Multi-modality Brain Imaging

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Introduction

▪ ▪ ▪ ▪ ▪ As the developments in x-ray technology and interventional techniques were being made, other neuroimaging methods were also being developed. It was reported the successful use of an intravenously injected radioactive substance for the detection of brain neoplasms. Radionuclide brain scanning rapidly became an important part of neurodiagnostics since this is a minimally invasive procedure with virtually no morbidity.

The commercial availability of computerized axial tomography(CT) in the early 1970s heralded remarkable advances in the area of radionuclide brain scanning. The application of the computer reconstruction methods used in CT to nuclear medicine studies resulted in the clinical availability of techniques such as single photon emission computed tomography(SPECT) and positron emission tomography(PET). Developements of modern PET scanning have been continued with the impressive improvements in the technology. Cerebral SPECT imaging techniques have been utilized for more than 20 years; however, many of the most clinically significant advances have occurred in only the last 5 years or so. Improvements in imaging times have enabled this technology to be more widely applied in a variety of brain disorders.

The development of CT in the late 1960s and early 1970s substantially transformed the field of neuroradiology. Computer technology was far less advanced at that time, and processing of the data required over 2 hours on large mainframe computer. The scanning time was later reduced to 9 hours by replacing the gamma-ray source with an x-ray tube. By the time that the first clinical scanner was introduced in 1972, the imaging and processing times had been reduced to minutes. These advances have resulted in tremendous improvements in both image resolution and imaging times.

The introduction of clinical MRI in the 1980s completed the modern transformation of neuroradiology and moved this radiologic specialty to the forefront of noninvasive medical imaging. By the mid-1980s MR technology became a standard part of many neuroradiologic practices and a name change occurred. In order to eliminate term "nuclear" was dropped. This left the terms magnetic resonance(MR), which continue to be used today. MR is now widely recognized as the imaging modality of choice for most central nervous system disorders.

Surprising, in the 1960s and early 1970s when CT and MR were beginning to be evaluated clinically, electroencephalography(EEG) reached a high point and functional evaluation techniques such as magnetoencephalography (MEG) first began. EEG, During the 1970s and 1980s EEG and MEG efforts were largely overshadowed by the remarkable advances in imaging provided by CT and MR. However, with interest in the 1990s shifting toward the analysis of brain function or dysfunction, there has been a tremendous resurgence in the focus on the brain's electrical activity. This has included functional mapping of the brain by EEG that may prove particularly effective in the evaluation of epilepsy.

MEG, which when combined with MRI forms a functional image of the brain or magnetic source imaging(MSI), was first used to measure brain activity 1968. However, unlike the remarkably rapid development in CT and MR, it was over two decades before clinical reports of the successful utilization of MEG and MSI began to emerge. This long delay in clinical utility was due predominantly to the limitations of the equipment requiring extraordinarily long acquisition times and even longer processing times. While the early CT and MR examinations could require 60 to 90 minutes of patient evaluation time and an additional 30 to 60 minutes of analysis, early MEG examinations could easily require 8 to 12 hours of acquisition time and days or weeks for analysis. However, as larger array systems(37 channels or more) have become available and with more sophisticated computer analysis programs, theses examinations can be conducted in 30 to 90 minutes with complete analysis less than an hour for many procedures.

Background and Significance

Clinicians gather relevant information from the various tests their patients undergo. In many instances, more than one imaging technique is used in clinical diagnosis, therapy planning, or evaluation of therapy.

Generally clinicians mentally determine the spatial relationship of the various images, thereby solving a complex three-dimensional puzzle.

Different imaging modalities usually provide complementary information.

SPECT, PET, and MRS(magnetic resonance spectroscopy)provide functional information but delineate anatomy poorly, whereas MRI, ultrasound, and X-ray imaging, including CT, depict aspects of anatomy, but provide little functional information. Integration of the information acquired with different techniques is difficult, owing both to the complementary nature of the contents of the images and to differences in resolution, positioning and orientation of the scanned volumes. Computer-assisted image matching has proven to be a valuable tool to combine information obtained from different imaging modalities. It produces the transformation that relates the coordinate systems of the images. In the case of matching two tomographic images,either image can then be resliced into spatial coordinates of the other image, which enables a comparison of corresponding slices.

Furthermore, one can combine information of multiple modalities by visualizing the results in a hybrid display. These fused images may either portray slices taken from the three-dimensional data sets, or volumetric structures.

Application areas of medical image matching are numerous and diverse, varying from clinical research to patient care. The information that can be obtained by an expert from images carrying complementary information may increase when the spatial relation between these images is established. In nuclear medicine, determination of the anatomical location of dysfunctional areas and studies on functional-structural relationships are facilitated by integration of functional and morphological information, and anatomical information may be used to improve PET or SPECT reconstruction. Convincing examples can be found in matching of data depicting primarily functional information (e.g.,SPECT,PET,or EEG)with anatomical images(e.g.,CT or MRI),so as to facilitate anatomical labeling of dysfunctional areas. Matching of brain images is a well represented subfield in the medical image registration literature. The reason for this is twofold Firsty, neurology and neurosurgery are important applicational fields in which patient case often involves multiple imaging techniques. Secondly, the head is a relatively rigid object, that does not deform significantly in between scans. Relatively simple transforms(global translation,rotations,and sometimes scaling) are needed to register the images.

Matching of deformable body parts, such as the lungs, the heart, or the abdomen, and matching of patient data with atlas images, requires the determination of more complex transformations, which makes the already difficult matching task even more arduous.

The association of brain functions with the specific brain structures from which they originate - brain mapping - has attracted enormous interest in the neuroscience community. Recent advances in brain medical imaging tedhnology, such as MR imaging and PET, have made possible the accumulation of a wealth of morphological and physiological data containing information on relationships between the structure of the brain and its functions, but also to quantitative these brain image data. As a result, over the past decade considerable progress has been made in mapping the distribution of functions in the human brain, particularly the normal brain.

Less information about brain structure /function relationships has been gleaned from injured brain, though the new imaging technologies are increasingly being applied to such patient populations. Regardless of whether subjects are normal or abnormal, however, a major obstacle has been that appropriate technologies for managing and analyzing the large volumes of image-related brain data that will be collected are lacking. This analytical limitation greatly diminished the ability to scientifically analyze data in a database.

Clinical applications

The clinical applications of neuroradiologic procedures involve patients from virtually every discipline of medicine. In particular, patients with specific neurologic syndromes are frequently referred for neuroradiologic evaluation. Many times, the strength of these modalities is demonstrated in spite of the fact that the patient's clinical history, examination, and suspected diagnosis appear unrelated to the final diagnosis. For example, a patient may present with relatively minor head trauma, no other neurologic symptoms, and no abnormality on clinical examination, but CT and/or MRI may demonstrate a remarkable amount of brain pathology. These cases have resulted in the increased use of CT and MRI, particularly in patients with minimal central nervous system complaints and normal clinical examinations. The remarkable sensitivity of these modalities to even the smallest regions of brain pathology is amazing, especially when the results are compared to those from the central nervous system evaluations performed less than 25 years ago.

Future directions

It is clear that the future of brain imaging includes functional brain imaging. The increasing number of modalities available for functional brain imaging and the exquisite anatomic detail available from MRI and CT make this future appear promising. The ability to identify a region of suspected pathology in individual brains with great precision and to superimpose detailed function(on a scale of millimeters of resolution and milliseconds of temporal activity) tests the limits of current technology. However, both millimeter spatial resolution and millisecond temporal resolution have been successfully demonstrated using current functional brain imaging techniques. Currently, the primary limitation is in the ability to process the extraordinarily large amounts of data available to the medical community, and this technology may result in not only a new level of diagnostic image quality but also a new view of the real-time activities of the brain.