Hybrid Imaging – An Introduction

Editorial

Over the past three decades, we have witnessed significant advances in medical imaging, which have improved the assessment of a multitude of disorders with higher accuracy and more precise spatial resolution. The introduction of Computed Tomography (CT) in 1973 opened a new era in structural imaging, which has continued up to now with further improvements in the practical applications of this powerful modality. CT has been of great value in a lot of disorders, particularly in a large number of surgical procedures, which are planned after acquisition of CT images demonstrating the anatomic lesions before operation. Soon after CT was introduced, Magnetic Resonance Imaging (MRI) became a main focus of interest because of its ability to investigate soft tissue abnormalities, particularly in the central nervous and musculoskeletal systems. For most neurological diseases, MRI has become the study of choice for detection and accurate characterization of the underlying disorder. Likewise, many musculoskeletal abnormalities lend themselves well to MR imaging because of its very high spatial and contrast resolutions in detecting lesions in this organ system. The practice of orthopedic surgery has also been substantially impacted upon by the capabilities that are provided by this very powerful modality.

In spite of the enormous contributions made by these two very powerful structural imaging techniques, practitioners of medicine have realized that changes noted by CT and MRI are related to the appearance of the, often later, structural manifestations of disease, and may be rather insensitive to early pathological abnormalities or early changes in already known pathological lesions. By now, it has become clear that alterations in cellular metabolism at the molecular level are often early indicators of disease activity, sometimes even asymptomatic, and therefore detecting such changes may provide evidence for abnormalities not detectable by current anatomical imaging techniques. The changes on the molecular level may never translate to structural abnormalities or may be delayed for weeks or months after the disease process is initiated. Likewise, changes following treatment may not be apparent on these images for an extended period of time after therapeutic interventions are implemented. Since some treatments may not be effective and should be terminated and replaced with alternative therapies, such delays may adversely impact the optimal management of many serious diseases including cancer, cardiac diseases, and central nervous and orthopedic disorders.

Positron Emission Tomography (PET), which utilizes positron emitting radionuclides labeled with biologically important analogues, has overcome many of the deficiencies that are enumerated above. This very powerful modality provides fairly high resolution images that are comparable to those of modern tomographic structural imaging techniques. In addition, this modality provides images with high contrast compared to the background. This allows detection of the disease in early stages, which leads to the introduction of rapid interventions soon after the disease has been discovered. Furthermore, PET is the only modality that allows accurate quantification of disease activity with high precision and reproducibility. The introduction of ^{18}F-fluoroDeoxyGlucose (FDG) by investigators at PENN started a new era in medical imaging, which has expanded into multiple domains over the past three decades. While the original intent for introducing this compound was to investigate neuropsychiatric disorders, it soon became apparent that FDG was an outstanding marker for assessing disease activity in cancer. Today FDG-PET is routinely employed for managing a large number of malignancies at diagnosis, staging, monitoring response to treatment, and detection of recurrence. However, FDG is a nonspecific tracer for detecting cancer and is also taken up by the inflammatory cells in various settings. This has led to the utility of this compound in assessing infection, inflammation, atherosclerosis, thrombosis and muscle disease. At the same time the obvious need of more specific tracers has resulted in a rapidly growing list of new, more specific PET compounds.

In recent years, PET and CT instruments have been assembled as a unit and in fact a majority of studies performed around the globe employ this combination for an effective utilization of both modalities. This approach allows comparing images from both instruments side by side or fused together for precise localization of molecular abnormalities at different anatomical sites as visualized by CT scan.

It has been clearly demonstrated that hybrid imaging with either SPECT or PET combined with CT hardware provides important information beyond that achievable with either technique alone. In addition, hybrid imaging reduces the number of equivocal results based on one imaging technique without the benefit of the other. For decades, physicians have employed side-by-side visual interpretation of images generated by different modalities obtained at different times. However, along with the introduction of combined hybrid imaging instruments, major efforts have been made in developing software that allows fusion images of various organs for research and clinical purposes particularly. This has been of great value in organs such as the brain where anatomic landmarks allow co-registration of structural and functional imaging successfully. However, the role of such approaches may disappear as hybrid imaging with dedicated instruments becomes widely available in the future.

Similarly PET and MR images can be fused electronically demonstrating the precise location of abnormalities detected by PET on structural images of MRI. Prototype PET/MRI instruments are under investigation around the world and it is expected that in the near future such assemblies will be of great value for combined PET/MRI for examining brain, pelvis, and musculoskeletal systems.

We therefore believe that it is very timely to emphasize the utility of combined PET, SPECT, CT and MRI in the appropriate clinical and research settings for optimal assessment of their role in the future practice of medicine. In this issue of hot topics on hybrid imaging, we present some of the more novel approaches that have been introduced to medicine by combining two or three different imaging modalities.

It should be emphasized that perfect co-registration of functional and structural imaging techniques may sometimes not be feasible because of physiologic activities that are ongoing between acquisitions of two sets of images. For example, while CT images are obtained within a short period of time for most of the body, PET images require a relatively long period of time to be completed. Therefore, respiratory motion and contractions in the bowel may prevent perfect alignment between the two sets of images. Fortunately, with improvements in software capabilities, the effects of such biologic factors have been minimized in recent years.

In this issue, Klausen *et al.* [1] discuss hardware and software challenges that are associated with fusion of different image sets generated by CT or MRI with those of SPECT or PET. Flotats *et al.* [2] present the latest developments in hybrid imaging of the cardiac and coronary artery diseases with PET-CT or SPECT-CT. Musiek *et al.* [3] describe describe the benefit of PET-CT and/or PET-MRI for the accurate diagnosis and the characterization of central nervous system disorders. Basu and Alavi [4] provide an overview of the impact of PET-CT and SPECT-CT hybrid imaging in the practice of oncology, which are part of standard care for cancer images. Kiil Berthelsen and colleagues [5] present the published literature and their own large experience using hybrid imaging in radiotherapy, where they show that this approach provides better calculation of effective dose to the tumor while sparing the surrounding tissues from excessive radiation exposure. Basu and colleagues [6] present current and novel quantitative techniques that are feasible by modern hybrid imaging. Binderup *et al.* [7] describe data based on their own experiences and present the most recent literature on potential applications as offered by hybrid imaging in translational medicine, which will accelerate our understanding of underlying molecular (patho)biology and pathophysiology in health and disease states. Udesen *et al.* [8] in their communication describe an example of many other, potential imaging combinations and strategies, which undoubtedly will appear in the coming decades. Hoejgaard and Hesse [9] conclude how these innovative developments are revolutionizing the practice of medicine and discuss educational and logistic challenges involved in the introduction of this new wonderful imaging world. They finally emphasize the need of strictly controlled, randomized trials in many different diseases for the evaluation of benefits and possible drawbacks of hybrid imaging imaging compared to image fusion of or just simple stand-alone structural and/or physiological imaging techniques.

REFERENCES

[1] Klausen Tl, Andersen F, Kemp B. Hardware and software approaches to multi-modality imaging. Curr Med Imaging Rev 2011; 7: 169-174.
[2] Flotats A, Hidalgo A, Hasbak P. Cardiac SPECT-CT and PET-CT imaging. Curr Med Imaging Rev 2011; 7: 175-92.
[3] Musiek ES, Borgwardt L, Saboury B. Alavi A. Hybrid ET imaging in neurologic disease: PET/MRI rather than PET/CT. Curr Med Imaging Rev 2011; 7: 193-201.
[4] Basu S, Alavi A. SPECT-CT and PET-CT in oncology - an overview. Curr Med Imaging Rev 2011; 7: 202-09.
[5] Bjoerk-Eriksen T, Berthelsen AK, Roed H, Jakobsen AL. PET/CT Based Dose Planning in Radiotherapy. Curr Med Imaging Rev 2011; 7: 210-15.
[6] Basu S, Holm S, Zaidi H, Alavi A. Quantitative Techniques in PET-CT Imaging. Curr Med Imaging Rev 2011; 7: 216-33.
[7] Binderup T, El-Ali H, Ambrosini V, *et al.* Molecular Imaging with Small Animal PET/CT. Curr Med Imaging Rev 2011; 7: 234-47.
[8] Udesen J, Ewertsen C, Gran F, *et al.* Ultrasonography Fused with PET-CT Hybrid Imaging. Curr Med Imaging Rev 2011; 7: 248-51.

Birger Hesse
Department of Clinical Physiology,
Nuclear Medicine & PET, Rigshospitalet,
University of Copenhagen, Copenhagen,
Denmark
Tel: +45 35454011;
Fax: +45 3545 4015;
E-mail: birger.hesse@rh.regionh.dk

Abass Alavi
Division of Nuclear Medicine,
Department of Radiology,
Hospital of the University of Pennsylvania,
3400 Spruce Street,
Philadelphia, PA 19104,
USA;
Tel: + 1 215-662-3069;
Fax: +1 215-349-5843;
E-mail: abass.alavi@uphs.upenn.edu