PET and NMR: New Perspectives in Neurolmaging and in Clinical
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THE IMPACT OF THE NEW TECHNIQUES IN THE NEUROLOGICAL SCIENCES

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INTRODUCTION

In our century new imaging technologies represent the most dramatic progress in medical, and particularly in neurological, diagnostic procedures. After the revolutionary detection of x-ray in 1895 it took more than five decades to develop a second way of imaging, i.e., nuclear medicine.

Ten years later the ultrasound technique, including Doppler sonography, was put into diagnostic use. Some 15 years ago computerized tomography (CT) was invented, and five years later the principle of magnetic resonance tomography was described (Fig 1).

The quick development of biomedical techniques has led to a revolution within the neurological sciences. These new techniques" serve scientific research and clinical usage, with enormous implications for the patients. In this contribution CT, magnetic resonance imaging (MRI), positron emission tomography (PET), digital imaging methods, and sonography are presented as new techniques.

When in 1973 Hounsfield introduced the technique of "reconstructive tomography" in medicine, a new era in medicine had begun.

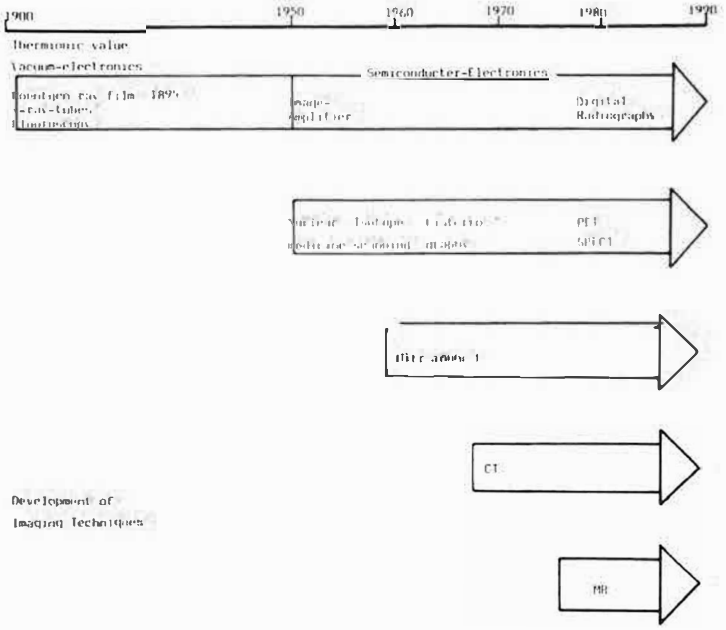

Figure 1. Development of imaging techniques.

The principle is simple: in order to get a glimpse of the section on a certain level, the signals of these slices are measured at certain angles. The sum of these signals can be divided into corresponding point-signals by a computer by means of a "reconstructive-algorithm". Thus one gains a two-dimensional picture of the slices. This basic principle applied to different signals led to tomographic methods, i.e., transmission computed tomography (TCT), single photon emission tomography (SPECT), PET, and MRI.

The development of these new techniques has increased world wide needs for imaging methods tremendously. Between 1978 and 1988 the financial expenses of 6 billion German Mark are supposed to double. The introduction of MRI has further increased these expenses. The decrease of conventional radiology and the growing of the new techniques like ultrasound, CT and MRI are remarkable (Fig. 2) (Graßmann, 1984).

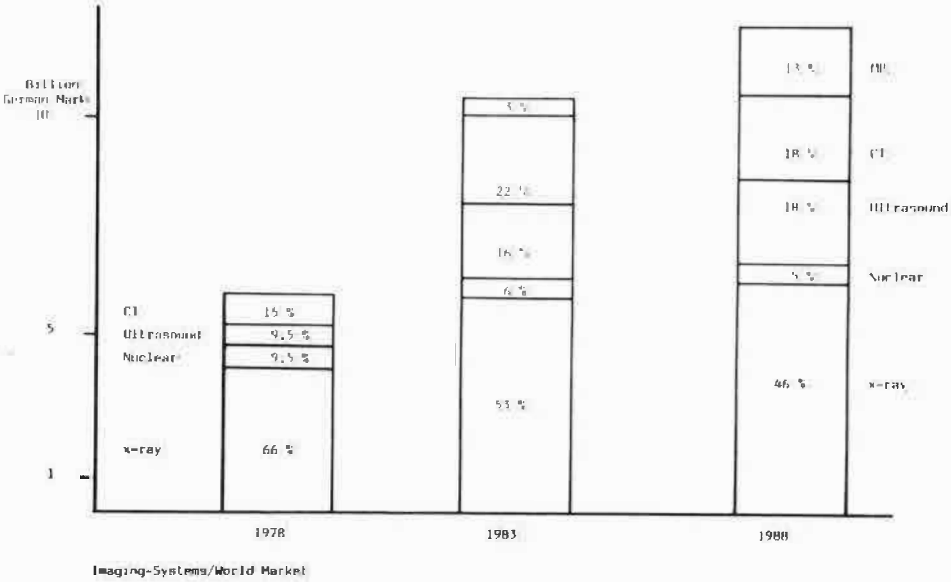

Figure 2. Imaging-systems/world market.

The impact of these new techniques is threefold, concerning scientific, health, and economic aspects. CT, MRI, and PET will serve as models in this contribution.

TRANSMISSION COMPUTED TOMOGRAPHY

Scientific Impact in Neurology

The imagination and ingenuity of Hounsfield and Ambrose refined the concept of Oldendorf (1961) by which differing radiodensities of the internal structure of a complex object could be electronically displayed in a manner differing from the two-dimensional facility of radiographic film (Oldendorf, 1961).

The availability of a technique that demonstrates the geography and character of both normal and abnormal intracranial structures without the necessity of air contrast in the cerebrospinal fluid space or catheter vascular contrast studies has altered the neurodiagnostic approach to intracranial clinical problems dramatically.

CT scanning has been compared extensively with all preexisting imaging methods and neuropathological procedures and finally CT was acknowledged, technically and scientifically, as an established diagnostic modality. Brain research without CT is unthinkable. CT is an integral part of neurological sciences, research, and neurological diagnosis and it represents a prerequisite for development of new neurological stereotactic methods and aids the regimen of radiotherapy.

Even after the introduction of MRI, CT is still of great importance, e.g., in establishing quick diagnosis in neurotraumatology. Of all brain tumors 98% are detected by CT, whose histological specificity reaches 90%. CT accounts for a large part of "in vivo" or "living" neuropathology (Gerstenbrand, Grčević, Aichner, 1985).

CT represented a considerable expansion of the possibilities available for the neuroradiological investigation of the base of the skull, spinal column, and spinal cord. The development of multiplanar reconstruction technique in the sagittal, coronal, or oblique projections with quasi-three-dimensional imaging and of the high quality, surface reconstruction imagery from sets of CT scans provides a new perspective on the information contained in sets of continuous CT scans and have been enthusiastically received by neurosurgeons (Aichner et al., 1985, Vanier et al., 1983).

Economic and Health Impact of CT

In 1983 a total of 6900 CT scanners was counted in the USA, Europe, and Japan, which had the highest density of these three regions (Fig 3) (Graßmann, 1984; Evens, 1981).

Economic analysis reveals that CT leads to marked reduction of health expense, since the patient does not necessarily need to be admitted. The admission time is shortened and other expensive investigations can be omitted without damage to or danger for the patient (Evens, 1981).

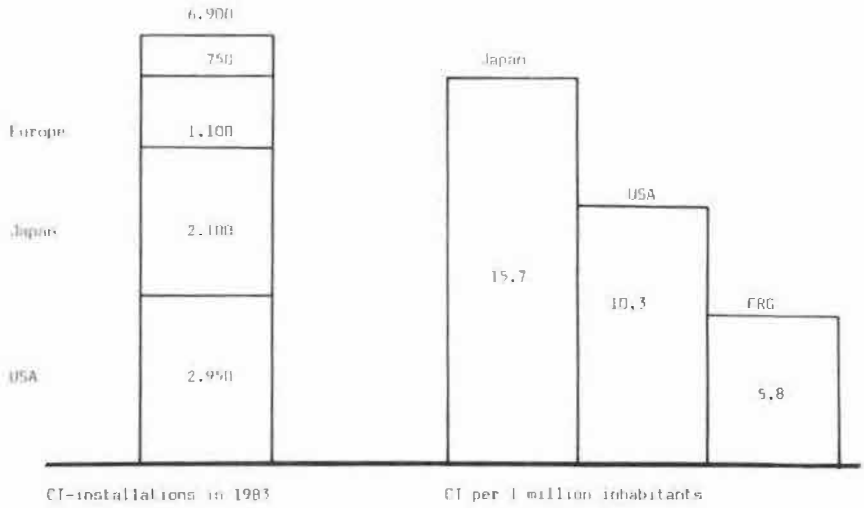

Figure 3. CT-installations in 1983.

MAGNETIC RESONANCE IMAGING

Scientific Impact in Neurology

Tremendous progress has been made in the short time since MRI has assumed a major role in neuroimaging. MRI will make major contributions in both the basic sciences and clinical use. "MRI has so much to offer to so many fields that it should not be confined to any one. This would be a disservice to the patients for which medicine exists" (Oldendorf, 1985).

At present the consensus seems to be that MRI and its cousin CT are complementary in this and other imaging applications. In reviewing the evaluation of abnormalities related to the brainstem, basal ganglia, temporal lobe, and spinal cord, it is said MRI is far more accurate than CT, cisternography, or pneumoencephalography.

The impact of MRI on the field of epilepsy is still unknown. MRI will probably be very useful in diagnosing focal lesions of a wide variety that might be epileptogenic. From recent studies it is clear that much more information about the brain is obtainable by MRI than is possible by CT (Laster et al., 1985). The interictal hypometabolism surrounding epileptogenic foci demonstrated by PET scanning may have certain correlates with MRI. It is not yet possible to predict the contribution MRI will make to epilepsy but it shows great promise.

MRI of the brain and spinal cord provides anatomical detail superior to that of CT. The image quality is superior to CT in areas such as the posterior fossa and spinal canal. MR scanners probably will replace CT within the next years for most brain scanning purposes and will offer considerably greater tissue characterization.

At the present the histologic specificity of MRI appears to be less than that of CT since diseases of widely varying causes and histology have prolonged T_1 and T_2 relaxation times. Recent investigations suggest that relaxation times will not be specific enough to differentiate benign and malignant tumors of the central nervous system because of considerable overlap.

It seems clear that MR technology and scientific understanding are nowhere near being mature. Scientists are beginning to explore higher field strengths, the applications of surface coils, and the development of paramagnetic contrast medium (Bilaniuk et al., 1984; Schenck et al., 1985; Runge et al., 1983).

The combination of an imaging approach without ionizing radiation with the capability to produce high resolution and three-dimensional images and the potential to assess metabolic and tissue functions makes MR one of the most exciting technologies ever to be applied to neurological sciences.

In vivo MR spectroscopy to date has been limited by the need for a high strength magnetic field of superb uniformity and has generally been accomplished using surface coils. Much in vivo spectroscopic work has focused on 31 P because of its important role in energy metabolism and intracellular pH in ischemic and metabolic disorders.

Phosphorus nuclear magnetic resonance [^{31}P NMR) spectroscopy has recently been shown to have great potential for monitoring the metabolism of mobile phosphorylated compounds in vivo. Most studies in human beings have focused on the response of skeletal - muscle metabolism to exercise and pathologic changes in muscle metabolism due to genetic deficiencies.

Preliminary work has been reported on neonatal brain (Younkin et al., 1984). Recent studies have shown that several tumors have different ^{31}P-spectra and that these spectra change over time and in response to treatment. ^{31}P NMR can be used to detect tumors in situ and will be able to monitor their response to treatment (Evanochko et al., 1984; Maris et al., 1985). Spectroscopy is a great hope, but the more we evaluate its usefulness, the more we realize how much we have to learn.

Economic and Health Impact of MRI in Neurology

MRI is certainly one of the highest priced technologies that we have ever seen because of the equipment costs, construction problems, and the inability to charge at this time. Economics will always be difficult for the future. Regulations and certificate of need will cause further problems.

It is beyond doubt that MRI results in high safety, security, and rapidity in neurological diagnosis, which is of great importance and is possibly life-saving, e.g., in the field of neurotraumatology or neuro-intensive-care-medicine. MRI information will reduce other diagnostic modalities and already reduces the hospital stay of the patients.

Many patients can be saved from invasive investigations, thus minimizing the patients' risk. The resulting humanitarian aspect should be stressed in particular. If applied responsibly MRI can result in reduction of costs and expenses to the same extent that computers and modern techniques have done in other fields of research and economics. The main effects of the neurodiagnostic imaging systems on the health expenses consist in the replacement of other diagnostic procedures, in the shortening of stay at the hospital, and in the shifting from in-patient care to outpatient care.

The world-wide increase in the number of neurologists includes the risk of overuse of the mentioned techniques. While in 1963 only 1822 neurologists were registered in the USA, this number has increased to 5142 in 1980, i.e., 2 neurologists per 100,000 population (Menken and Sheps, 1985). The increased and generous use of these new imaging technologies does not lead cogently to benefit in the outcome of the patients. Many additional examinations seem to add little information that cannot be obtained from a careful neurological history and examination. Many neurologists expect their patients' problems to be solved by the new technologies and every patient demands it. There is a serious need to find a middle course between blind acceptance of the new technologies as routine investigation, valuable procedure for an individual's problem, and experimental studies. On the whole, the availability of CT and MRI should not be restricted for financial reasons.

CT and MRI represent the standard imaging methods for "in vivo neuropathology" or "living neuropathology". MR spectroscopy and PET allow the visualization of neurochemistry and neuropharmacology; however, the meaning of the imaged spectra has to be interpreted in the future.

POSITRON EMISSION TOMOGRAPHY

PET is a method for measuring the distribution of radiotracers labeled with positron-emitting isotopes such as ^{11}C, ^{18}F, and ^{15}O and has been used to quantify regional glucose utilization, oxygen utilization, blood volume, blood flow, blood-brain barrier permeability, pH, and amino acid utilization. Recently dopamine and opiate receptors were imaged noninvasively by PET in human brain using dopamine antagonist and carfentanil. Opiate receptors and endogenous peptides have been implicated in conditions such as depression, schizophrenia, Parkinson's disease, senile dementia, pain, etc. (Frost et al., 1985; Wagner et al., 1984). The impact of PET on the neurological sciences has yet to be realized. Epilepsy may be one of the proven diagnostic applications to date. EEG and PET are good localizers of epileptic activity and should be considered complementary. The combined use of PET and EEG adds an important new dimension to the clinical investigation of patients with surgically treatable lesions (Mazziotta and Engel, 1984).

Whether the complexity and cost of PET can be reduced through technological advances such as development of small cyclotron technology and semiautomated production of positron-labeled radio-pharmaceuticals should become more clear in the future. If such advances can be accomplished, then wider dissemination of this technology should follow. Its impact on basic neurological science and clinical practice will undoubtedly be realized.

CONCLUSION

Much of the progress in clinical neurology during this century has come from the development of new diagnostic procedures, and several of these new technologies have resulted in new ways of imaging the central nervous system. Each of the brain imaging techniques depicts some structural and/or functional characteristic of the brain; imaging of the brain structure by CT and MRI and imaging of the neurochemistry and neuropharmacology using MR spectroscopy and PET certainly offer a promising perspective for coming years.

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