and food production, and to ecological systems that the planet may become uninhabitable in biological terms.

The physicians' conviction that nuclear war is becoming ever more likely is based on the continuing proliferation of nuclear weapons and their refinement. As weapons have become more accurate the response time has shortened; weapons left on the ground would almost certainly be destroyed, so that any nuclear conflict would very quickly become total. Furthermore, the increasing complexity of computer systems raises the spectre of war occurring as a result of technical malfunction.

Secondly, the physicians' examination of likely scenarios for attacks has shown that victims could hope for no medical treatment. Massive destruction would be complicated by lethal amounts of fallout, which would make movement in the open suicidal for many days or even weeks in all countries attacked—and also in many non-combatant countries too. The overwhelming belief of the assembled delegates was that plans for medical rescue and civil defence services create a dangerously false impression. No such services could operate. Even on the fringes of the devastated areas any surviving medical services would quickly be overwhelmed by the numbers of casualties.

There is, indeed, a conflict of interests. On the one hand, the physicians' movement is clearly right in campaigning against acceptance of the concepts of limited or survivable nuclear war. Proliferation of weapons must be halted; the appalling consequences of nuclear war need wider publicity, and in particular the peoples of every country should be made aware of the possibility (whatever figure is put on the probability) that nuclear war would make the whole planet uninhabitable and so would destroy the human race.

On the other hand, some doctors would survive in the first days of a nuclear war—in remote areas protected from fallout by geographical features. A very few would survive in the attack zones and would want to help the victims around them. The natural wish of many doctors and hospital personnel to make plans for such circumstances should not be criticised too harshly; it may be an ostrich-like wish to deny reality but it is understandable as a natural professional desire to be equipped to deal with a frightening possibility.

The international movement of physicians deserves support. Epidemics are controlled by preventive measures, not by organising treatment services. If nuclear war occurs it will be the start of the final epidemic—and prevention is the proper medical response to that threat.

Regular Review

Recent developments in imaging techniques

IVAN MOSELEY

Hi-fi enthusiasts are now reaping the benefits of one of the more recent applications of electronic technology: digitisation of audio signals. Only the most technically aware understand more than the basic principles of data acquisition and analysis; the rest of us are content merely to listen to our equipment with even greater pleasure than before.

Parallel changes have occurred in diagnostic imaging; digitisation of radiological and other images and the application of computers to the manipulation of the data obtained have burgeoned very recently to provide diagnostic information of a quite different order from that previously available. Few of us engaged in clinical practice see all facets of image data processing. The purpose of this review is to explain, in non-technical terms, recent developments in data acquisition and analysis and to attempt an assessment of their potential clinical yield.

Computed tomography (CT)

Fringe experiments in analysis of radionuclide scans apart, the first major clinical application of image digitisation in radiology was computed x-ray tomography. Its principles and its impact on clinical practice are too well known to need

amplification here. The technology of computed tomography has continued to advance, however, particularly in data analysis; and many of the recent developments are unfamiliar to anyone other than a minority of radiologists, the more so since nearly all scanners currently working in Britain are obsolescent.

Of the numerous computer software developments, five can be identified as of present or potential importance. The first is multiplanar reformat facilities (fig 1). The axial plane, in which computed tomography sections are most commonly obtained, is relatively unfamiliar to most clinicians—and indeed to many anatomists. Physical constraints preclude positioning the patient to obtain other planes of section that might be more useful in planning a surgical approach. Modern scanners, however, within a few seconds can construct sections in coronal, sagittal, or a large variety of oblique planes, using the data from the axial sections. Recent programs even allow tortuous structures such as the splenic vein to be “unravelling” and shown throughout their length in relation to their surroundings. Programs under development permit three-dimensional reconstruction, with shading to indicate depth, and can “shine a light” on to the reconstructed body from any angle.

Second is the use of variable scan speed, contrast, and spatial

resolution. Most modern machines can operate over a range of times down to one or two seconds. They also have the ability to deconvolve the raw digital data in a range of ways to provide higher spatial or contrast resolution as applicable in specific areas of interest, without increased irradiation of the patient.

FIG 1—Multiplanar CT reconstruction. Form of large recurrent pituitary adenoma and its relation to the tentorium are clarified by coronal (above) and oblique coronal (below) reconstructions, using data from series of axial scans.

Thirdly, several methods can be used to obtain dynamic information from a series of static images. The passage of intravenous iodinated contrast medium through an organ can be traced, with sampling times that are as little as one-third of a static image cycle. Density-time curves in specific organs or regions can be produced almost instantaneously, and the computer will even produce functional images showing, for instance, the time from injection to peak density increase at every point of the body in a given plane, related to a grey scale.

Cardiac studies can be carried out in two ways: pulsing the x-ray beam by the electrocardiograph is the most obvious; but a more ingenious one is to carry out continuous scanning over eight to 10 cardiac cycles and then retrospectively to identify the x-ray data that correspond to 100 ms segments of the electrocardiograph cycle. When, say, 20 images representing the full cycle have been constructed, they can be displayed in real time on a television monitor. The clinical value of such programs will depend in part on the extent to which other developments mentioned below render them unnecessary.

Fourthly, virtually all scanners now being sold offer an alternative mode of image production—digital radiographs. The patient, on his couch, is moved between the x-ray source and the bank of detectors. A digital image of the region thus scanned is reconstructed by the computer and displayed in analogue form as an image resembling a conventional radiograph (fig 2). Unlike a conventional radiograph, however, it is amenable to digital analysis and interrogation. Currently this digital image is being used to identify the region from which computed tomography sections will be obtained and subsequently to indicate their levels. Another recent development enables the radiologist to identify the site of a lesion on the familiar axial computed tomography images, and then have it automatically outlined in the digital radiograph.

Fifthly, since computed tomography images are essentially maps of absorption of radiation energy, they give exactly the

information required by the radiotherapy planner for calculation of tumour and tissue dose. As allowance is made automatically for the different penetrance of rays in the diagnostic and therapeutic parts of the spectrum, true dose characteristics for the individual patient—rather than for an idealised body—can be obtained rapidly and easily from computed tomography data. A task that would occupy a trained planner for several hours can be carried out with greater confidence in a few minutes.

Digital radiography

Considerable advances have been made in producing clinically useful data with systems developed from the digital imaging by computed tomography scanners described above. A television camera may be used to scan the output from an image intensifier, digitising the signal and using a computer to produce analogue pictures. The radiation dose is smaller than with conventional techniques and the saving in very expensive radiographic film enormous.

Such analogue versions of digital images may well out standard radiographs in a few years; but the digital basis of the images confers other exciting possibilities, notably comparison of similar images.

One application of this procedure, still largely experimental, relies on pulsed irradiation using a beam of variable energy. The relative x-ray absorption of the body tissues such as bone and muscle varies with the wavelength of the beam. Comparison of the digitised versions of the emergent beam when the energy of the incident rays is changed can provide data from which an image can be constructed showing either the calcified structures or the soft tissues alone or in combination. Subtracting the bones from a chest radiograph or removing the overlying shadows from the spine is useful as well as entertaining.

Dual-energy digital radiography can readily isolate from its surroundings a blood vessel or a kidney containing an iodinated

FIG 2—Digital radiograph of legs with osteosarcoma of tibia. Picture is not digital version of conventional radiograph but is constructed de novo from digital data.

contrast medium of the type used in arteriography and urography. Rapid variation in x-ray kilovoltage presents several difficulties, however, and a more practical arrangement has been devised: digital subtraction angiography. The image intensifier and television camera are centred over the region of interest—for example, the cervical carotid or renal arteries (fig 3)—and a relatively small dose of contrast medium is injected rapidly into a peripheral vein. Digital readouts of the

FIG 3—Digital subtraction angiography. Outpatient aortogram for investigation of hypertension. Contrast medium (50 ml) injected into peripheral vein; entire study took 15 minutes. (Courtesy of Dr D Enzmann, Stanford University, and International General Electric Company, New York, Ltd.)

field of view are obtained just before, during, and after the arrival of the contrast medium in the arteries. The computer works out, in real time, how the images before and after contrast differ; and the video display unit shows the resulting angiogram, in which only the vessels are visible. Spatial resolution is slightly inferior to that of current intra-arterial angiograms but is diagnostically adequate. I recently saw one nurse and two radiographers carry out five carotid angiograms, one renal angiogram, and an angiocardigram on outpatients in 90 minutes. Intravenous pulmonary and aortofemoral angiograms of high diagnostic quality are also easily obtained.

There can be little doubt that when the first units are installed in Britain (probably within the next year) we shall become aware of a genuine contribution to the management of patients and an enormous saving in x-ray film. Development of data analysis systems has proceeded apace: computer calculation of blood velocities, cardiac ejection fractions and phase disturbances, and myocardial perfusion is available now. A combination of dual-energy and digital-temporal subtraction (hybrid subtraction) could theoretically remove many of the movement artefacts that can be a problem in examination of some regions; at present about one in every 10 intravenous carotid studies is invalidated by swallowing induced by the contrast medium.

Nuclear magnetic resonance

Data acquisition in nuclear magnetic resonance owes nothing to computed tomography technology, but rapid

development of its data analysis systems has benefited enormously from achievements in the latter.

Nuclear magnetic resonance uses no ionising radiations; the property of nuclear magnetic resonance is common to many chemical structures and the method has been used in chemical analysis for over two decades. Its application to biological imaging is more recent, and, like computed tomography, has been pioneered in Britain. When any body containing protons is placed in a strong magnetic field, about one-millionth of those protons align themselves with the field. They may be dislodged by a short burst of radiofrequency waves, after which they resume their previous alignment with the emission of a small amount of characteristic energy. The fundamental advance in nuclear magnetic resonance imaging is to place the body within a spatially graduated magnetic field, so that the characteristics of the energy release identify not only the nature of the proton but also its site.

Several centres in Britain are now producing images based on proton density that rival in spatial resolution all but the most modern computed tomography scanners (fig 4). Nuclear

FIG 4—Nuclear magnetic resonance. Midline sagittal section of head. Data from certain volume of tissue collected over about 10 minutes, after which such sections can be constructed in any required plane. Note strong signals (white) from subcutaneous fat and from bone marrow in the basisphenoid. Cerebrospinal fluid appears black, though rich in protons; this is probably due to its motion. (Courtesy of Technicare Imaging Ltd.)

magnetic resonance has several potential advantages over computed tomography. Firstly, images can be constructed de novo in almost any plane within the body. Secondly, since the nuclear magnetic resonance is a complex phenomenon, there exists a considerable theoretical potential for characterisation of tissues, though recent nuclear magnetic resonance analysis of cerebral biopsy specimens in vitro suggests that differential diagnosis will be if anything less accurate than with computed tomography. Thirdly, some regions relatively inaccessible to computed tomography (for example, the spinal cord) pose fewer problems for nuclear magnetic resonance. Finally, so far as is known, the magnetic fields and radiofrequency waves employed are devoid of significant biological effects. In the current atmosphere of more or (frequently) less informed

antipathy to the use of radioactive substances, this factor may prove a social rather than biomedical stimulus.

The drawbacks of nuclear magnetic resonance should not, however, be played down. Data acquisition is slow, of the order of 10 minutes; the equipment is costly—of the same order as a computed tomography scanner—and bulky: a whole-body nuclear magnetic resonance unit two metres long and one metre in diameter weighs about 4000 kg (4 tons) and contains superconducting magnets with their problems of handling liquid nitrogen and helium.

Since units are now available commercially, studies to establish the clinical utility of nuclear magnetic resonance must be of high priority. As yet we do not know whether it will be an adjunct to computed tomography or whether it will supplant it. Since up-to-date installations of either kind cost about £500 000 we cannot realistically conceive of them operating side by side in the average district general hospital.

Emission computed tomography

Emission radiography, using injected or inhaled radio-nuclides, is not a new technique but it has developed recently as a result of the application of data acquisition and, more importantly, data analysis technology. Indeed, work in the latter antedated x-ray computed tomography.

While there is no doubt that the diagnostic accuracy of isotope studies has thereby been increased, application of the results has been limited by poor spatial resolution, lack of specificity, and an inability to display, for example, some cerebral structural lesions without blood-brain barrier defects. Even with the most refined techniques, emission tomography seems most promising for metabolic studies. With the use of short-lived isotopes such as oxygen-15 or deoxyglucose labelled with fluorine-18, transverse sectional images of the brain can be constructed to give quantitative information about regional blood flow, oxygen extraction and utilisation, or glucose uptake. Extremely interesting data on the balance between perfusion and tissue necrosis in ischaemic infarction have already been obtained that could in the long term persuade us to modify our views on the management of stroke (fig 5).

Emission tomography is essentially non-invasive and relatively inexpensive, but its diffusion will be restricted by the need for access to a cyclotron for the short-lived isotopes.

Conclusions

Radiology made relatively few fundamental advances in its first 75 years as a specialty, while in the past 10 years quite unforeseen changes have occurred. At the recent Radiological Societies of North America Exhibition in Chicago (the Motor Show of the radiology industry) many of the major manufacturers unveiled their new computed tomography scanners, digital angiography units, and nuclear magnetic resonance imagers. In my own hospital the annual medical equipment budget for all departments combined would fall short of the price of any one of these. While good clinical medicine must

FIG 5—Positron emission CT. Scan performed eight hours after cerebral infarct. There is focal reduction (black area) in cerebral blood flow (CBF), reflected by avid oxygen extraction (OER), which is insufficient to maintain oxygen consumption (CMRO2). This pattern of "critical perfusion" thought to indicate acute ischaemia. (Courtesy of Drs R S J Frackowiak, R J S Wise, and staff of the Physics Isotope Section, MRC Cyclotron Unit, Hammersmith Hospital, London.)

come first, we must not forget that most of these recent developments aim to extend our diagnostic range and to replace erstwhile invasive procedures with simple, reliable, anodyne, and cost-effective screening methods. To rule out widespread use of modern technology because of the major financial investment needed could prove shortsighted.

IVAN MOSELEY

Consultant Radiologist,
National Hospital,
London WC1N 3BG

Correction

Schools of public health

The personal review by Professor Roy Acheson (20 February, p 534) wrongly stated that Professor Le Quesne had recommended that the department of nutrition should move from the London School of Hygiene and Tropical Medicine. Professor Le Quesne in fact said: "The distinguished work of this department might strengthen its links with clinical medicine."