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AXIAL SCANNING WITH 900 MeV ALPHA PARTICLES

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Summary

High energy (fast) alpha particles can be used for nondestructive radiography of the human body because small electron density changes are reflected in measurable alpha particle energy changes. Using high resolution radiation detectors and computer techniques for transaxial reconstruction, it is possible to present information that is not available from conventional radiographs with doses one-tenth that required for photon scanning procedures incorporated in the EMI or similar scanners.

Conventional x-ray imaging does well in the evaluation of large differences in density, such as bone, soft tissue and air. Artificial differences can be made by introducing air or iodine compounds. However, the diagnostic information of conventional x-rays is limited because the tissues of interest are obscured by superposition of over- or underlying tissues in the projected radiograph.

In order to circumvent these problems, methods have been developed wherein an anatomical slice or transverse section is produced. Computerized transaxial tomographic displays utilizing x-ray sources, such as the EMI scanner, are currently being utilized today. Present research with alpha particles initiated at the 184" cyclotron is an attempt to improve on spatial resolution and density sensitivity.

A beam of alpha particles at about 900 MeV is directed down a beam channel to a facility which houses the detection equipment and the biological object or patient (Fig. 1). The detection equipment consists

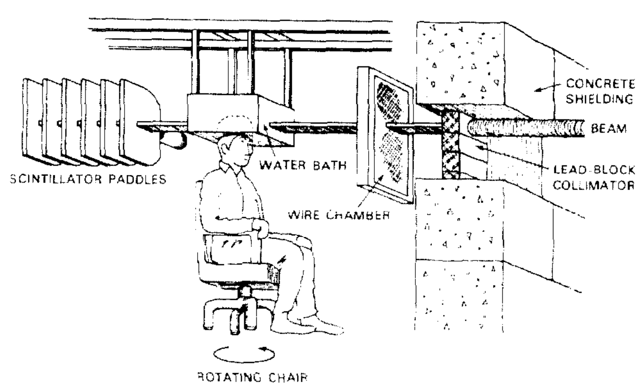

Fig. 1 Schematic of the Alpha Radiography Facility.

of three multi-wire proportional chambers and a range counter telescope, presently consisting of 13 scintillation counters. Multiple views are obtained by rotation of the subject at appropriate intervals for data collection. These quantitative data are collected, recorded, and manipulated on line by a PDP-15 computer for three dimensional reconstruction of density distributions or transverse axial tomography. The experimental apparatus is located in two small portable houses; one for the electronic and computer interface equipment, and the other, situated in the beam line, for wire chambers, range counter stack, and the patient positioning equipment. A rotating chair with adjustable X, Y, and Z axes is used for patient imaging. An angle encoder with the necessary interface electronics reads out the angular position of the patient to the computer for each event.

In anticipation of clinical trials, extensive health physics radiation dosemetry measurements were made. The neutron dose to the subject is 10^{-12} rad (10^{-10}ergs/gm tissue) per incident alpha particle. The gamma ray dose is also negligible. The relative biological effectiveness is near 1.0 for plateau alpha particles.

Various phantoms were run in order to determine range and spatial resolution. For transaxial reconstruction studies one phantom consisted of 6 mm and 12 mm round and square polyethylene and lucite rods. This was immersed in solutions of various electron densities to evaluate spatial and density sensitivity (Fig. 2).

Fig. 2 Polyethylene and Lucite Stick Phantom.

Another type of phantom consisted of a parafin model of the ventricles of the human brain (Fig. 3), which was also immersed in solutions of various electron densities. Computer reconstructions from data obtained using these phantoms (Fig. 4) were made using iterative direct and Fourier transform algorithms[1]. In addition a beagle dog head and a human skull with cow brain were used. Measurements were made of the stopping power of various biological materials, such as blood, brain, muscle, and fat, as well as parafin, lucite, polyethylene, and saline solution.

From eighteen imaging experiments involving these phantoms, we concluded that density differences smaller than two per cent could be detected with low doses and we would be able to easily distinguish brain ventricles in human subjects with doses less than 50 mrads (5 ergs/gm). The electron density difference

Fig. 3 Parafin model of the ventricles of the human brain immursed in saline solution. The model is in a water box which provides an equalizing path for the incident particles.

between cerebral spinal fluid and brain tissue is three to four per cent. Approval for human trials was given by the Committee for Protection of Human Subjects.

For imaging the head, the parallel particle paths were confined to a flat rectangular slit by a lead colimator with an aperture 1.3 cm by 18 cm and 32 angles were used (11.25° intervals) with 5000 events per angle. Only six scintillation paddles (1.2 mm thick) were available for these first studies. The reconstructions did not show detail inside the skull and it was determined that the beam slit, which was only 18 cm wide, was not adequate for high sensitivity reconstruction of a 21 cm wide head.

Thus, for the next trial, the lead colimator was widened and the necessary adjustments were made on the analyzing magnets in the beam line to insure a wide beam with adequate spatial coherence.

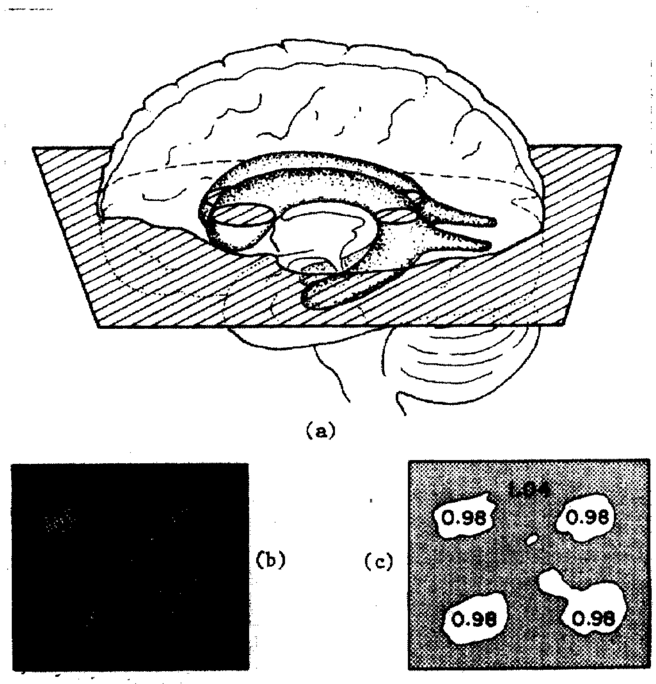

Fig. 4 (a) A plane intersecting the ventricles in the human brain. (b) The reconstructed image of the parafin ventricle model. (c) Densities of the parafin model and the surrounding saline solution.

The second subject experiment gave successful results (Fig. 5). The ventricles are clearly seen and other areas of the brain were distinguishable. This compares well to an EMI[2] scan taken at the Mayo Clinic facility on the same subject by Dr. Hillier Baker, Jr. The EMI scan was made with 1° intervals and a matrix size of 160 x 160 cells, and thus, has better resolution than the alpha particle image made by us with 11.25° intervals and a matrix size of 110 x 110 cells; however, the EMI scan required a dose of 1600 mrad as compared to 30 mrad for the alpha particle image.

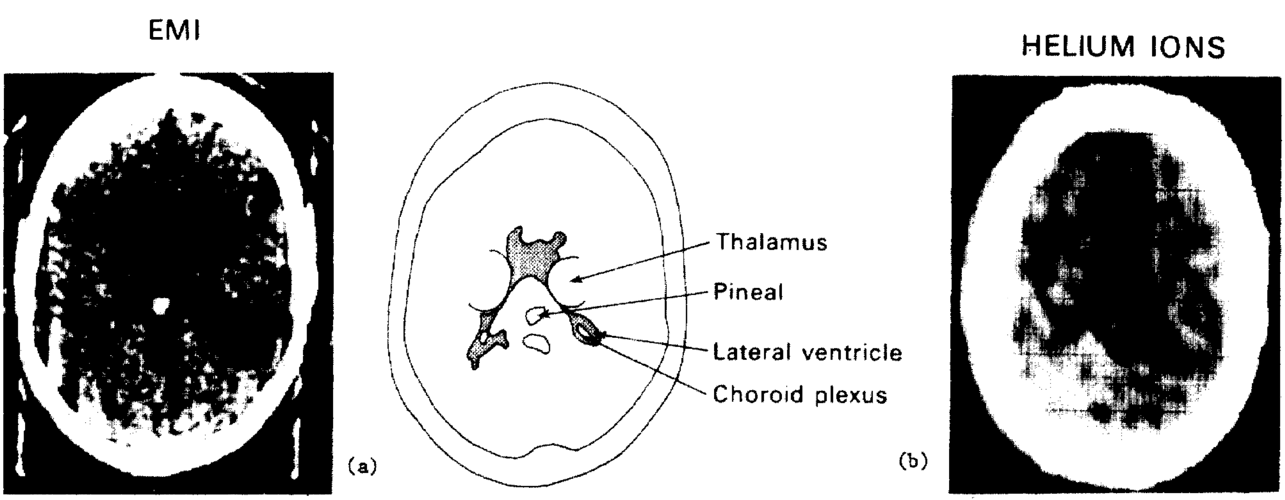

Fig. 5 (a) EMI scan consisting of 180 views and requiring a 1600 mrad dose to the subject. (b) Helium ion image of the same subject consisting of 64 views and requiring only a 30 mrad dose.

All of the reconstructed images so far use data only from the first wire chamber. The installation of the other two wire chambers has just been completed and they are currently being brought on-line. These chambers are located behind the patient and measure the particle's exit angle caused by multiple scattering. Three chambers will give better spatial resolution than one chamber by a factor of $2\sqrt{2}$.

One of the advantages of alpha particle radiography is that much less radiation dose is given to the patient. Calculations comparing x-ray imaging, such as with the EMI scanner and alpha particle imaging, indicate that from 10 to 50 times more dose (depending on thickness) is required by x-ray methods in order to achieve equal density resolution. Thus, low dose alpha particle radiography is a new safe tool for three-dimensional reconstruction of organ anatomy.

The results of these and future studies on density and spatial resolution can be readily extrapolated to protons, tritons, and heavier particles by scaling range straggling, dose, and multiple scattering. For example, protons have a range straggling parameter of one per cent which is two times that of alpha particles. Thus, for the same range resolution four times more protons are needed. Since the dose deposited by a proton is one-fourth that of an alpha particle, the dose for protons will be equal to that from alpha particles for equal density detection. However, counting speed requirements will be four times greater, and for equivalent spatial resolution, 16 times more protons are needed since the root-mean-square scattering of protons is twice that of alphas. Similar analyses can be made to scale for comparison to heavier ions such as carbon and neon.

Previous work with protons by Koehler[3] and with heavier ions[4] has shown that accelerated charged particles give radiographs of high contrast. This work is the first example of three-dimensional reconstruction using charged particles.

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