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# HISTORICAL NOTES ON COMPUTERIZED AXIAL TOMOGRAPHY**

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## SUMMARY

**The original experiments on computerized tomography at the Central Research Laboratories of EMI are discussed. Examples trace the history of improvement in definition and process time, leading to results from the first EMI Scanner which was installed in the Atkinson Morley's Hospital in September 1971.**

**Author's note** (July 1976)

Since this paper was presented, in May 1974, EMI has introduced two new machines utilizing computerized tomography.

The head machine provides increased resolution and faster scan time for head examinations, together with improved patient handling facilities. The body machine is a specially designed general purpose system taking pictures on a 320 x 320 matrix in 20 seconds. Some sample pictures taken are shown.

## RÉSUMÉ

**Les premiers travaux sur la tomographie axiale transverse avec ordinateur au Central Research Laboratories of EMI sont décrits. On revit, au moyen d'exemples, les progrès de la définition ainsi que du temps d'émission qui ont conduit au premier résultat fourni par "l'EMI scannes" installé à l'hôpital Atkinson Morley en septembre 1971.**

**Note de l'Auteur** (juillet 1976).

Depuis la présentation de ce travail en mai 1974, EMI a introduit deux nouveaux appareils de tomographie axiale avec ordinateur.

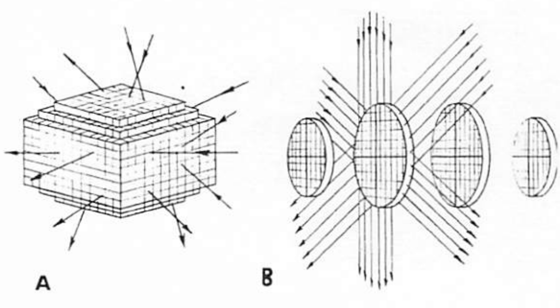
L'appareil destiné à l'étude crânienne fournit un balayage plus rapide et de meilleure résolution au cours des examens du crâne et permet également une manipulation plus facile des patients. L'appareil destiné à l'étude du corps consiste en un système d'utilisation générale construit spécialement pour fournir des images sur une matrice de 320 x 320 en 20 secondes. Présentation de quelques exemples.

I have been asked to give you a short talk on the history of computerized axial tomography and some of the interesting experiments which led up to its growth.

In 1967 I was investigating pattern recognition techniques at the Central Research Laboratories of EMI. During this work it became clear that there were many areas where large amounts of information could be made available, but the techniques used for retrieving it were so inefficient that a large proportion of the available data was completely wasted.

It was deduced that measurements of x-ray transmission, taken from all possible directions through a body, would contain all the information on the internal structure of that body. It was appreciated that the results would be very difficult to interpret; nonetheless the information would require only a mathematical solution, and this could be performed on a computer. Obviously the results would contain all the necessary information to produce a three-dimensional picture (Fig. 1A).

In formulating practical methods of presenting the results to the diagnostician, it was decided that the most convenient form would be to divide it, as in the principle of tomography, into pictures representing a series of "slices." These would give a three-dimensional representation of the tissue structure collectively. The approach also meant that the transmission readings taken through the body could be limited to a single plane. Each beam path, therefore, is part of a series of simultaneous equations from which a picture can be constructed.




Figures 1A-1B

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**Paper presented at the First International Meeting on Computerized Axial Tomography
Montreal Neurological Institute, May 1974

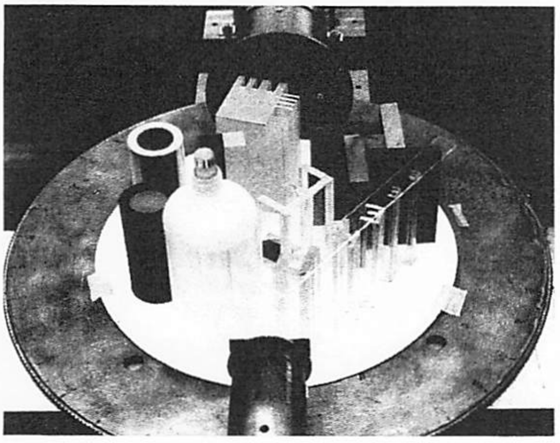


Figure 2

The computerized system is shown on the right of the diagram (Fig. 1B). The x-ray photons would be passed along the plane of the slice via its edges. In this case the whole path length of the x-ray beam would pass through the slice and therefore the transmission reading obtained would be 100% relevant to the slice, the solution of which would not be affected by external unknowns, and it was recognized that this was an important fact.

Calculations made on the efficiency of this principle were so encouraging that it was at this point that the usefulness of the technique was realized. They showed that it would be possible to measure the absolute values of the absorption coefficient of areas within the slice with an accuracy approaching one hundred times greater than by conventional methods. This figure would be aided by the use of detectors which were many times more sensitive than photographic film. It was estimated that the absorption coefficient of each element of the slice could be calculated to an accuracy of ½%.

In order to prove that the mathematical solution would work, tests were carried out in 1967 using a computer. A picture was interpreted as a series of numbers in a

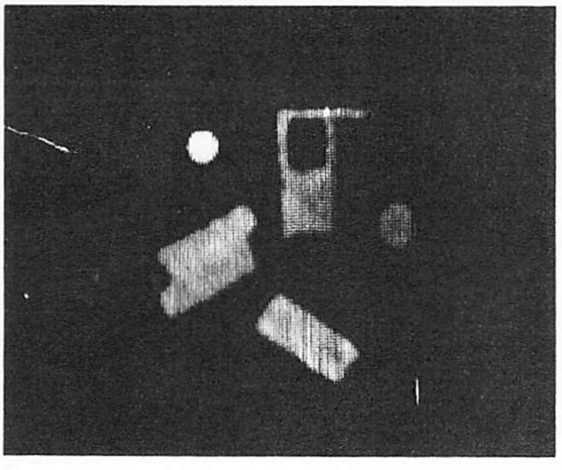


Figure 3

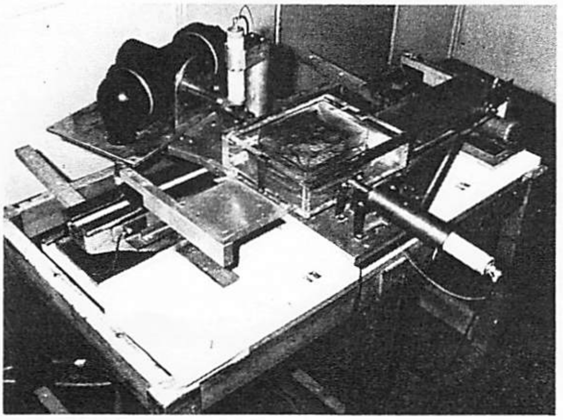


Figure 4

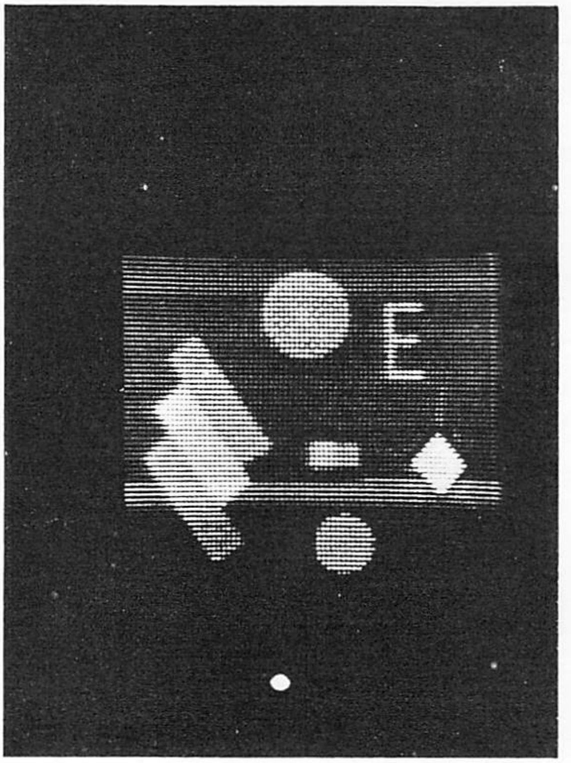



Figure 5

matrix. The computer was then programmed to calculate the values of the equivalent transmission reading taken through this mathematical model. The process was then carried out in reverse, so that the picture was reconstructed from the values of transmission previously calculated. It was repeated with simulated random noise values added, similar to that expected from the photon noise of the x-ray beam. The resultant noise on the picture was no higher than as predicted.

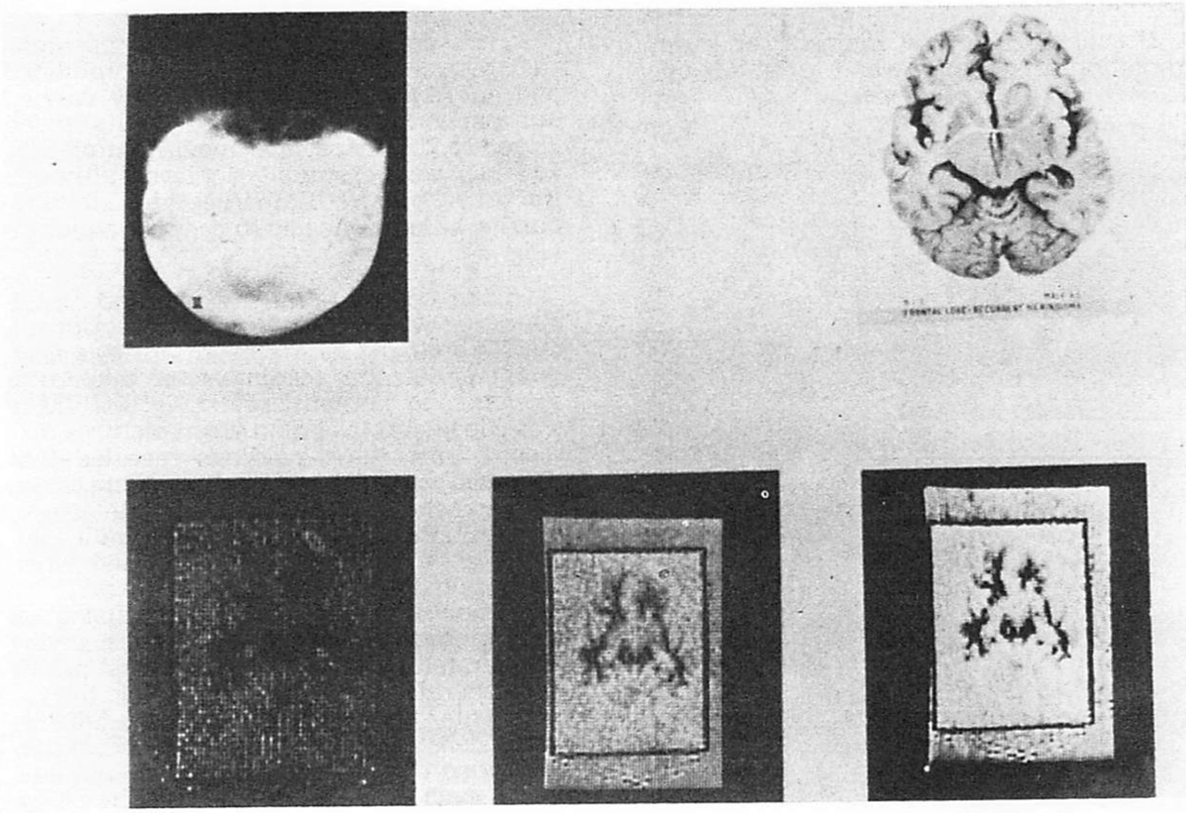


Figure 6

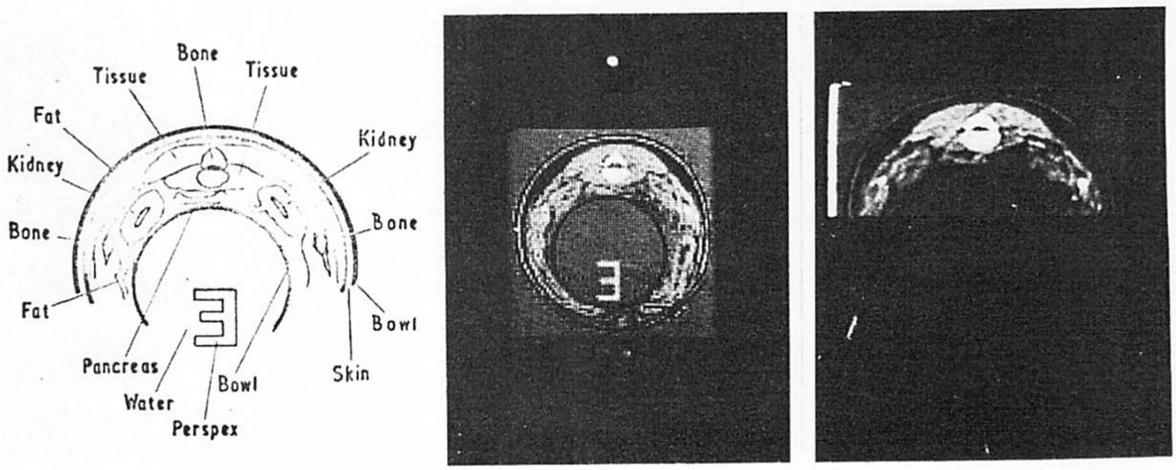



Figure 7

The British Department of Health encouraged us to test the practical feasibility of the technique and a simple laboratory machine was built on a lathe bed, the lead screw being driven in steps by an electric motor and the specimen rotated in one degree steps, at the end of each linear scan (Fig. 2). An Americium gamma source was used and the radiation was measured by counting techniques.

Because of the low intensity of gamma radiation, the machine had to be left operating for at least nine days to produce one picture. It took a large computer two and a half hours to process the readings. The computer had to solve 28,000 simultaneous equations and was programmed in Fortran.

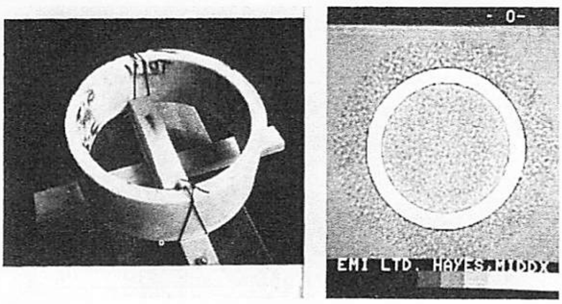
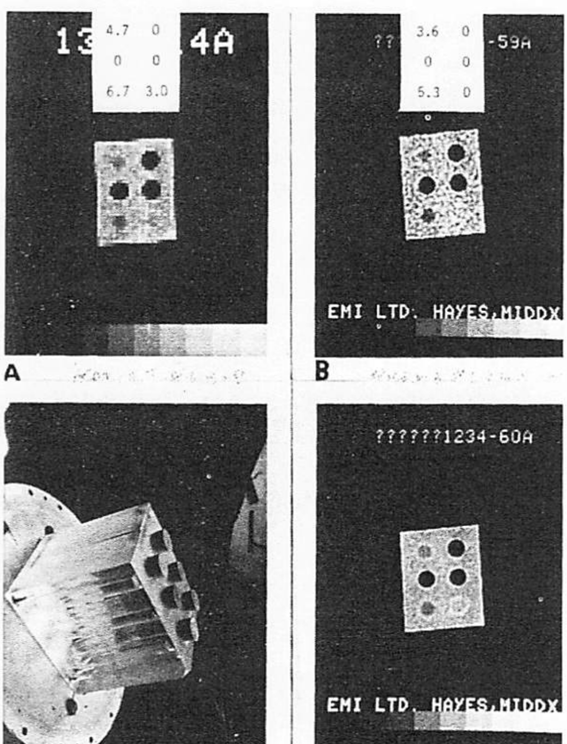



Figure 8

Discouragingly, the best accuracy during these experiments was of the order of 4% which was inconsistent with the maximum possible value theoretically (Fig. 3).

In consequence, the method of interpolation between picture points was modified and subsequent experiments were carried out using x-rays (Fig. 4). Results much closer to the theoretical maximum of ½% accuracy were eventually achieved, although the process was still unacceptably slow, requiring at least one day to produce a picture (Fig. 5).

In the course of this work, and in co-operation with Dr. James Ambrose, Consultant Radiologist at Atkinson Morley's Hospital, Wimbledon, readings were taken of a specimen of human brain (Fig. 6). There was considerable elation when pictures processed from these readings revealed that not only were the tumors in the specimen clearly isolated, but it was possible also to discriminate between grey and white matter. Our enthusiasm was dampened when further analysis of the results revealed that the formalin used to preserve the specimen had enhanced the readings, thus giving exaggerated results. Fresh bullocks' brains were therefore used to crosscheck the experiments, and although the variations in tissue density were less pronounced, it was confirmed that a large amount of anatomic detail, such as the ventricles and the pineal body, was readily discernible. In parallel, tests were carried out on sections through pigs in the area of the kidneys, and this work also produced most encouraging results (Fig. 7).




A B C D

Figure 9

A specification for a brain machine, incorporating the new technique, was submitted to the Department of Health and Social Security; with their co-operation, design and development work began in August 1970.

The first machine was installed at Atkinson Morley's Hospital in September 1971, under the guidance of Dr. Ambrose. The processing time for each picture was reduced to twenty minutes on an ICL 1905 computer, by using machine code instead of Fortran; it had been originally intended to pass the data over a telephone data link to a remote computer for processing.

Later certain new mini-computers became available and it was decided to incorporate one of these as an integral part of the system. This now enables the machine to process a picture in approximately four and a half minutes.

Recently we have been working on improvements to the definition and the removal of picture artefacts; as a consequence, the number of picture points has increased by a factor of "4" to give a matrix of 160 x 160 points.

We decided it would be inadvisable to reduce the x-ray beam width in order to increase definition, as this would reduce the number of photons and hence the accuracy of each reading. However, it is possible to resolve objects considerably nar-

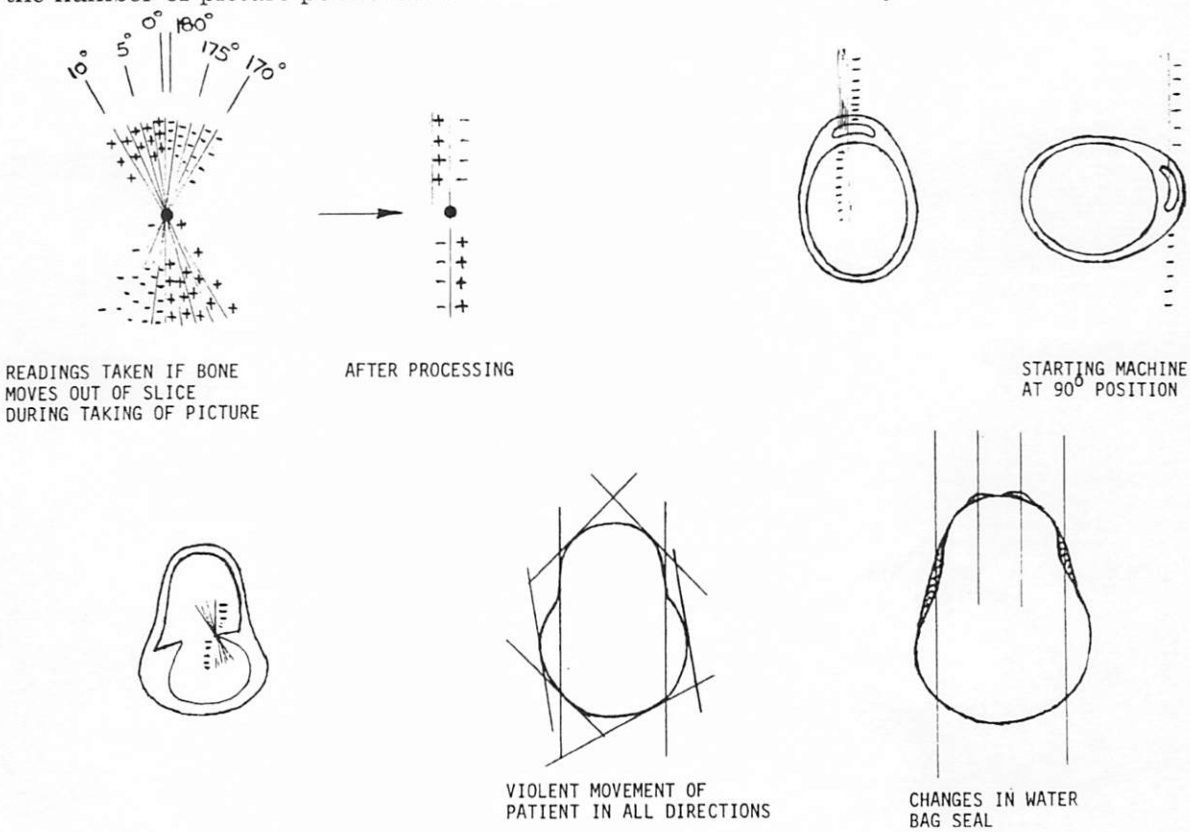



Figure 10

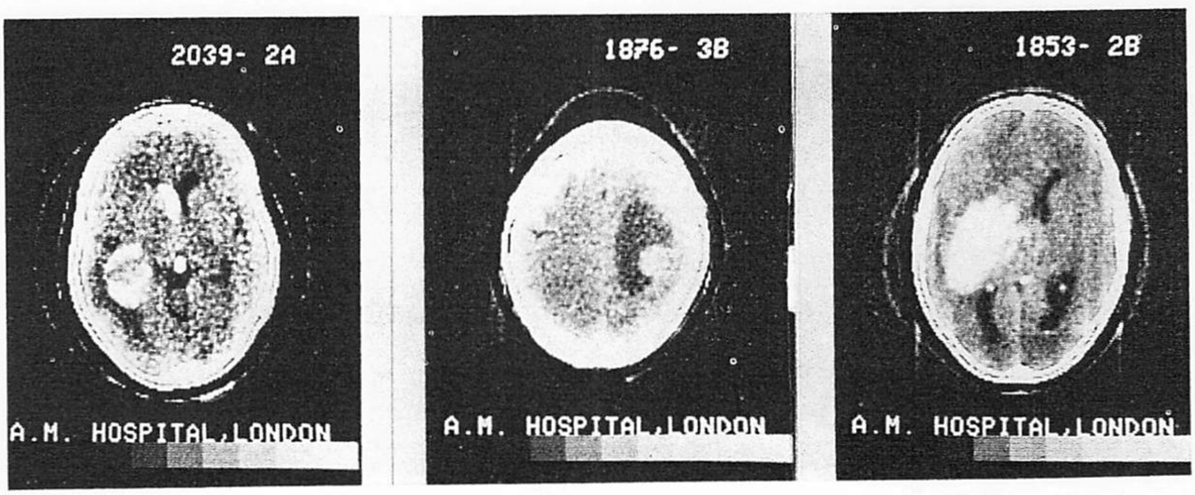



Figure 11

rower than the beam width using a new algorithm and only minor mechanical modifications to the EMISCANNER.

Figure 8 shows one of the first pictures taken on the machine using the new system and demonstrating its high resolution capabilities. The picture shown is of a phantom representing the bone of the skull; note the lack of overswing and the absence of high values in what would be equivalent to the cortex.

**Photon Noise**

The last pictures were displayed at high sensitivity and this showed up the background noise.

If the time for taking a picture is unchanged, the number of photons measured per reading will be the same for both the old and the new systems and the information received will be the same in both cases. It is not expected therefore that the new system could have any improvements on noise over the old one. However, the removal of noise produced by the large mesh squares of the 80 x 80 matrix is a considerable improvement, i.e., large squares can produce staircase patterns and density edges which are a form of noise.

By suitable adjustments to the algorithm the noise "grain" can be varied in area and amplitude in inverse proportion and a suitable "grain" size may be chosen.

The phantom shown in Figure 9C was constructed to demonstrate that indistinct tumors, barely discernible within the noise, could be detected on the 160 x 160 system (Fig. 9B) as well as (or better than) the 80 x 80 system (Fig. 9A). The phantom consists of a block of perspex in which six holes have been drilled and filled with saline solution of various strengths which have been chosen to give absorption values close to that of perspex. Note the good definition on the edges of the holes which have readings greater than noise.

In the last experiment (Fig. 9D) the machine was left running for a considerable time, at a very high dose, thus reducing the photon noise on the picture. From this picture we deduce that the quantizing and mathematical noise is only a small proportion of the total noise of the picture and is an indication of the efficiency of the algorithm.

Figure 10 illustrates that many artefacts are caused by the patient moving during the examination.

The new algorithm processes pictures considerably faster. The two relevant pictures

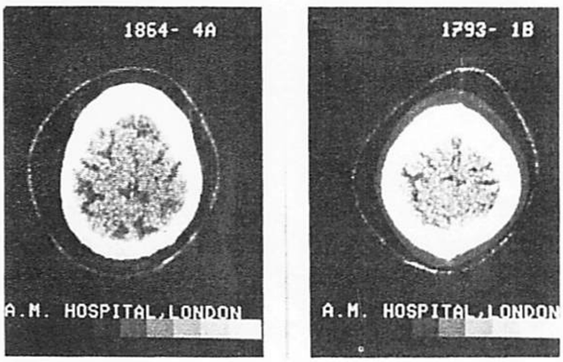



Figure 12

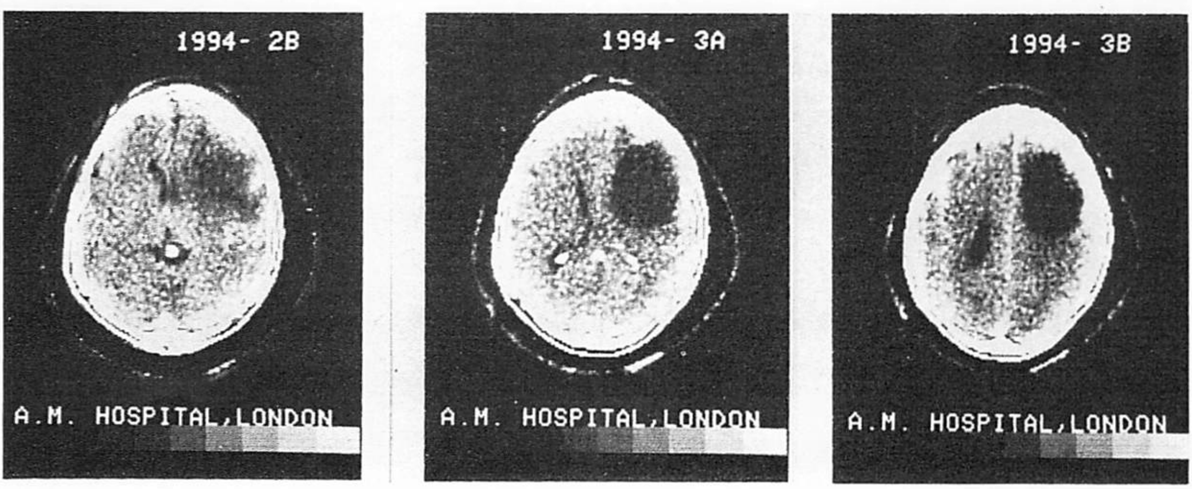



Figure 13

of slices may now be processed and viewed half a minute after the patient's scan has been completed. The printing has also been arranged so that it wastes minimum possible time and can be controlled independently. The modifications to the machine to fit these improvements are quite minor.

Dr. Ambrose of Atkinson Morley's Hospital has kindly lent me some of the high definition pictures he has recently taken using the 160 x 160 matrix. The improvement over the 80 x 80 matrix can be appreciated readily (Figs. 11-18).

2039 2A — Hematoma in left posterior temporal area from ruptured angioma lying next to the trigone of the left lateral ventricle. Note the low density defect in the 2A scan thought to represent the angioma. Note also the subependyma blood more anteriorly.

1876 3B — Typical metastasis. Dense due to closely knit structure, i.e., low water content. Note the presence of peripheral edema.

1853 2B — Large primary intracerebral hematoma. Note good definition of ventricular system and hematoma.

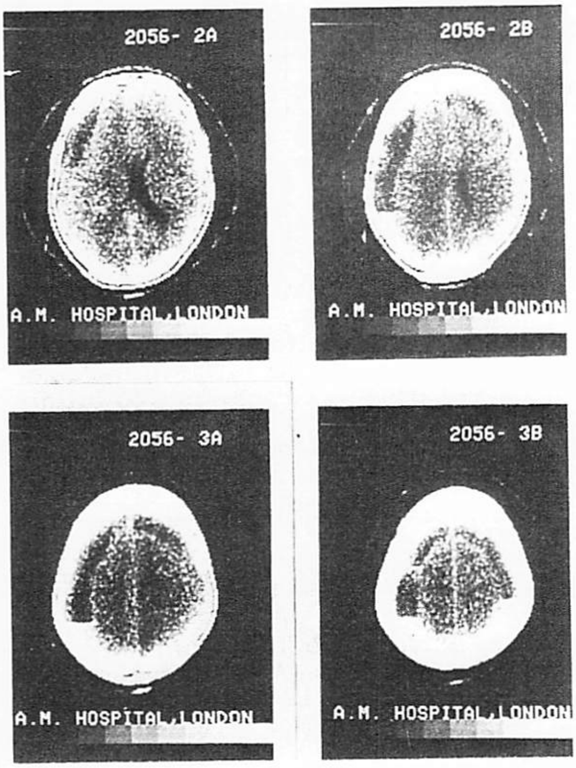



Figure 14

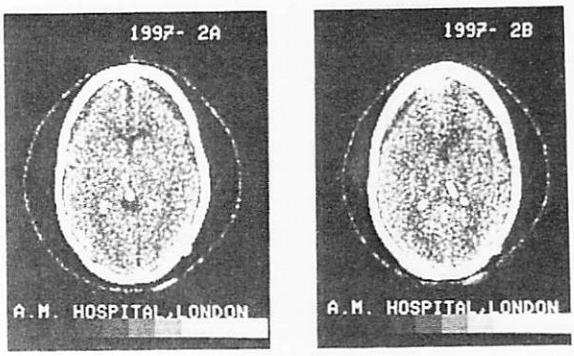



Figure 15

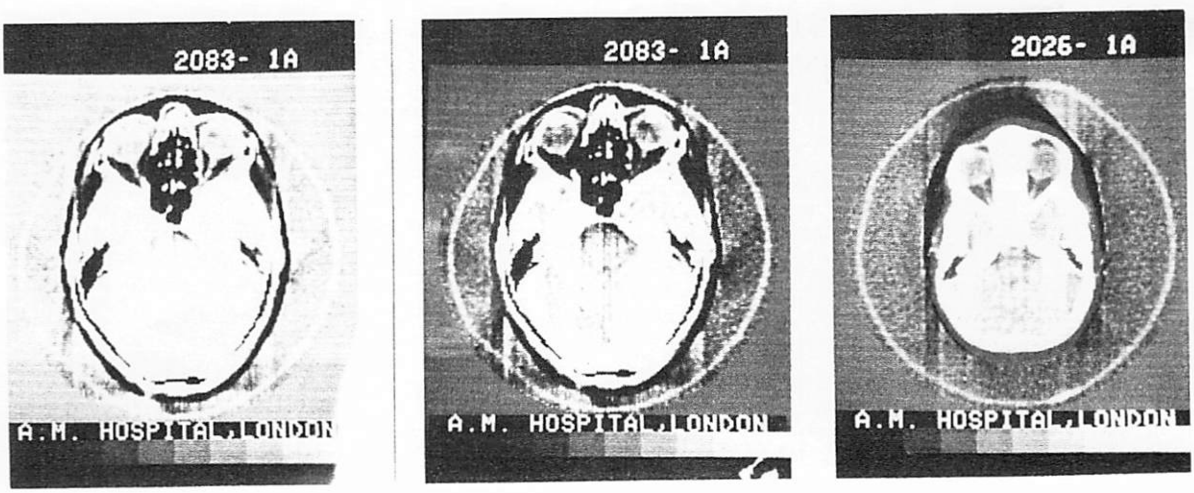



Figure 16

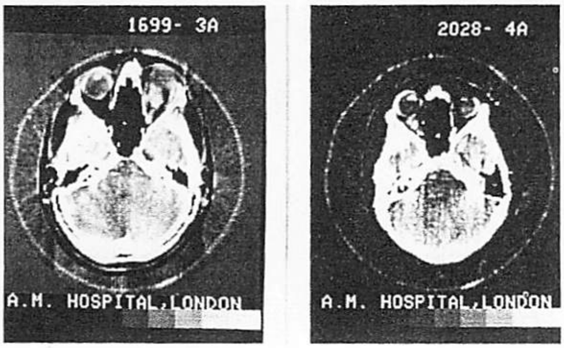



Figure 17

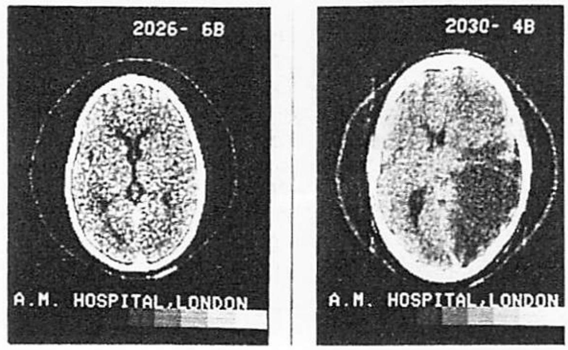



Figure 18

1864 4A — Case of senile dementia. Note gross widening of cerebral sulci.

1793 1B — The same.

1994 2B, 3A, 3B — Malignant glioma: Cystic astrocytoma, Grade 4. Right frontal lobe.

2056 — Chronic subdural hematoma bilateral. Left is larger than right. Fluid levels left and right due to clots in fluid falling to the back.

1997 2A, 2B — Small anterior bilateral subdurals.

2083 1A — Demonstration of optic nerve.

2026 1A — Demonstration of optic nerves in a child.

1699 3A — Tumor behind right eye giving rise to proptosis. Anterior situation immediately behind the globe. Not operated on yet.

2028 4A — Tumor behind left eye giving a proptosis. Note relation to course of optic nerve. Not operated on yet.

2026 6B Normal child scanned for suspected virus illness. Note great vein of Galen specified with Conray 10 ml given intravenously — picture taken five minutes after.

2030 4B — Large malignant cystic glioma parietal lobe in young man presenting visual deterioration. No signs other than gross papilledema due to raised intracranial pressure. Nodule not demonstrated in this scan but was shown in one made at a higher level. Note the edematous brain around the cyst.

Since this paper was presented, in May 1974, EMI has introduced two new machines utilizing Computerized Tomography.

The head machine provides increased resolution and faster scan time for head examinations, together with improved patient handling facilities. The body machine is a specially designed general purpose system taking pictures on a 320 x 320 matrix in 20 seconds. Some sample pictures taken are shown.

*ACKNOWLEDGEMENTS — I would like to acknowledge the work of Mr. LeMay and Mr. Gollifer who produced some of the high definition pictures in this article.*

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