Computerized x-ray scanning of the brain

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Computerized scanning of the brain is a new diagnostic x-ray method that utilizes modern electronic and computer technology for the measurement of the transmission of x-ray photons through tissue. The cranium is scanned in successive layers by a narrow beam of x-rays in such a way that the transmission of x-ray photons across a particular slice can be measured, and by means of a computer and a suitable algorithm used to construct a detailed differential picture of the internal structure and tissues of the brain.

KEY WORDS · brain scan · x-ray photons · computer · brain layers · intracranial differential diagnosis

INVESTIGATORS in any field inherit knowledge gathered by those who have gone before, and in this respect, although it is but 3 years short of the tercentenary of the death of Dr. Thomas Willis on November 11, 1675, we are still indebted to him. In this context, it is interesting to note that in 1672, although Wilhelm Konrad von Roentgen's discovery of x-rays was still more than two centuries in the future, a contemporary man of science, Isaac Newton, was describing his findings concerning the interaction of light with matter!

Thomas Willis may be described as the father of neurology. He coined the word "neurology" and was the first to make a systematic survey of the anatomy of the brain. It is therefore appropriate that this lecture should deal with a new method of looking at the anatomy of the brain with minimal inconvenience to the patient, without trauma, and with no risk of complication.

Conventional x-ray systems, the basic elements of which have remained largely limited by their inability to differentiate unchanged for more than 70 years, are between tissues of nearly similar density; hence, we need many and varied contrast radiological examinations.

The idea of matrix representation to visualize inaccessible structures has been used in fields as diverse as electron microscopy, radio-astronomy, and radioisotope brain scanning. In January, 1961, Oldendorf, a practicing neurologist, described an experimental system which, in theory, he thought ought to be able to produce a cross-sectional display of "radio-density discontinuities" within the cranium. Unfortunately, the idea was not developed and remained in abeyance until G. N. Hounsfield, using x-rays, independently developed a usable diagnostic system (Fig. 1).

Description of the Scanner

Design

With the use of a suitably designed scanning gantry, a continuously operating x-ray tube, and a narrow collimated x-ray beam, the transmission of x-ray photons across a slice of tissue may be measured by
a system of crystal detectors in such a way that 28,000 readings are obtained. The x-ray tube is made to perform a linear scanning motion in the plane of the slice of tissue being examined.

A light interruption arrangement limits the detector system to 160 equally spaced readings in each linear scanning motion. The whole gantry then notches around 1°, and the linear scanning motion is repeated in the reverse direction and so on until an arc of 180° has been completed (Fig. 2). The results so obtained form the basis of 28,800 simultaneous equations that are

Fig. 1. Block diagram of the brain scanning system.

Fig. 2. Scanning sequence diagram showing the x-ray tube A with its collimated beam and equally collimated detector system B, mounted in a common frame. The diagram shows the directions of the scanning motions of the x-ray tube in the common frame carrying the detectors in exact opposition, the irradiation of the slice under examination and how the system notches around 1° at a time after every linear scan.
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solved by a computer. The solutions are transformed into absorption algorithm coefficients, and by means of a suitable logarithm related and fitted to their correct cells in a matrix of chosen size.

The initial laboratory bench experiments were made on various biological specimens, which included bottled pathological specimens of human brain (Fig. 3), fresh ox brains, and human body fluids such as blood and cerebrospinal fluid (CSF). The results of these experiments were sufficiently encouraging to build a prototype apparatus for clinical use (Fig. 4).

Fig. 3. Experimental scan made of a bottled transverse section of brain, showing a large tumor involving the third ventricle. The cortex does not show, but the pattern of the white matter is clearly seen. The white spots on the cut surface of the tumor correspond to hemorrhages (arrows).

Fig. 4. Left: Photograph of patient lying on the hydraulic lift table before being put into the machine. The scanning gantry is at the head of the table. Right: Patient in the machine with the gantry moving around the head. The control console and the printer for the paper printout are in the immediate foreground.
Fig. 5. Line diagram illustrating the two contiguous slices examined in each scan. This is achieved by collimating the input to two crystal detectors mounted side by side so that each looks at exactly half the slice being irradiated.

**Operation of Scanner**

The operation of this apparatus and the results obtained from it form the subject matter of this lecture. The apparatus is designed to examine the cranium in a series of thin, contiguous slices, each made in the transverse axial plane (Fig. 5); the slice may be either 2.6 or 1.6 cm thick. The paired, similarly collimated crystal detec-

look at one half of the total slice thickness, tors, mounted in the common frame in exact opposition to the x-ray beam, will therefore i.e., 1.3 or 0.8 cm, depending on the size of the diaphragm used to limit the input, and each scan will produce two contiguous pictures. The results obtained from scanning the head are stored, computed, and then made available from a magnetic disc to construct a picture on a cathode ray tube display (Fig. 6). The numerical results relating to each cell in the matrix are made available in a paper printout.

The operation of the apparatus is simple, but since a continuously operating system is

Fig. 6. Display unit showing the cathode ray tube picture and the various controls for picture quality and for measuring tissue density range.
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FIG. 8. The patient's head has been placed in the cap which has then been allowed to shrink slowly onto the scalp, eliminating any air gap.

FIG. 10. The white tape has the levels of the orbitomeatal line and the first scan marked on it.

being used to collect data in numerical form, radiographers or technicians must become versed in some of the ways in which the scanner differs from more conventional equipment. These are summarized below.

Warm-Up of X-Ray Tube. The x-ray tube is continuously operating (fixed anode, oil-cooled) and requires a fairly lengthy warming up procedure. This is similar to that followed with x-ray therapy tubes.

Positioning the Patient's Head. The patient's head must be located in a water-filled perspex box, the front side of which consists of a rubber diaphragm that can be drawn in to form a cap by reducing the water pressure in the box (Fig. 7).

Once the patient's head has been correctly positioned, the rubber diaphragm (cap) is allowed to shrink slowly onto the scalp, eliminating the air gap between the scalp and the rubber diaphragm (Fig. 8). The water-filled box and the rubber diaphragm serve a dual purpose. The elimination of an air gap and the pressure of water around the head ensure that the x-ray beam is transmitted through a homogeneous medium, making the results more accurate and simplifying the calculations. A plastic cone fixed to a ring behind the diaphragm enables the head to be held firmly yet comfortably in the box (Fig. 9).

A simple measuring system is used to locate the level of any particular scan. The orbitomeatal line is an easily identifiable baseline, and the measurement of levels to be scanned is made from it. A strip of white tape is fixed to the scalp in front of the ear and carried over to the other side in front of the vertex. The levels to be scanned are then marked on the tape (Fig. 10), and, once the head has been located in the box, alignment of each successive scan (slice) with the center of the x-ray beam is achieved by reading off the level marked on the tape with a scale on the side of the head cone (Fig. 9) and then adjusting a marker to the same reading on another scale attached to the side of the gantry stand. This is done by a simple worm-screw arrangement that moves the whole head-box assembly into or out of the scanner; the box in turn is linked to the table top.
Setting up the Computer. The technician must set up the computer and operate a control console that starts the reciprocating and rotating movements of the mechanical scanner.

Operating the Viewer. The technician needs to operate a viewer console after a picture has been processed. In practice, by using a slice width of 1.3 cm, a series of four complete scans will usually provide a sufficiently comprehensive coverage of the cranium. Occasionally, five scans may be necessary, and if a 0.8 cm slice width is used, the number of scans required to provide the same coverage will be correspondingly greater. Once a scan has been started, the patient is required to remain quite still for approximately 4½ minutes. This is the time required for the gantry to notch around 180 times and for the x-ray tube to make 180 linear scanning motions.

Results and Interpretation

Normal Scan

The pictures obtained from each scan are made up of elements, each of which represents a cell in the chosen matrix. The representation is that of a slice made in the transverse axial plane and must be viewed as if the cranial contents at a particular level were being looked at from above. With the serial number at the top of the picture the viewer is correctly oriented as to front and back, left and right side.

The examination is both quantitative and qualitative. The paper printout of the calculated absorption coefficients is presented in a format that corresponds roughly to the shape of the slice. This enables the numerical values in any particular structure to be located easily (Fig. 11). The values that are printed vary according to the density of the tissues in the volume represented by the matrix cell. The volume of each cell is determined by the slice thickness and the size of the matrix. Using a slice thickness of 1.3 cm and an 80 × 80 matrix, the dimensions of each cube of tissue would be 3 × 3 × 13 mm³, i.e., 117 mm³.

The cathode ray tube picture is an intensity display based on the relative densities of different tissue structures (Fig. 12). To allow tissue density values to be
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Fig. 12. Polaroid picture of a scan made at 4.0 cm. The tissues exhibiting the highest density are shown as peak white areas, while tissues of lowest density are shown as black areas. The subarachnoid space, the interhemispherical fissure, the difference between cortex and white matter, the lateral ventricles, the septum pellucidum, the third ventricle, and calcified pineal body are major features that are easily defined.

compared with water, a convenient scale has been chosen that allows a range of 1000 units between air at one end and bone at the other. Water lies at the center at +500, so that by subtracting 500 from all values the scale varies from −500 for air through water at the midpoint of zero to a value slightly in excess of +500 for compact bone. For an operating kilovoltage of 120 kV, these units can be converted to absolute absorption values by adding 500 and multiplying the sum by 0.19/500, i.e., water with a scale value of zero becomes 0.19 and compact bone at +500 becomes 0.4.

With the absorption coefficients of other tissues similarly adjusted for the same operating kilovoltage, the scale varies from values slightly in excess of +500 for compact bone to −500 for air in the paranasal sinuses, mastoid air cells, or for air trapped around the scalp. The most dense tissue normally encountered is compact bone and is displayed as peak white on the cathode ray tube display. The CSF has a value of +1 and is displayed as black. Most of the soft intracranial tissues fall into a comparatively narrow density range (0 to +20) above that of the CSF and are displayed as shades of gray, lightening toward white with increasing density.

Since the absorption coefficients are

Fig. 13. Relationship of scans to sections through normal brain: brain sections are 1.0 thick and were made at 3.0 cm (upper), 4.0 cm (center), and 7.0 cm (lower) above the floor of the temporal fossa. Scans made at comparable levels are shown with each section. The major features defined in the upper and center scans are the subarachnoid space, the cortex and white matter, the Sylvian fissures, third ventricle, lateral ventricles, septum pellucidum. In the lower section, the cerebral sulci are clearly defined.
measured to an accuracy of 0.5%, the method is able to detect and register small differences in tissue density. The cerebral cortex is appreciably more dense than the white matter. Density differences are also registered in the deep complex structures of the corpus striatum. In some scans, the inwardly convex band of the internal capsule may be made out (Fig. 13).

Comparison of the cathode ray tube picture with the printout shows that the black spaces filled with CSF are shown as groups of low value absorption coefficients with the lowest numbers at or near the center. Volumes near the periphery of a fluid-filled space may include the tissue boundaries. The absorption coefficients will therefore be higher, depending on the relative proportions of tissue and fluid in each small volume.

The values of the absorption coefficients for the cerebral cortex vary between +17 and +23, and from +12 to +16 for white matter. Fluid-filled spaces vary from zero to values as high as +7 or +8 at the boundaries. Fluid blood has a value of about +7 and the values of tissues containing calcium, i.e., the pineal body and choroid plexuses, will depend on the amount of calcium present or whether it is aggregated. The values may vary from +20 to as high as +100 or more. The amount of calcium may be insufficient to show up in ordinary skull radiographs, but with the greatly increased sensitivity of computerized scanning, the pineal body and other structures containing calcium will show as a white area.

Ordinarily, the density variation of normal tissues is confined to values within the 4% to 5% range above zero. The picture brightness and contrast can be adjusted within this small range from peak white to full black, i.e., in a normal scan, the picture brightness can be adjusted so that the cerebral cortex will show as a thin white band while the deeper white matter will be shown in varying shades of gray. The ventricles and other fluid-filled spaces will show up as black areas.

Figure 13 shows horizontal sections made through a normal brain removed at autopsy. The sections that are 1.0 cm thick were made at 3.0, 4.0, and 7.0 cm, and are shown next to computerized scans made at similar levels. Some of the features that are defined include the difference between gray and white matter, the Sylvian fissures, the interhemispherical fissure, the lateral ventricles, the third ventricle, the calcified pineal body, and choroid plexuses. Sections that pass through the posterior fossa may show the brain stem, fourth ventricle, the pontine and interpeduncular cisterns, and the cisterns of the cerebellopontine angles (Fig. 14). The thin, low density band, which is seen immediately beneath the compact bone of the inner table in part, represents subarachnoid space, but some of the scattered negative values are without doubt due to computer overswing, arising from the abrupt density drop from compact bone to CSF.

Abnormal Scan

In neurological practice, the common lesions that require identification are cerebral neoplasms of all varieties, hematomas, infarctions, and infections. To this list must be added cerebral edema, which often accompanies these lesions and complicates...
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Structures are identified and their shape, size, and position defined. Changes in tissue density are then looked for. Usually a space-occupying lesion will produce a characteristic displacement or deformity of some part of the ventricular system, but for precise identification, the extent of tissue change needs to be defined.

Tissue abnormalities may be divided into three large groups, according to the density alterations they exhibit in the scan pictures:

**Group 1.** Lesions with an average density higher than that of normal tissue.

**Group 2.** Lesions with an average density lower than that of the surrounding normal tissue.

**Group 3.** Lesions with the same density as normal tissue.

1. Calcium is an important factor contributing to the higher average density of a lesion. Calcification may occur in the form of calcospherites, psammoma bodies, or aggregates in a variety of different lesions (Figs. 15 left and 16).

Meningiomas, low-grade astrocytomas, oligodendrogliomas, and ependymomas are examples of neoplasms that may show up as "white areas" because of their high tissue density. Calcium aggregates in lesions such as angiomas, the walls of large aneurysms, craniopharyngiomas, degenerations, and indolent infective disease may raise the average tissue density sufficiently to be shown in scans passing through the affected area.

In intracranial hemorrhages of all types, once clotting has occurred, serum is absorbed and the concentrated blood constituents then have a much higher average density (+28) than normal brain. Hemoglobin and calcium ions play an important part in this increase of average density. This enables any hematoma to be easily distinguished. Primary intracranial hemorrhages are seen in a hitherto unobtainable perspective. From a surgical point of view, the demonstration of a hematoma, its size, relationship to deep structures, or the point of nearest approach to the surface of the brain or the extent of surrounding edema may be very valuable (Fig. 17). In subarachnoid hemorrhage the method may

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**Fig. 15.** Scans of an intraventricular meningioma. **Upper:** The tumor is a well-defined area of slightly increased density in the right trigone. Note the displacement of the lateral ventricles. Histology: fibroblastic meningioma. **Lower:** Scans made 5 minutes after the intravenous injection of 20 ml of Conray 420.

**Fig. 16.** Scans of a cystic calcified left frontal oligodendroglioma. The cyst is of low density and is the well-defined black area in the left frontal lobe. The calcium aggregates are shown as peak white areas. Note the displacement and distortion of the ventricular system. Histology: oligodendroglioma.
be used to locate a small hematoma. Where aneurysms are multiple and in the absence of local vessel spasm or displacements, this may be a valuable means of identifying or confirming which aneurysm has in fact ruptured.

In craniocerebral trauma, computerized scanning provides an easy method of distinguishing between extradural, subdural, or intracerebral hematoma and cerebral edema resulting from brain damage (Figs. 18 and 19).

Group 2. Diminished tissue density, on the other hand, may arise out of a more varied number of pathological conditions. The breakdown of cell structure in infarctions, infections, massive coagulative necrosis in malignant tumors, macroscopic and microscopic cyst formation, degenerative alterations of various kinds, collections of fluid and edema are some of the main changes that will reduce tissue density and are observed as darker areas in the scan pictures. Since the average tissue density is being measured, it is not surprising that no distinctive pattern has yet emerged from our studies of the numerical values of absorption coefficients in low density lesions. It should, however, be possible in the majority of cases to distinguish tumors from degenerative and other non-neoplastic lesions. The pattern of tissue involvement, the tendency to necrosis and cyst formation in malignant tumors, and the displacement and distortion of identifiable structures such as the ventricular system and pineal body may aid in identifying the nature of the abnormality (Fig. 20).

Cerebral metastases may be identified by their multiplicity (Fig. 21). They are often accompanied by a disproportionate amount of edema, and in some cases the extent of the tumor may be hidden. Occasionally, metastases are dense and show up clearly. Hemorrhage into a cerebral tumor may, in some cases, be responsible for the high
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Fig. 20. Scans of a malignant glioma. The lesion is shown as a large irregular low-density area in the left frontal lobe. The low density areas are soft tissues that may be affected by edema or necrosis and are shown as dark or black shades. A Grade IV astrocytoma was confirmed by craniotomy.

Fig. 21. Scans of multiple metastases in a middle-aged woman examined for exclusion of a primary cerebral tumor in the right hemisphere. Two lesions are demonstrated in the scans. The lesion in the right frontal lobe (upper scans) is a low-density lesion, either necrotic or with extensive edema. At operation, this was revealed to be a gelatinous necrotic metastatic adenocarcinoma, probably from the large bowel. The smaller dense lesion in the medial aspect of the right posterior parietal lobe (lower scans) has had its density enhanced with intravenous sodium iothalamate (see Figs. 15 lower, 27, and 28). Note the displacement of the ventricular system and the amount of edema in the parietal lobe (lower left scan).

density. Cystic degeneration is sometimes seen, and cellular debris and particulate matter falling to the back form a fluid level (Fig. 22).

In infarction, it is often possible to identify the lesion by the extensive involvement of both cortex and white matter and the absence of features usually seen in association with space-occupying lesions. In the early stages of infarction, the pattern of tissue involvement may vary, but, in general, the presence of edema fluid will lower the average tissue density, and the change may become manifest in the first 12 to 24 hours after the vessel occlusion. This change may not be obvious in the polaroid pictures, but averaging the values given by the computer printout in the suspect area and then comparing them with the values in the corresponding unaffected area in the contralateral hemisphere should show a significant difference. (This maneuver also provides a possible method for monitoring the amount of extracellular fluid in a variety of places.)
conditions.) The extent of the involved area usually becomes more clearly defined as time passes following the infarction. In the first week the boundaries tend to be irregular, while by the second week when the process of phagocytosis is advanced, the infarcted area is well defined and is seen as a low density area involving the cortex and white matter and with relatively smooth margins (Fig. 23).

Some benign tumors, because of their location and constitution, may exhibit characteristics that enable specific identification. Cystic craniopharyngioma, epidermoid cysts, or cholesteatoma are examples of such tumors. The fatty nature of these tumors or cyst contents are indicated by the negative values of the absorption coefficients. Negative values indicate that the average density of the tissue is lower than that of water. A cholesterol-filled cyst may have values reaching as low as $-40$ (Figs. 24 and 25).

Subacute and chronic subdural hematomas, as one would expect from clinical experience, fall into three groups:

1. A hematoma that has a slightly thicker consistency may exhibit the same average density as the underlying brain. The boundary between the brain and hematoma is poorly defined and may be seen only as a faint, slightly dark area. The ventricular system is, of course, displaced and this is the most outstanding feature (Fig. 26 left).

2. A hematoma that is thin and watery has a low density and is clearly seen in the scan pictures as a lens-shaped dark area capping the cortex (Fig. 26 center).

3. A hematoma that has a thick, semisolid, tar-like consistency exhibits a higher average density than the underlying brain, and is easily seen as a broad white band beneath the inner table (Fig. 26 right). This type of
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Fig. 24. Upper: Four scans of a craniopharyngioma made at 4.5 and 6.0 cm in a middle-aged patient with lifelong poor vision, lately becoming blind in the left eye. Note the central cyst with a loculus extending into the left frontal lobe. Specks of calcification are visible in the cyst wall (third and fourth scans). The top of the cyst protrudes into the floor of the anterior aspect of the lateral ventricles and third ventricle. Lower: Computer print-out of scan made at 4.5 cm. The negative values of the absorption coefficients within the cyst indicate that the contents have a density lower than that of water and are most likely to be cholesterol.
Scans of a solid craniopharyngioma in a 9-year-old boy. The third ventricle is obstructed by a solid tumor that can be seen as a roughly oval-shaped low density lesion occupying the position of the third ventricle. Note the degree of obstructive hydrocephalus.

Hematoma is probably best classified as subacute.

In craniocephalic trauma, computerized scanning, as has been mentioned, offers an easy method of differentiating between hematoma and edema as the cause of compression or swelling of the brain. As in infarction, the edema fluid may not cause an obvious darkening of the affected area in the polaroid pictures. In these patients it may also be necessary to average out the absorption coefficients in defined areas and compare them with the values in corresponding areas in the contralateral hemisphere.

Group 3. Lesions exhibiting average tissue densities that are the same as those of the surrounding normal brain are difficult to identify in the ordinary scan. Where the lesion is large enough to displace or distort identifiable structures such as the ventricular system, the existence of the lesion is recognized but its exact location is not identifiable. Should a lesion be comparatively small and peripheral in location, it may not produce any displacement or distortion and may, therefore, escape detection. However, since the sensitivity and accuracy of the method is of a very high order, artificially raising the density of abnormal tissue or enhancing the density difference at the boundaries of affected tissue becomes a possibility. The breakdown of the blood-brain barrier in an abnormal area should enable small amounts of specially selected circulating substances containing heavy atoms to pass into the abnormal tissue and to be retained for relatively long periods of time. Sodium iothalamate (Conray) is obtainable in a preparation that contains 420 mg of atomic iodine per milliliter. Once injected into the bloodstream, iodine compounds may dissociate to some extent or combine with blood proteins to form large, complex molecules. In this or in an unaltered form, the iodine-containing compound may pass through the blood-brain barrier and lodge beyond the basement membrane. Passive diffusion, active transport, or pinocytosis are among the possible mechanisms. The process is rapid and the increased density may, in many cases, be seen in a scan made 5 minutes after the intravenous injection of 20 ml of sodium iothalamate solution (Figs. 15 lower, 27, and 28). It is probable that the process is detectable soon after the first pass of the blood containing the compound. The density increase has been shown to persist for as long as 9 hours in some tumors. As would be expected, tumors with large vascular beds tend to show up more densely than those that are comparatively avascular or necrotic. Meningiomas exhibit a marked increase in density.

At the present time, scans are carried out in a normal way and depending on the clinical problem, e.g., a suspected cerebral tumor, tissue density enhancement may be added to the examination. This means repeating the procedure after the intravenous injection of sodium iothalamate. The time required for a complete examination may therefore be doubled, but the added information may be invaluable.

Discussion

It is unlikely that computerized scanning of the brain will immediately reduce the
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Fig. 26. Scans of a subdural hematoma. Left: Left chronic subdural hematoma. The density of the subdural fluid is similar to that of brain. The indications of its presence are the displaced ventricular system and the faint diagonal low-density dark streak in the left occiput representing the hematoma-brain interface. Center: Typical low-density hematoma capping the cortex on the right side. Note the marked ventricular displacement. Right: Left-sided subacute subdural hematoma showing up as a dense band capping the cortex in the temporal and parietal area displacing the ventricular system.

present practice of cerebral arteriography or pneumoencephalography, but like radioisotope brain scanning, it will undoubtedly come to occupy an increasingly important position in investigation of disease of the central nervous system.

The scope of the information afforded by computerized scanning is such that a large number of patients requiring investigation for neurological complaints will need to be subjected only to plain skull radiography, a radioisotope brain scan, or a computerized scan either singly or in combination. These investigations may provide sufficient information in respect to location, tissue abnormality, displacement of structures, and possibly the nature of a lesion for treatment to be instituted. Depending on the type of problem being presented, computerized scanning may assume either a definitive or a complementary role, e.g., in craniocerebral trauma or conditions in which it is necessary to demonstrate the ventricular system easily and quickly, e.g., a patient with known or suspected obstructive hydrocephalus, or to eliminate the possibility of space-occupying lesions in patients with dementia, epilepsy of late onset, and a variety of other neurological abnormalities.

At the present stage of development, there are some limitations and sources of difficulty which, while not detracting from the undoubted value of the method, need to be mentioned. The resolution of the system is limited mainly by the size of the matrix chosen and the density difference between structures or tissues that need to be accurately shown in their true dimensions. Where the density difference is small, averaging of tissue density in the matrix cells at the periphery of an area of interest tends to blur or smear the true dimensions. If, on the other hand, the density difference is great, as between hematoma and brain tissue, then the blurring or smearing effect is much less evident and the dimensions are shown with much greater accuracy. It is therefore unlikely that the method will replace pneumography in the demonstration of small anatomical detail in the subarachnoid cisterns, the cerebellopontine angles, the region of the pituitary fossa, or the optic chiasm.

The system moves relatively slowly, and because of this, difficulties may arise. Each scan takes 4½ minutes to complete. This is a long time for a patient to remain perfectly still, and small movements nearly always do occur. In scans of the midsection of the cranium, these movements do not seriously affect the quality of the pictures, but lower down, near the base, the effect is more
serious and the diagnostic quality of the pictures may be destroyed. The alignment of readings is disturbed, and aberrations are introduced into the pictures. These appear as vertical streaks, which may be white or black depending on whether the scan passes through dense bone structures or air-filled paranasal sinuses, or mastoid air cells. Heavy sedation has been used in restless patients, but is clearly much less satisfactory than conscious cooperation.

For the reasons mentioned, scans of the posterior fossa and skull base tend to be less easy to conduct and less satisfactory than those of the broad midsection. The method operates to maximum advantage when there are no large changes in tissue density. The air-filled paranasal sinuses and mastoid air cells give large negative values while the dense, complex, bone structures give high positive values. The system is therefore required to operate between the extremes of the range of tissue density, and small movements of the head will therefore introduce a considerable amount of aberration.

In order to examine the posterior fossa in some patients, it may be necessary to angle the plane of the scan with respect to the orbitomeatal line so that some of the complex bone structures in the skull base are avoided. Some patients with posterior fossa lesions have painful neck stiffness which makes it impossible for them to cooperate without some assistance in the form of analgesia, sedation, and even general anesthesia.

In the high convexity of the cranium, the bone walls slope with an increasing flatness toward the midline, so that the plane of section, although still normal to the long axis of the body, is no longer normal to the skin surface. A triangular segment of brain will therefore be hidden by the slope of the bone contained in the width of the section, i.e., 1.3 cm. This difficulty can be partly overcome by using a smaller diaphragm (reducing the width of a section to 0.8 cm). This will reduce the number of photons, and the picture quality will suffer to a small extent.

The x-ray dose per examination is of the same order as in a routine skull film. Each scan imparts a skin dose of 1.9 R per unit area, and as the beam is highly collimated, the surface scatter is small. The water in the perspex head-box gives a filtration equivalent to 5 mm of aluminum.

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