Introduction into modern aspects of neuroimaging

F. Gerstenbrand

University of Innsbruck, Head of the Department of Neurology, General Secretary of the Research Group of Neuroimaging, World Federation of Neurology, Anichstraße 35, 6020 Innsbruck, Austria

The complexity of the human central nervous system and its information processing pathways still is only partly understood. The necessity to correlate neurologic symptoms and neuropathology to neuroimaging modalities is obvious, especially when introducing a new technology into diagnostic workups.

When the World Federation of Neurology decided on the foundation of a research group on Neuroimaging, the goal was to integrate developing morphologic and functional imaging modalities into clinical neurology, neurophysiology and neuropathology. An interdisciplinary and complementary approach to improve the understanding of normal and diseased brain should be established and an international platform created for all scientists working in this field. The purpose of the present symposium on neuroimaging during the XIV World Congress on Neurology, is directed to provide an overview of the current technologies and future potentials as well as dedicated exchange and distribution of the rapidly increasing knowledge.

In the discussion of new methods it should be remembered that it was even before Wilhelm C. Röntgen detected X-rays, when Sir William McKuen diagnosed an intracerebral abscess in an 11 year old boy who was still alive. Three years later, in 1879, he operated on a subdural hematoma entirely based on clinical diagnosis. Six years later Alexander H. Bennet, from the Hospital of Epilepsy, London, diagnosed a right rolandic fissure neoplasm in a 25 year old patient, who subsequently underwent surgery performed by Rickman G. Godlee. From our present day point of view, with all the modern imaging modalities at hand, it is hard to understand that classical neurology succeeded in exact topographic anatomical location of intracerebral and intraspinal pathologies before the advent of neuroimaging.

X-ray examinations of the head and spine rapidly became a subspeciality of radiology. Professor Arthur Schüller (Vienna) based on his important contributions to that field, is considered the founder of neuroradiology (Fig. 1). However, plain X-rays only visualize bony structures and the development went on to the introduction of positive and negative contrast agents. Myelography is still used in the clinical routine, whereas pneumoencephalography today is obsolete in diagnosis of CNS disorders.

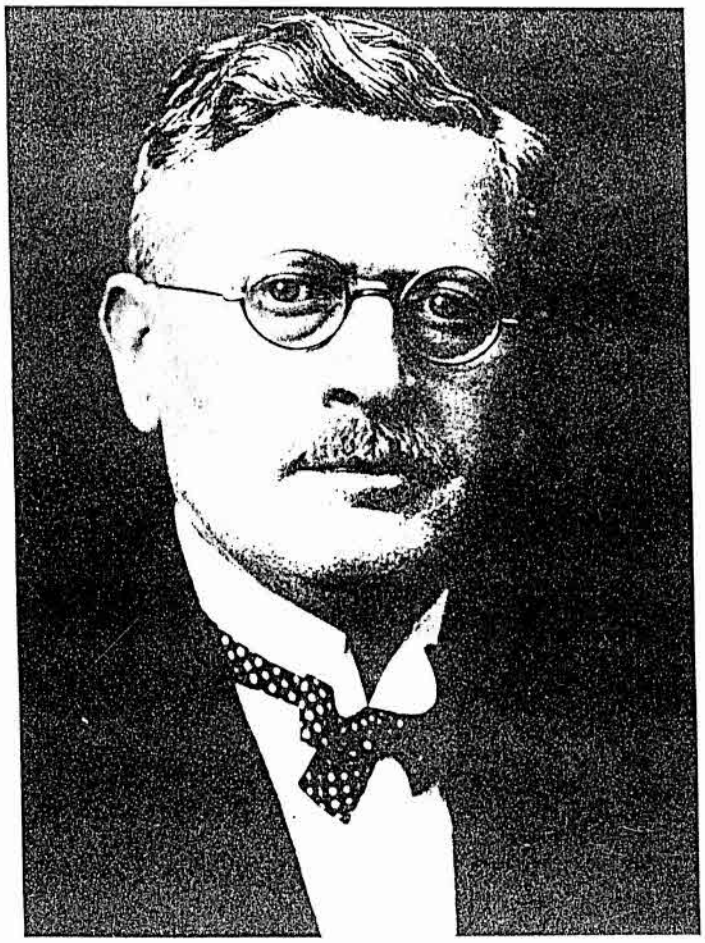

Fig. 1. Arthur Schüller (1874–1957) (taken from 'Bildarchiv des Institutes für Geschichte der Medizin der Universität Wien').

Fifty years after the introduction of X-rays Egas Moniz described the brain as a dark continent. Moniz, Professor of Neurology in Lisbon, first used intravascular contrast agents and developed arteriography, but brain morphology was still not directly visualized.

Therefore the introduction of computed tomography by Hounsfield may be referred to as the first revolution in neuroimaging. Rarely in the history of medicine has a discovery swept the diagnostic world as rapidly as computed tomography. The very first patient of Ambrose and Hounsfield had a left frontal lobe tumor and Ambrose described his excitement with the words: "The result caused Hounsfield and me to jump up and down like football players who just scored a winning goal".

Later, direct visualization of brain morphology raised the concept of living pathology introduced by Grcevic. Modern computed tomography equipments allow the high resolution display of even small bony near structures like the pituitary gland, and slice thicknesses of less than 1 mm are possible. Dynamic CT and Xenon-CT point new ways to the evaluation of brain perfusion and represent an approach to combine functional with morphologic imaging.

Bloch and Prucell in 1946 independently recognized the physical phenomenon of nuclear magnetic resonance. For more than 30 years NMR was used in the physical and chemical laboratories to study molecular structure. New magnet technologies and computer equipments gave way to the second revolution in neuroimaging, the experience that nuclear magnetic resonance may be used to obtain cross-sectional images. The first NMR head scan was obtained on May 28, 1979 exhibiting superior soft tissue contrast to computed tomography in a completely noninvasive manner (Hulkes et al., 1980).

During the last decade MRI rapidly developed to a routine clinical method, providing unique information about central nervous system structures and pathologies. Today MRI is recognized superior to CT considering most CNS disorders, based on excellent soft tissue contrast, accentuation of relaxation parameters, multislice capability in multiplanar orientations and the absence of bony artifacts. For the first time noninvasive diagnosis of spinal cord and the adjacent tissues became possible.

The inherent sensitivity of MRI to flow now can be used clinically for selective visualization of vascular structures, referred to the term MR angiography. Combined with MR imaging a rapid and completely noninvasive approach to morphological and vascular diagnosis in cerebro-vascular disease reaches daily routine.

Gradient echo sequences also enable isotropic 3D imaging of the whole brain with the capability of arbitrary reconstructions and postprocessing, directing to improved surgical and irradiation planning.

However, magnetic resonance is not limited to proton imaging, first applications of sodium imaging in cerebrovascular disease and tumors had been reported. Magnetic resonance spectroscopy now can be performed in vivo, providing new insights into brain metabolism. Observation of phosphor metabolites in a definite volume of tissue was shown useful in perinatal asphyxia and therapy monitoring of intracranial neoplasms. The latest introduction is proton spectroscopy, which allows (after suppression of the dominant water peak) observation of low concentrated metabolites like choline, creatine and N-acetyl-aspartate in vivo. Demonstration of lactate within the brain exhibits an unexpected capacity in the evaluation of cerebral infarction.

Some hundred times more sensitive than MR spectroscopy, positron emission tomography (PET) is used to visualize brain function. Today a range of more than 200 biochemical substrates have been labeled with short-living radio-isotopes, including aminoacids, carboxylic acids, amides, amines, alcohols, sugars, steroids and specific substrates, analogues and drugs. Not only are pathologic conditions investigated using PET, physiologic activation of distinct brain regions may also

be demonstrated under normal conditions. Major clinical applications are directed to the differentiation of dementias during its early stages and to determine treatment efficiencies.

Based on high costs and short living isotopes PET will probably be restricted to major medical centers. Less expensive, Single Photon Emission Tomography (SPECT) can be performed on a routine basis and new radio-isotopes enable important information regarding brain perfusion and tracer utilization on various pathologic conditions.

Another functional examination modality was finally introduced into neuro-imaging. After Berger's discovery of EEG in 1929 clinical neurophysiology grew to a powerful examination in neurological disorders. The development of more sophisticated computers now enables mapping of electrophysiological activity of the brain surface based on conventional EEG leads and the possibility to integrate functional data into other morphologic imaging results. Whereas EEG is restricted to superficial electromagnetic potentials, Magnetencephalography, just leaving experimental laboratories, point a new way to the investigation of electrophysiological data of the deep structures within the brain. Also evoked potentials developing to visualize the patency of neural pathways.

It is important to recognize that all the modern technologies were not introduced to replace each other but to complementarily improve the assessment of central nervous system disease. Computed tomography depending on X-ray absorption of heavy nuclei reveal another morphological information than Magnetic Resonance Tomography, which is related to interactions with small nuclei. Both together introduce a multinuclear morphologic approach. Finally CT as well as MRI developed to answer functional questions, XENON-CT in direction to perfusion studies and Magnetic Resonance Angiography towards vascular diagnosis.

On the other hand Magnetic Resonance Angiography will certainly not replace conventional X-ray Angiography, but will determine a more selected indication. Conventional angiography changes more and more to a therapeutic technique in the hand of the interventional neuroradiologists.

Further, complementary information will be completed using PET, SPECT and EEG mapping in case of CNS disorders and in evaluation of normal brain function.

Application of the modern technologies opens a new dimension in diagnosis and monitoring of neurologic disorders, however, it has to be emphasized that a dedicated indication based on clinical neurologic examination is mandatory. With respect to scientific purposes neuroimaging provides previously unknown possibilities to improve our knowledge about brain physiology and pathology.

ADVANCES IN CLINICAL NEUROIMAGING

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Editors:

F. Gerstenbrand
Department of Neurology
University Hospital
Innsbruck
Austria

N. Grčević
Department of Neuropathology
University of Zagreb
Zagreb
Yugoslavia

and

F. Aichner
Department of Neurology and Magnetic Resonance
University Hospital
Innsbruck
Austria

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