Wellcome Film Project

The EMI Scanner: Computerised X-Ray Scanning of the Brain

The Scientific Basis of Medicine

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University of London Audio-Visual Centre, 1975.

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Black-and-white

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<**Opening titles**>

<**Dr James Ambrose, standing, to camera. Camera pans back and Ambrose refers to a slide showing an illustration of the brain**>

This talk is to do with the new method of investigating the brain. But first of all I think I ought to put the method into perspective by telling you what may happen to a patient entering hospital for investigation of disease of the central nervous system. And for the sake of simplicity we're going to suppose that our patient has a tumour somewhere in the right hemisphere, probably in the right parietal lobe.

Now, before we can institute treatment, we must know exactly where that tumour is and, if possible, what it is – whether it is a primary tumour or whether it is a secondary malignant tumour from a site elsewhere in the body, or whether it is

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benign. Now, in addition, we have a whole battery of investigations which we can use. And we must choose these with due care for our patient.

<**Ambrose over table showing different diagnostic techniques for defining tumour types**>

Some of these investigations are simple and non-invasive, whilst others involve the use of complex invasive techniques and there is always the outside chance of a serious complication occurring. The simple techniques include: straight skull radiography, radio-nuclide scanning and ultrasound, whereas the more complex invasive techniques may take the form of either cerebral angiography or cerebral pneumography. If I were a patient I think I'd be scared to death at the mere thought of having any of the last two mentioned investigations performed on me.

Now it is an unfortunate fact that each of these investigations allows us only a restricted look at the structures which comprise the whole cranium.

<**Ambrose over examples of diagnostic technique listed above, including: x-ray and radioisotope. Ultrasound, arteriography and cerebral pneumography are described over table from above**>

Skull radiographs show us the bony structures in various projections but give us no indication of the soft tissue structures contained within. The conventional system of x-ray source, object and sensitive film, ensures that all the information relating to differential absorption along the path of the x-ray beam will be superimposed on a particular place on the film. The dense, bony confines of the skull therefore have a blanketing effect and we get little or no indication of the intracranial anatomy. We may be restricted to seeing only the displaced pineal body when it is calcified.

Radioisotope scanning shows us where the administered isotope has collected in abnormal concentration, but again, it gives little indication of the anatomy existing within the cranium.

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Ultrasound shows by echolocation the position and form of interfaces within the brain. We may thus be able to say whether the midline or adjacent structures are displaced or deformed, or whether the interfaces arising from abnormal conditions within a mass, such as a haematoma or a tumour; we again do not get a direct look at the soft tissue structures.

Arteriography enables us to look at the vascular structure of the brain and from displacements, change in contour, pathological changes in fine vessel structure or disease of the vessels themselves, we may be able to deduce the site and probable nature of the lesion.

Cerebral pneumography enables us to see those structures which are normally filled with fluid. That is the ventricular system, the subarachnoid basal systems, the cerebral sulci, and again from changes in positions, size and contour we may be able to deduce what has happened.

<**Ambrose to camera, then over EMI scans of brain**>

It requires no great stretch of the imagination to see that what we have required for a long time now is a system which would enable us to look at the structure of the brain without causing the patient fear or discomfort.

This <*turns and points dramatically*> is the EMI scan of the patient whose skull x-rays and techniques in brain scan we have been looking at. It is now nearly 80 years since Röntgen discovered x-rays and it is true to say that in that time the system of x-ray source, object and sensitive film has changed but little. There is, however, a way in which we can change the system.

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<**Ambrose over illustrations showing how a more effective scanning technique could work**>

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Let's imagine that we are going to look at a cross section of some part of the body. In our case, the cranium. This will be a finite thickness and we are going to irradiate it with a collimated beam of x-rays. Over the thickness of the slice we can imagine that the beam will be nearly parallel and therefore of nearly constant dimensions. By using a system of crystal detectors we can measure the number of photons entering at a certain point and the number of photons emerging at the corresponding, exactly opposite points at the circumference. By mounting the x-ray tube and crystal detectors in a common frame, the collimated x-ray beam can be made to scan along the plane of the slice. During this movement, the irradiation of the slice is regarded as a continuous sequence of beam paths or x-ray transmission profiles.

Along the path of the beam, x-ray photons will undergo exponential absorption. And if we regard the slice as being made up of a number of parallel adjoining beam profiles, we could, if we were able to calculate the absorption coefficience of equal individual segments of each beam path, effect a reconstruction of the internal structure. A total of 240 equally spaced readings are made in each linear scanning motion of the x-ray tube. This is then followed by a 1˚ rotation of the whole gantry around the circumference of the slice and the scanning motion is repeated and so on until a rotation of 180˚ has been completed.

<**Ambrose to camera**>

In 1968, Mr GN Hounsfield, a research engineer at EMI, effected a solution to this problem. But, before I go on to describe the apparatus which we call the EMI scanner, I would like to mention the names of three people who looked at this problem in different ways but always with the same objective in mind.

The first is a Los Angeles neurologist, WH Oldendorf, who in 1961 devised an experiment which led him to believe that he might be able to calculate absorption values along the path of a beam of x-rays passing through the head. He did, in fact, reach out towards the solution but didn't quite make it.

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The second is a physicist, AM Cormac, who in 1963 was experimenting with x-ray transmission profiles and found that he was able by back projection to accurately calculate the absorption values of the pure aluminium and oak wood portions of his model.

The third person was DE Kuhl, who in 1968, after a number of years of experimenting with projectional methods, finally solved the problem and created an effective transverse sectional radionuclide brain scan.

Now let us look at the EMI scanner and see if we can explain the method employed.

<**Ambrose over film showing male patient having EMI scan, then computer reading of scan results**>

With this apparatus, the cranium is regarded as a series of contiguous slices, each made in the transversal axial plane. Each slice is scanned, in turn, using a highly collimated x-ray beam, and an equally collimated system of crystal detectors. Projections are obtained by measuring the attenuation of x-ray photons across the slice from a large number of sequential, exactly corresponding points around the circumference.

A computer is used to assemble this information and arrange it in a form suitable for use in a series of mathematical operations. This series of mathematical operations, or algorithm, is then used to effect the reconstruction of the anatomy of the slice. Reconstruction is made by regarding each slice as a matrix made up of 160 by 160 cells. Each cell represents a block of tissue 1.5 by 1.5 by 13 cubic millimetres. The last dimension, 13 cubic millimetres, is the thickness of the slice. Using back projection methods, an absorption value is calculated and related to its correct cell in the matrix, along the corresponding beam path or projection. The computer registers 43,000 readings of x-ray photon transmission and it is from these readings that a sufficient number of simultaneous equations can be constructed to enable the computer to calculate the necessary 25,600 absorption values for the matrix of 160

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by 160 cells. The absorption values are used as picture points in a cathode ray tube intensity display, based on the relative densities of different tissue structures.

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<**Ambrose over scale listing absorption values, then EMI scan of a brain, displaying different densities of brain tissue**>

A convenient scale of absorption values has been devised so that there is a range of 1000 units between the least dense normally encountered substance, which is the air in the paranasal sinuses and mastoid air cells, and the most dense substance which is the compact bone of the skull. Air has an absorption value of approximately -500, and compact bone an absorption value slightly in excess of +500. The soft tissues of the brain have a fairly low density and vary between +1 and +22, or approximately 4% of the positive range.

The most dense tissue, that is, bone is depicted as pique white, while the least dense tissues, air and cerebrospinal fluid, are depicted as black. Soft tissues of the brain are depicted in shades of grey, shading from dark to white with increasing density. By operating the appropriate controls, the operator can select a display which gives maximum detail for the tissues under examination.

<**Ambrose over film showing a woman undergoing EMI scanning**>

The operation of the scanner differs from that of other x-ray equipment but is essentially simple. The x-ray tube, which is continuously operating, requires a lengthy warming up procedure, similar to that followed with x-ray therapy tubes. The patient's head must be correctly located in the machine and, for ease of the calculation and accuracy, must be placed in the centre of an exactly square Perspex box which is filled with water. This is achieved by forming the front face of the box with a rubber diaphragm which can be drawn in to form a cap in the centre of the box. When the patient's head is located in the box the cap can then be allowed to shrink onto the patient's scalp, thus eliminating an air gap. A simple measuring

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device is then used to locate the correct level of the scan and once the computer, x-ray control consol and scanning gantry have been correctly integrated, scanning sequence can begin. It takes about 5 minutes to complete during which time the patient must remain perfectly still. Pictures of two contiguous slices are available, approximately 20 seconds after the completion of the scan. A complete examination from base to vertex usually requires 4 complete scans, that is, 8 pictures.

<**Ambrose over continuous sequence of slides showing EMI brain scans, discusses the appearance and diagnosis of each case, uses indication stick**>

Now, let us consider the results and their interpretation. The pictorial display is examined in much the same way as a conventional radiograph. Structures are identified and their shape, size and position defined. Changes in absorption are then looked for. The perspective differs from that to which we have become accustomed in conventional radiographs, and we may have to cast our minds back to our medical student days when we were accustomed to looking at transverse sections of the brain. However, the importance of the display is that living anatomy may now be shown quite simply and with no particular discomfort to the patient.

In the posterior fossa we can see the fourth ventricle, the brain stem, the pontine system and the lateral extensions into the cerebellopontine angles. Coming to the next slice up, we can see the quadrigeminal system, we can see the thin slit of the third ventricle and the sylvian fissures situated more laterally in the temporal fossae. Up one more slice we see the anterior horns of the lateral ventricles, the bodies of the lateral ventricles, the third ventricle, the pineal body, calcified choroid plexuses and the occipital horns and trigones of the lateral ventricles. Situated more laterally we can again see the slits of the sylvian fissures and between these and the lateral ventricles we can see the complex structure of the corpora striata. Still coming up we see the top halves of the lateral ventricles, again with the choroid plexuses and the third ventricle. And coming still higher, we see the extreme parts of the roof of the lateral ventricles with the corpus callosum between them. In the top most cut, we've come up above the major form structures and we now see the homogeneous density of the white matter and in these scans, unless there is an abnormality present, we

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can't really distinguish cortex from white matter. But if there is oedema, or if the patient has cerebral atrophy causing widening of the cerebral sulci, we can distinguish these structures.

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Now, let's consider the abnormal scan. In neurological practice, the common lesions which require identification are cerebral neoplasms of all varieties, haematomas, infarctions and infections. To this list must be added cerebral oedema which often accompanies these lesions and complicates the clinical picture as well as the findings of other methods of investigation.

As I have mentioned before, 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 conveniently divided into three large groups according to density alterations they exhibit in the scan pictures. Firstly, lesions with an average density higher than that of normal tissue. Secondly, lesions with an average density lower than that of the surrounding normal tissue. And thirdly, lesions with the same density as normal tissue.

Now, high absorption values may arise out of deposition of calcium in different types of lesions. It may also arise out of lower water content in a closely knit or fibrous structure or to a haemorrhage in which clotting has occurred. Low grade astrocytomas, oligodendrogliomas or ependymomas are examples of neoplasms which show up as white areas in computerised scans because of their calcium content and consequently high absorption values. The calcium aggregates may be in seroma[?] bodies or calcospherite formations.

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Now, this is a patient with an oligodendroglioma and you can see the calcium aggregates as dense spots within the tumour. It has produced a deformity of the anterior horns of the lateral ventricles and must be clearly extending into the genie of the corpus callosum. The dark area is an area of oedema.

Now, the next patient is a quite different problem, this is a patient with a benign tumour. This is a meningioma and shows up because of the calcification in the seroma[?] bodies. Behind the tumour you can see a roughly crescentic area of darker brain which is oedematous.

Other lesions containing calcium are equally well shown. In haemorrhage, once clotting has occurred, serum is progressively absorbed and the concentrated blood constituents will then have a much higher average absorption value than normal brain. Absorption values for haematoma may vary from +22 to +36 depending on the amount of serum absorbed. This large difference in absorption values between haematoma and normal brain enables the computerised scan to operate to great advantage in craniocerebral trauma or, indeed, in any condition where a haemorrhage is suspected and the haematoma requires to be delineated.

Now here we have a patient with an obvious extradural haematoma in the left posterior parietal area. You can see its characteristically inward convex edge and it shows the very high density of clotted blood. The lateral ventricle on the contra-lateral side is seen to be displaced away from the midline.

The next patient is a different problem. This is a man who was admitted to hospital deeply unconscious with a history of having been sick, fallen backwards and struck his head on the bathroom floor. The question then arose as to what sort of damage he had sustained to his brain – did he have an extradural haematoma, subdural haematoma, an intracerebral haematoma or was his brain merely contused? The EMI scan gives us the answer because here, in the frontal lobes, we can see this patchy increase of density which looks like segments of cauliflower surrounded by darker areas which are obviously oedematous brain. This is frontal lobe contusion, in fact, a contrecoup injury.

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Primary intracerebral haemorrhages are seen in a hitherto unobtainable perspective, and from a surgical point of view the demonstration of the haematoma, its size, relationship to deep structures and the point of nearest approach to the surface of the brain, or the extent of surrounding oedema, may be very valuable.

Now here we have a patient with just such a haemorrhage, you can see the extent of it, what structures it has involved and where it comes closest to the surface. You can also see what the compression effect on the lateral ventricles has been and also see a thin strip of clotted blood lying sub-appendomly[?] along the lateral wall of the compressed right lateral ventricle.

Here is another patient with a primary haemorrhage but this time in the vermis of the cerebellum. Now, this is an extremely dangerous type of haemorrhage as far as life is concerned and the sooner it is diagnosed and the compression relieved, the better for the patient. Here you can see that the EMI scan has provided us with all the information we require – we can, in fact, perform an operation and remove the clot merely on this information.

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In other cases of haemorrhage, a ruptured aneurysm may be responsible and if we have multiple aneurysms it may be difficult, or impossible, using the means ordinarily at our disposal to distinguish which aneurysm has erupted. This is where the EMI scan plays another important role. We can detect the small, local haematoma. And this is just such a case. This was a patient with multiple aneurysms including an anterior communicating artery aneurysm. Here is the haematoma, lying immediately in front of the third ventricle, indicating that the anterior communicating artery aneurysm had, in fact, ruptured.

Low absorption values occur in many different disease processes including neoplasms, infections, infarctions or, indeed, any process where there is a breakdown of normal cell structure and / or an increasing water content. For

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example, coagulative necrosis, microscopic and macroscopic cyst formation or gross demyelinating processes.

Now, in this scan we can see a well-defined area of low density. This is obviously a cyst filled with fluid and it's associated with a malignant tumour. Here we have another area of low density, this time less well defined. And in the centre we can see some area of slightly increased density: this is a metastasis from a carcinoma of the bronchus and the dark area surrounding it is, in fact, oedematous brain while this rather ragged irregular area in the middle is, in fact, the neoplastic tissue.

In other scans we may see changes which we are unable to interpret in terms of precise pathology. Now, in these two scans here we can see dark areas which may or may not indicate oedema and we require to know a little bit more about the patient. Now, in most cases we usually do. For instance, if this patient here had an emphysema of the lung which was drained and then later on became ill, developed a left hemiparesis, we would suspect she might have developed a metastatic abscess in the right cerebral hemisphere, and the EMI scan was, in fact, showing the oedema – we can't, actually see the abscess cavity itself but I'll come back to this particular patient later on.

In the next scan we see a very similar appearance, this time affecting the left frontal lobe but without much displacement of the ventricular system. And again we require to know a little bit more about the patient. If this patient had had a sudden incident which resulted in a right-sided hemiplegia we would say that he or she had sustained a stroke, possibly an embolism, possibly a thrombosis or even possibly a haemorrhage. Now, we know it isn't a haemorrhage because we can't see the density of the haematoma but we see a large well-defined low density area, and this indicates that the patient has, in fact, sustained an occlusion of a major vessel and this is the infarcted brain showing up as an area of low density.

As one would expect, subdural haematomas vary considerably in consistency. Those haematomas which have a thin watery consistency are seen as characteristic low-density crescents capping the cortex. Where the consistency is thick and tarry the

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haematoma may be more dense than underlying brain and shows as a dense crescent. Other subdural haematomas with the same density as the underlying brain may give rise to difficulty in the diagnosis. The large displacement of the ventricular system and the unbroken, apparently normal brain density, should point to the correct diagnosis.

Now, here we have a typical low-density subdural haematoma. You can see the low-density crescent capping the cortex on the left side, but there is more detail in this. If we look at the contralateral hemisphere we can see the cerebrospinal fluid lying along the falx cerebri on the right side and we can also see some detail of the cerebral sulci, but none on the left side. This is an indication that the subarachnoid space on this side and the cerebral sulci are compressed.

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The third group of lesions exhibit average x-ray absorption values which are the same as the surrounding normal brain and are difficult to identify in ordinary scans. When the lesion is large enough to displace or distort identifiable structures such as the ventricular system, the existence of a lesion is recognised but its exact location may not be identifiable. Should the lesion be small and peripheral in location it may not even produce any distortion or displacement and may, therefore, escape detection. However, since the sensitivity and accuracy of the method is of a very high order, artificially raising the absorption values of normal tissue and enhancing the density boundaries of the affected tissues becomes a distinct possibility. The breakdown of the blood-brain barrier in abnormal tissues allows small amounts of circulating substances containing heavy atoms to pass into the abnormal tissues and to be retained for relatively long periods of time. Sodium iothalamate, which is available in most x-ray departments as a contrast medium, can be injected in large amounts and appears to pass through the blood-brain barrier mainly by a process of passive diffusion. The process is rapid and increased density may be seen in many cases in scans made 5 minutes after the intravenous injection of 60ml of sodium iothalamate, or Conray 420 which is its trade name. As the process is one of passive diffusion, the degree of the opacification is dependent on the concentration of

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circulating sodium iothalamate, and as one would expect, tumours with large vascular beds tend to show up more densely than those which are comparatively avascular or necrotic.

In some disease processes the lesion may not be seen in the ordinary scans and certainly not distinguishable from the surrounding oedema which it has produced. In these cases density enhancement of the normal tissue with sodium iothalamate becomes very valuable.

Now here we have a patient with a meningioma. This can be distinguished in the normal scan because of the oedema behind it, but if that oedema had not been there one could imagine that this could not have been distinguishable from the normal brain. But give the patient 60ml of Conray 420 by intravenous injection, and then scan immediately after the injection, you can see the tumour very clearly. It has increased in density very, very considerably and shows a sharply demarcated boundary. This is an indication that it is probably benign.

Here is another patient with a lesion which was difficult to identify in the normal scan. This was a patient who had a sudden vascular incident which left him with cortical blindness. Now the chances were that this patient had, somehow or other, occluded his posterior cerebral artery circulation. We gave him 60ml of Conray 420 by intravenous injection and here you can see the greatly increased density of the infarcted tissue in the distribution of both posterior cerebral arteries.

Small tumours such as metastases may be identified and in others the extent of invasion and infiltration by tumour tissue may be seen. And abscess cavity may be distinguished from the intense oedema which it usually promotes in the surrounding tissues. Now here we have a patient with a typical malignant glioma. The density of the malignant tissue has been enhanced with Conray, and you can see how it comes backwards, it has greatly deformed the anterior horns of both lateral ventricles, it has invaded the genu of the corpus callosum and extended across the midline into the medial aspect of the left frontal lobe. Behind it you can see where there is soft, oedematous brain.

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Now, casting our minds back to the patient who had had an emphysema drained, and who was suspected of having developed a metastatic abscess in the right cerebral hemisphere, you will remember that all we could see was oedematous brain; we could not really identify the abscess. But having given the patient 60ml of Conray 420 or sodium iothalamate, we can now see it. It shows up as a dense ring. This is because the granulation tissue in the wall of the abscess cavity has taken up the contrast medium.

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Now, with attention to correct scanning technique and arranging scans to coincide with the areas of interest, tumours in and around the pituitary fossa may be identified. Here is a patient with a large pituitary adenoma. In the first scan we can just see the tumour protruding above the pituitary fossa and deforming the chiasmatic system, it is not really very dense but if we give the patient 60ml of Conray 420, the density is considerably enhanced. This is of value when the tumours are small or difficult to identify and we can easily imagine a situation where we could see a small asymmetric tumour rising out of the pituitary fossa.

When we come to the tectal plate area this may also be examined in some detail. Tumours arising in this area will cause an obstruction. The lateral ventricles will enlarge and the third ventricle will become widened. The tumour itself may be partly calcified in which case it's a pinealoma or some sort of tumour which arises in the tectal plate area. Now, the suprapineal recess is usually obliterated and we can't see it. Here is just such a patient. Here is the tumour of slightly increased density, occupying the posterior portion of the third ventricle, obstructing the outflow of cerebrospinal fluid and causing ventricular dilatation.

Now lastly, with some slight modification of technique, the contents of the orbit may be examined. The optic nerve is surrounded in the muscle cone by fatty tissue and as this has negative absorption values on the scale used, any alteration of density due to abnormal tissue may be easily identified.

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Here we have a patient with a tumour which is causing proptosis of the right eye. If you cast your eyes on the left side you can see globe of the eye, you can see the optic nerve, you can see the thin strap of the lateral rectus muscle and the unbroken, low density of the fatty tissue within the muscle cone. On the right side, the situation is altogether different. The optic nerve is straightened and displaced medially and here, in the outer lateral quadrant of the eye, you can see a large dense tumour. This is a cavernous haemangioma.

<**Ambrose to camera**>

Now, in conclusion, since the EMI scanner is able to provide a demonstration of the intracranial anatomy, quite simply, without danger to the patient, and with no particular discomfort, it clearly has an important part to play in the investigation of conditions which are not clearly defined and which, in the ordinary course of events, would require at least one contrast radiological procedure.

The apparatus which we have been describing is basically the prototype design and is, therefore, very much a first generation scanner. Improvements will no doubt be made in the directions of speed, accuracy, resolution and the extension of computer-aided operations such as light pencil averaging of subject areas, data storage, classification and comparison with previous experience. Application of the method to the thorax and abdomen has, from the very beginning, excited great attention, but there are formidable obstacles in the way – x-ray dose, sensitivity, matrix size, density range and voluntary and involuntary movements are just some of the obstacles which must be overcome. This makes the design of an apparatus much more complex. This, however, should not be beyond the ingenuity of modern technology. Thank you.

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