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# Imaging for Neurological Disease: Current Status and New Developments

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Approximately a century ago we were in the process of discrediting phrenology which attempted to predict behavior on the basis of the shape of the skull. With the advent of x-ray it was possible to detect fractures, tumors and infections which altered the structure of bone, and to use the frequently calcified pineal gland as a marker of shifts in the intracranial structures. In the years surrounding World War I we learned to use the introduction of air in the cerebrospinal fluid to achieve x-ray contrast for the definition of intracranial contents. Just prior to World War II came the ability to visualize the arteries and veins of the head by arterial injection of x-ray opaque substances; similar agents were injected into the cerebrospinal fluid. Over time these techniques gained in sophistication and safety but were associated with substantial limitations of accuracy, risk, and discomfort. The advent of computerized tomographic (CT) radiography of the skull and spine in the 1970s provoked a real revolution in the speed, accuracy, and safety of neurological diagnosis. Now magnetic resonance imaging (MRI) provides better accuracy and safety without an improvement in speed. Other technologies beckon and it is hard for any of us to confidently predict the future.

The advent of the new neuroradiological techniques has been of enormous benefit to patients and to the quality and efficiency of medical care. They have profoundly affected the behavior of physicians and hospitals. Traditionally, it was common to house patients in the hospital for days or weeks to achieve with substantial pain and risk what can now be seen in an hour with a CT or MRI. As these new techniques become widespread it will be increasingly clear that we need fewer hospital beds. Much of the old technology persists and is needed from time to time to provide details which newer techniques cannot reliably provide at present. This equipment is often old, costly to maintain, and used with efficiency only in large medical centers. This, together with the high capital costs of new equipment and the gradual effects of clumsy efforts to reward efficiency will favor large medical centers over smaller ones. Many smaller urban hospitals will close or change their function. Smaller but essential rural hospitals will have serious financial problems and will thereby tend to rely on now outmoded technologies. Within the profession, control of

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diagnostic procedures and revenues is increasingly shifting to radiologists and away from neurosurgeons and neurologists. The actual illness cost per patient to care for many diseases is down if one can discount the high debt services of new equipment.

In many instances the limited partnership is the new form of fee splitting. If I invest in an MRI or multipurpose imaging center, I have an incentive to refer patients to that unit. We personally regard this as unethical; however, ethics of this sort have been in poor shape for a long time. Attempts to make mobile units have attracted lots of capital, have fared better than would have been predicted— and such units are attractive to the smaller hospital or medical group.

It is difficult to predict the future economies of medical imaging without an examination of the context in which it will occur. We are rapidly moving to a linked three tier system of medical care. The affluent will retain and pay dearly for freedom of choice to use the doctor and hospital of their preference. The vast middle group of Americans will accept limitations of choice in various prepaid programs. The poor will go back to county hospitals and clinics or to facilities which contract for these services. The affluent group gets smaller with each rise of premiums. The services for the poor will be undercapitalized. The economics will be dominated by the middle group which will increasingly press for cost cutting measures. In the long run this will favor larger hospitals, larger medical groups, and those with the least debt. In short, the rich will get richer and the poor will get poorer. We do not forsee the advent of small, cheap, inexpensive imaging technologies which will favor the solo practitioner, the small hospital, or the small medical group. It may work for a time in a few fields but it is improbable in the long term for the same reasons that we have seen a decline in the number of automobile companies, aircraft manufacturers, and similar industries with high cost of capital. Medicine is becoming a large corporate enterprise and those who seek to invest in companies will do best with those companies which have a record for innovation and efficiency, for providing good equipment, good terms, and good service. The old American x-ray manufacturers were stodgy and got pushed aside by the Europeans; General Electric, Johnson and Johnson and a few others have regained some turf but small companies with new ideas, particularly those in Japan, will give them a run for it. In sum, we will see large corporate medical organizations which will lease or purchase evolving technology, balancing price and service as they do so.

What technologies will they purchase? There will be a continuing need for ordinary x-rays of the skull and spine. Film may be replaced by digitized imaging but impetus for this will lag unless the price of silver soars. We still need better, safer, and water soluble x-ray opaque agents for myelograms and arteriograms. These studies will become less frequent but the need for some will persist. Computerized tomography will be the workhorse of the average hospital for many years. The need to develop inexpensive, sturdy CT machines for export will grow and will be tied to the value of third world economies. Countries such as Brazil—which cannot afford the measles vaccine to save one of every 500 children— will not quickly buy CT scanners to save for a decade or so for a smaller population of adults. The third world will need birth control, food, sewage, and clean water for a long time before it needs a high volume of diagnostic technology. In the first and second worlds the CT will probably continue to be an important factor for another decade or two. Much will depend on progress in magnetic resonance technology.

## MRI and CT Imaging of the Nervous System

For the nervous system there are rather few instances in which current CT scanning is superior to MRI and there are very many instances in which current MRI is superior to CT scanning. The major drawbacks to MRI are initial costs and the duration of a single study. If the duration of single studies can be reduced from 40 minutes to five minutes, and if consecutive thinner slices can be sampled, MRI will rapidly supplant CT for most purposes in developed countries even at current prices. If versatile magnetic fields can be created at lower costs, the rush to MRI will accelerate. Both time and cost will fall but the rate of change is hard to predict. Hard strapped hospitals and the declining value of depreciation will slow the shift to newer technologies.

The development of various agents such as particular rare earths to highlight certain magnetic properties will be substantial; such techniques may largely supplant arteriography and ultrasound (Doppler) technologies. Magnets of high power will permit spectroscopy to expand the diagnostic power of MRI. Current images are based on the magnetic resonance of hydrogen nuclei or proteins (Ramsey, 1984). Spectroscopy will initially focus on phosphate nuclei. The metabolism of the brain and other organs "burns" sugar in oxygen to produce energy, carbon dioxide, and water. Energy is stored as organic phosphates which is then released for nerve conduction, muscle contraction, and other forms of work. The state of these phosphates in the image of a tissue can provide information on its recent metabolism and its state of activity. Magnetic resonance imaging of protons will not distinguish a live animal from a recently deceased animal. Imaging of phosphates will measure the energy potential of tissue and will change with death of a tissue or impaired blood supply to a tissue. If it is possible to do accurate MRI spectroscopy with surface coils with portable equipment in an intensive care unit, this will be a powerful tool in the day to day evaluation of relative health in various tissues but particularly in the heart and brain.

## Positron Emission Tomography

Positron emission tomography will prove to be a very sensitive measure of local metabolism in the brain. Using radioactive isotopes of short half-life one can tag many metabolic pathways and localize their use in the brain. One can also do these studies while the brain is carrying out a particular task. For instance, if you think about throwing a ball with your right arm a small area in the left cerebral hemisphere will increase its metabolism of radioactive glucose. If you actually throw a ball an adjacent area will light up. Yes, Orwell's Big Brother may in fact be on the way to make the current lie detector as silly as the medieval proclivity to judge guilt based on the pendulous character of ear lobes. Positron emission tomography has already become superior to other technologies for the detection of an epileptic focus and in the clinical diagnosis of Alzheimer's disease (de Leon et al., 1983). PET will be a very potent tool for study of the local action of many drugs within the nervous system and elsewhere in the body. Clinical pharmacology will be greatly advanced by PET technology. We are a little surprised that the major pharmaceutical houses have not rushed to support and control university centers of PET scanning. At the University of California Irvine, a PET scanner in the Department of Psychiatry is dedicated to the study of mental illness. It is likely that the PET scanner will bring to psychiatry what the CT brought to physical disease of the brain. With precise techniques to measure psychopathology and precise techniques to study psychopharmacologic agents, psychiatry may quickly move to become a more precise science.

The value of PET scanning to study human behavior and the basic aspects of fatigue and sleep will be a great step forward. Further, PET scanning is not much more costly than MRI or CT technologies. The problem rests in the cost of generating short-lived isotopes which require an adjacent cyclotron. A cyclotron and a house for it are likely to cost about $2,000,000.00. Positron emission tomography will remain an instrument for the major research center for a long time to come. Single proton emission tomography is a poor cousin of positron emission tomography (Coleman, Drayer, and Jaszczak, 1982). It may be a valuable research tool under some circumstances and, with new isotopes may provide a valuable clinical service.

## Ultrasound

The role of ultrasound in the diagnosis of nervous system disease has a long and nondistinguished history. At present its value is limited to studies of large blood vessel flows in the neck and the intraoperative definition of tumors. Use of ultrasound to examine vessels has been vastly improved by combining pulse-gated Doppler and ultrasonography to produce what is known as duplex ultrasonography. The virtue of ultrasound is its safety and easy use at the bedside, most notably in obstetrics (Ramsey, 1984). The bony skull and spine limits ultrasound in the nervous system. On the other hand, the potential of ultrasound to study muscle and particularly muscle spasm is greatly underestimated. If the money wasted on using ultrasound as an expensive high tech alternative to the heating pad had been spent on using ultrasound to study the parameters of muscle spasm we would be far advanced.

## Ancillary Neurodiagnostic Technologies

Electrophysiology has progressively enriched our diagnostic approach to nervous system disease for many years. Electromyography, nerve conduction studies, evoked potentials, and electroencephalography will continue to be important tools with continued refinements. Computerized mapping electroencephalographic techniques are currently in fashion but have little to offer except pretty pictures of physical diseases of the brain; for studies of psychological states they may be of some value.

Nuclear medicine utilizing more durable isotopes remains an important resource outside the nervous system; we have a hunch that traditional nuclear medicine may still provide less expensive means to address some of the issues for which we currently turn to positron emission tomography such as localization of neurotransmitters and immunological events (Chiu, McWilliams, and Christie, 1978).

Magnetometric devices to record spontaneous or modified magnetic fields over the surface of brain and muscle remain an investigative tool of uncertain value. While this technique is not without its enthusiasts, it has drawn venture capital for a decade without creating much hard evidence of clinical value. It may be a winner but the risk is substantial.

Intervention techniques which use long delicate catheters to introduce balloons, lasers, radiation sources, and chemicals into smaller and smaller vessels is a highly specialized field utilizing fairly traditional radiology but extraordinarily fine catheters which are better and more exact each year. Angioplasty has sharply reduced the need for coronary surgery and is likely to serve a similar role in peripheral blood vessels. The use of balloons and similar devices to close holes in arteries is an extraordinary and successful tour de force but is not an investment opportunity unless these techniques can become routine in the management of aneurysms and arteriovenous malformations. Neurosurgeons will be as loathe to give up this turf as the heart surgeons were to surrender the coronary artery.

## Final Comments

The explosive growth of new techniques for imaging the nervous system will intrigue and reward the clinical investigator for years to come. The major growth in diagnostic capability will be in magnetic resonance technology. The present authors are not physicists nor radiologists, but the science of magnetism is in its infancy, is not well understood by the physicist, and is new ground for the radiologist. Hence, the contemporary hospital administrator must be cautious and not assume that the newest idea is the best idea. Progress will rest with those who can make the most versatile and powerful fields containing the shortest possible intervals of imaging. It may prove to be that as with computers in general, and CT scanning in particular, over time the last shall be first on the "user" side. But those with the capital and initiative to start early and keep plugging may persevere and prosper, as General Electric has done so far with computerized tomography.

The papers that follow address the major advancements that have occurred in neuroradiology. Each of the technologies are reviewed with respect to their use in clinical neurodiagnostics. The utility of brain imaging in the practice of neurology, neurosurgery, and psychiatry, has greatly contributed to the ever increasing precision in neurological diagnosis. It is our hope that this special issue affords some perspective to the interdisciplinary readership of *The Journal of Mind and Behavior* on the power of these fast evolving biomedical techniques.

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