildsen, Kristiansen and Engeset, through Engeset's report of 1944, described a hundred cases in which a water soluble substance was used rather than a colloidal mixture. They also revived Moniz's early method of percutaneous carotid puncture and paved the way for vertebral contrast study. Because of the inferior nature of contrast media available during World War II, the adoption of the angiographic method was retarded even then in many places, particularly in America. During the last fifteen years, angiography has arrived at its appropriate place of importance in diagnostic neuroradiology. Meanwhile, prior to the new angiographic era, many important refinements of pneumographic diagnosis were being worked out by Lysholm, Dyke, Twining, Robertson, Lindgren and others. All physicians involved in any aspect of radiologic or neurologic practice are deeply indebted to the pioneers, only a few of whom are mentioned above.

In recent years neuroradiology has extended greatly in scope. Many young physicians have specialized in clinical neurology and neurosurgery since the war of 1939–1945. Because of wider neurologic service, the demand for correlative roentgen diagnosis has spread into smaller communities. Many radiologists are called upon today to perform special procedures which, in years past, were carried out almost exclusively in neurologic centers.

The scope of neuroradiology has also been extended in depth. More accurate diagnosis of diseases of the central nervous system can now be attained through improved roentgen methods. As more minds devote more time to exploration of this still young subspecialty, many refinements of neuroradiologic diagnosis are evolving. The development is occurring, in part, through increases in knowledge and experience, allowing the radiologist to recognize variations from the normal and to localize abnormal shadows. The store of information being amassed in neurology, neuropathology, neurophysiology, and allied fields makes it possible for the radiologist to identify more frequently the abnormal processes that are found. This increasing knowledge puts greater demands on neuroradiology. The need will grow for radiologists especially trained in the diagnostic methods applicable to neural disease.

Also extending the depth of neuroradiology are the many examinations that currently are referred to as special procedures. Skill in instrumentation is now a requisite for the neuroradiologist, as well as ability in directing the making of films and the rendering of an interpretation. When faults of technique are committed by someone else, misinterpretation often follows. The head must always know what the hands have done. There is a strong trend away from a division of responsibilities, with every indication that this is proving beneficial for the patient.

The scope of neuroradiology now extends in length to both ends of the electromagnetic spectrum and into other media. The use of gamma rays from radioactive isotopes for scanning, and the use of heat waves in thermography, are now well-established procedures that are being incorporated in neuroradiologic clinical practice. The use of ultrasonic waves for echoencephalography also is widely accepted. Radiologists have made many important contributions to the development of these techniques and to other special methods of examination of the central nervous system. It cannot be foretold what future impact electronic devices will have in the diagnosis of neural disorders nor which of the newer procedures will fall within the province of the neuroradiologist. In the future, as in the past, a neuroradiologist with sufficient interest in the newer procedures can develop them to supplement the standard examinations.

Although many important books and monographs concerned with segments of neuroradiology have been published, only a few English language works dealing with the entire field have appeared. We have been led to believe, therefore, that it would be useful to bring together material which might serve as (1) a text for the student, (2) a handbook for those in the graduate study of radiology, and (3) a record of the working principles of neuroradiology found useful by the authors. The resulting volume is obviously incomplete. In the first place, our primary concern was roentgenology, rather than all of radiology. As a result we have not included detailed discussions of scintillation scanning and other newer procedures. Some reference, however, to their current importance is made in the section "Selection of Diagnostic Procedure." Second, even in the limited field of roentgenology the discussion of some subjects is not as detailed as some might like. Certainly no attempt has been made to include all of the controversial views that appear in the literature. Rather, we have tried to deal with the more commonly experienced diagnostic problems, as encountered in our daily practices, and to make available to the profession what we have learned about a variety of conditions. In our discussions of differential diagnosis we have sometimes gone afield, treating secondary subjects at considerable length despite the fact that they do not fit comfortably into the presentation. Third, we have limited our considerations to conditions of neurological importance insofar as possible. Extended descriptions of osseous lesions not primarily of neural significance have been omitted intentionally.

The work is divided into four major categories: (1) "The Skull," (2) "Intracranial Pneumography," (3) "Angiography," and (4) "Diseases of the Spinal Cord." Separately treated are two subjects that do not fit well into any of the four major categories: (1) "Selection of Diagnostic Procedure," and (2) "Head Injuries and Their Complications." The location of the former was chosen because it was felt that medical students and trainees in radiology could profit most from the considerations after exposure to the factual information presented in the first three sections of the work. The subject of trauma and its aftermath obviously spans all of the diagnostic categories.

We have, of course, drawn upon the experience of others as described in their writings and transmitted through personal communications. We have tried, even when only a concept or opinion has been borrowed, to make acknowledgment, and wherever possible to refer to the original work from which data were taken. When proper recognition has not been given, it certainly has not been the intent of the authors to minimize the importance of the works of others who have contributed to the field.

Dr. Ross Golden, who stimulated the undertaking of this work, has wisely pointed out that advancement of radiology is more easily achieved when a climate of cordial interdependence and mutual confidence between clinicians and radiologists pervades a medical institution. Such an atmosphere is exemplified by the Columbia Presbyterian Medical Center and is a particular heritage of the Neurological Institute of New York, from which the major portion of this work stems. The material is drawn from an experience now approaching a score of years during which we have served successively as attending radiologists to the Neurological Institute. In addition, we have been able to go back to the museum material collected by the late Dr. Cornelius G. Dyke, who preceded us in this post. We are most deeply indebted to all of the attending, visiting and house physicians and surgeons who have referred cases to us for radiologic examination, and have made their records so freely available over the years. Dr. H Houston Merritt has unceasingly promoted the development of radiology at the Neurological Institute, and for his professional cooperation and personal interest we would like to take the opportunity to thank him most sincerely.

We would be most ungrateful if we failed to acknowledge with deep appreciation the aid given by the host of individuals concerned with the production of this work. We are deeply indebted to Dr. Laurence L. Robbins who read and criticized the manuscript, and to our associates, Dr. William B. Seaman and Dr. Charles A. Bream, who were helpful in many ways during its preparation. Important contributions have been made by Dr. D. Gordon Potts, Capt. Herbert F. Johnson, Dr. Luther E. Barnhardt, Mrs. Margery W. Westray, and many other individuals who assisted in assembling and checking various portions of the material. Our dedicated secretaries, who typed the manuscript, Mrs. Sallie J. Grenberg and Mrs. Winifred Sowa, deserve special recognition and thanks. Others who have helped are Miss Tod Dee Craig and Miss Adele Spiegler, who made the drawings, and Mr. Armand Diaz, who made almost all of the photographs. We also most sincerely appreciate the cooperation of those of our colleagues who have loaned material better suited for reproduction than that in our own files; individual recognition has been given with the illustrations.

We have been fortunate, indeed, to have The Williams and Wilkins Company undertake publication of this book. Mr. Francis E. Old, his scholarly editorial staff, and his highly skilled engravers and printers have made the final phases of preparation particularly easy for the authors. Mr. Old has been generous in his cooperation and personal attention to the work during its preparation and publication, and for his interest and many courtesies we are most sincerely grateful.

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THE SKULL

Skull Radiography

Radiologic examination of the skull is an essential part of any investigation of patients suffering from neurologic conditions; its importance cannot be overemphasized. The examination should be thorough and geared to the particular problem; the films should be of the highest technical quality. At times special types of plain film examinations are required, such as laminagraphy. When the patient's history does not point to any specific area that requires special examination, the "routine views" are taken. These vary somewhat, depending on individual preferences, but certain basic films are always made. In dealing with any spherical object such as the skull, it is necessary to view the subject from more than one side. Because in radiographs a composite depiction of the right and left or front and back of the skull is obtained, at least right angle views must be made. Many prefer to take both right and left lateral views and posteroanterior and anteroposterior views in every instance. It is our custom routinely to take a single stereoscopic lateral view which permits us to have a three-dimensional view in every case without any additional expense. We consider it essential to obtain at least one stereoscopic lateral view because this view is helpful in detecting intracranial calcifications which might be obscured by the bones, in determining the position of an intracranial shadow, in defining the side where a given density is in relation to the bones, and in clarifying the relationship of the anterior clinoid processes, among other uses. This cannot be done when only right and left lateral views are made. For instance, it is not possible to tell from a lateral view which is the right and which is the left clinoid process, and whether a density not

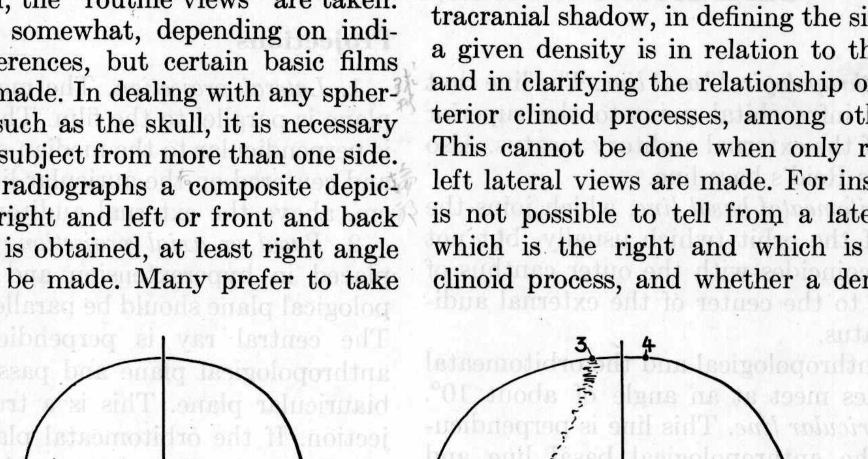

Fig. 1.—Reference Lines and Planes Used in Radiography of the Skull

(1) Infraorbital point. (2) nasion. (3) bregma. (4) vertex. (5) lambda. (6) inion. (7a) center of the external auditory canal or axis of the external auditory meatus. (7b) superior border of the meatus. (8) superior border of the orbit. (9) center of the orbit. (10) pterion. (11) asterion. (12) lowest point of the occiput. (13) mastoid tip. (14) glabella.

(A) The anthropologic basal line on lateral view; the infraorbital line on anteroposterior view. (B) the interorbital or interpupillary line. (C) the superior horizontal line. (D) the orbitomeatal basal line. (E) the auricular line.

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seen in the frontal views is to the right or to the left of the midline. On the other hand, in certain instances both lateral views are highly desirable, as in the case of suspected fractures, in dealing with young children, and in special clinical situations in which satisfactory stereoscopic films cannot be obtained. In the posteroanterior projection two films are usually made; one is the *straight posteroanterior view*, and the other is the *inclined posteroanterior view* (fig. 26). The third film in frontal projection is the *half axial view* (formerly called cerebellar, occipital, or Towne view) which may be made in the anteroposterior or posteroanterior projection.

The terminology and the reference lines or planes used throughout this text are in accordance with the recommendations of the International Commission on Neuroradiology of the World Federation of Neurology. Great confusion has existed up to the present in the methods used by the various authors in obtaining what are essentially the same results. This has brought with it a great variety of eponyms for the designation of the same views or minor variations thereof. Figure 1 represents the various reference lines and planes recommended by the Commission.

DEFINITIONS OF LINES, PLANES AND PROJECTIONS

Lines

1. *Anthropological basal line.* The line that joins the infraorbital point to the superior border of the external auditory meatus. Also known as Reid's base line.

2. *Orbitomeatal basal line,* which joins the center of the orbit (which usually, but not always, coincides with the outer canthus of the eye) to the center of the external auditory meatus.

The anthropological and the orbitomeatal basal lines meet at an angle of about 10°.

3. *Auricular line.* This line is perpendicular to the anthropological basal line and passes through the external auditory meatus.

4. *Interorbital or interpupillary line.* The line that joins the center of the two orbits or the two pupils. It is perpendicular to the median-sagittal plane.

5. *Infraorbital line,* which joins the two infraorbital points.

Planes

1. *Median sagittal plane.* The plane that divides the skull symmetrically in half.

2. *Horizontal plane of Frankfurt.* This plane contains the bilateral anthropological basal lines (anthropological plane).

3. *Orbitomeatal plane.* This plane contains the bilateral orbitomeatal basal lines.

4. *Frontal biauricular plane.* This plane is perpendicular to the horizontal plane of Frankfurt and passes through the center of the two external auditory meatuses.

Projections

1. *Lateral projection.* The median-sagittal plane is parallel to the film. The central ray is perpendicular to the median-sagittal plane and centered on the auricular line, 3.0 or 4.0 cm. above the external auditory meatus.

2. *Basal or axial projection.* The head is placed in hyperextension and the anthropological plane should be parallel to the film. The central ray is perpendicular to the anthropological plane and passes along the biauricular plane. This is a true axial projection. If the orbitomeatal plane is placed parallel to the film, the central ray must be angled 10 to 15° dorsorostrally.

3. *Subaxial projection.* The orbitomeatal plane is parallel to the film and the central ray is perpendicular to the orbitomeatal plane.

4. *Straight posteroanterior projection.* The orbitomeatal plane is perpendicular to the film; usually the forehead and nose touch the film; the median-sagittal plane is perpendicular to the film. The central ray is directed perpendicular to the film. The point of exit of the central ray is the nasion.

5. *Inclined posteroanterior projection.* Same position of the head as above, but the tube is angled 15° craniocaudally to form an angle of 15° with the orbitomeatal line (or about 25° to the anthropological basal line). The point of exit of the central ray is at the

nasion. This projection resembles the Caldwell's view.

6. *Anteroposterior half axial projection.* The head rests on the occiput. The median-sagittal plane is perpendicular to the film. The orbitomeatal plane is perpendicular to the film and the central ray makes an angle of 25 to 30° craniocaudally to the plane. If the anthropological plane is perpendicular to the film, the central ray makes an angle of 35 to 40° craniocaudally. The central ray passes through the external auditory meatus and through the median-sagittal plane.

7. *Posteroanterior half axial projection.* The orbitomeatal line is perpendicular to the film; the sagittal plane is perpendicular to the film; the tube is angled 25 to 30° caudocranially.

8. *Straight anteroposterior projection.* The same as the straight posteroanterior projection but with the occiput in contact with the film. The orbitomeatal line is perpendicular to the film; the central ray is parallel to the orbitomeatal line and is centered to the nasion.

9. *Inclined anteroposterior projection.* The same as the posteroanterior inclined projection but with the occiput in contact with the film. To obtain the same results, the tube is angled 15° caudocranially if the orbitomeatal line is perpendicular to the film; the central ray is centered to the nasion.

10. *Occipitozygomatic projection* (*Stenvers projection*). The face is rotated 45° to the opposite side of that being radiographed, the region of the zygoma is in contact with the film, the orbitomeatal line is perpendicular to the film. The central ray is angled 12° caudocranially and passes through the plane of the external auditory meatus.

The *optic foramen view* is also an occipitozygomatic projection but the tube is angled caudally about 15°. In a correctly positioned optic foramen view this structure is projected over the lower outer quadrant of the orbit. The exact position and angulation cannot be standardized because of great individual variability in skull shape and changes occurring with growth.

In patients who present special problems such as visual difficulties, diminished hearing, and involvement of cranial nerves, other views are necessary. The special views may be those of the optic foramina, the petrous pyramids, or the base of the skull. Films made in other projections, such as oblique views of the mastoid and views customarily employed in the examination of the sinuses, are also taken in some cases.

Without a thorough knowledge of the anatomy, it is not possible to make a proper interpretation of many of the shadows that are seen on the films as a result of all manners of distortions and projections that occur in x-ray examinations. In addition, considerable variation exists from patient to patient in the configuration of the various structures, in fact, *variation is the rule*. No anatomist, before the age of x-rays, was ever able to accumulate in a lifetime as many variations of the skull as are possible for the average interested radiologist who sees many thousands of skulls in just a few years.

In the following pages we will attempt to correlate the anatomy of the skull with that which is seen on the radiographs and to a limited extent to make specific comments about technique. In order to obtain the maximum amount of information, the radiographs should be of good quality. Films that are slightly overpenetrated are to be preferred in examining the skull because small but important calcium deposits in the brain could easily go undetected on lighter films, particularly in patients who have relatively thick cranial bones.

Anatomy

The skull is divided into two parts: (1) the *cranium,* which contains and protects the brain; and (2) the *skeleton of the face*. In the description to follow, the skeleton of the face will not be dealt with separately except for those portions that are near the base of the skull, to which reference must be made frequently.

LATERAL PROJECTION

A straight lateral view of the skull is made as described above. Another radiograph is immediately made without moving the head of the patient, after shifting the tube cephalad for a distance of 2.5 to 4 inches, depending on the distance between the tube and the film used to take the radiograph. The longer the distance between tube and film is, the longer the shift of the tube should be to obtain a good stereoscopic image. The tube shift used to take the stereoscopic film causes a slight separation of the floors of the anterior and middle fossae which is often advantageous. The lateral view has an appearance which simulates a sagittal section of the skull (fig. 2). A lateral view taken without turning the patient's head, usually made in the sitting position, is preferable.

In studying the lateral view of the skull, a method should be developed so that all of the anatomical structures are examined in an orderly fashion. The descriptions that follow will contain the usual sequence that has been our habit for many years. (1) Size and shape of the cranium. (2) Thickness and density of the bones. (3) The sutures. (4) The vascular markings. (5) The structures along the base. (6) The cranial cavity.

Size and Shape

Considerable variation exists in the size and shape of the skull of different individuals. Rather than to determine the absolute size, it is often more important to compare the approximate area occupied by the cranium with that occupied by the facial bones. The area occupied by the face is approximately half of the area of the cranium in an adult. In children, the facial area occupies less than 50 per cent that of the cranium, and the younger the child, the smaller the face is in relation to it. A skull that is longer than average is usually referred to as *dolichocephalic*; one that is shorter and broader than average is called *brachycephalic*; and one that is average in its relation between the length and the width is called *mesaticephalic*. These terms refer to the *cephalic index* obtained by the formula breadth × 100/length. A mesaticephalic skull has a cephalic index of 75 to 85. Over 85 is brachycephalic. Individuals with a dolichocephalic type of skull usually have a relatively shorter vertical diameter as measured from the basion to the bregma. On the other hand, those with a brachycephalic skull probably would have a greater vertical diameter. It is important to appreciate the shape of the skull when trying to estimate the relative positions of certain structures of the brain such as the pineal, the anterior cerebral artery, the deep cerebral veins, and the lateral ventricles. It is good practice, therefore, to pay attention to the cranial shape in every instance in order to develop a mental picture of the probable shape of the brain that would adapt to each skull. Such estimation must be made in every instance when one is trying to determine the correct position of the pineal calcification in the lateral projection. For further details see under "Pineal Localization," page 1.27.

Thickness and Density of the Bones

Great variations exist in the thickness of the bones of the *cranium* (also called calvaria and vault). On the average, the bones are thicker in the negro than in the white races, but this is by no means an infallible rule. Certain areas of the calvaria have a tendency to be thinner than others; a thin area is usually present in the frontoparietal region in the neighborhood of the coronal suture, and another, inferiorly above the roofs of the orbit. A thin area is usually present above the internal occipital protuberance. The most consistently radiolucent area of the skull is the temporal region, sometimes extremely so, because the temporal squamosa is usually thin. There is sometimes a band of increased density forming an arc at the upper portion of the temporal radiolucent area which represents perisutural density at the suture between the temporal squama and the parietal bone.

Convolutional markings. In addition to the normal areas of decreased density mentioned above, irregular areas of diminished density, called *convolutional impressions* or *digital markings*, are often seen spread

FIG. 2.—NORMAL LATERAL VIEW OF SKULL

The picture illustrates the normal appearance of the sutures and vascular markings as well as the normal appearance of the sella turcica and other basal structures. The middle meningeal channels are well shown and symmetrical (*arrows*) There are diploic venous channels in the frontal region which have their typical slightly irregular appearance. The appearance of the base of the skull is similar to that seen in Fig. 16. The clivus (*arrows*) is well shown, as is the lower margin of the foramen magnum (basion). The posterior margin of the foramen magnum (opisthion) can be easily found by following the line of the anterior margin of the posterior arch of the atlas upward and backward (*posterior arrow*).

throughout the bones of the skull. They represent depressions on the inner table of the skull undoubtedly related to pulsations of the brain and to the convolutions, although the depressions do not have the exact shape of the gyri of the brain. However, they must be related to the fact that there is a smaller cushion of cerebrospinal fluid over the convolutions than over the sulci and, therefore, pulsations of the convolutions would be transmitted readily to the inner table of the skull. For this reason, convolutional markings are frequently found in children, who have growing brains, but are less commonly found in adults. Convolutional markings tend to disappear after 12 or 13 years of age but are often found in young adults, particularly in females with relatively thin cranial bones. Sometimes the convolutional markings are not seen because the films are light, but if a darker film is made, at least some of them are seen. This is partly

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