Advances in Molecular Imaging

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Introduction

Molecular imaging is a rapidly growing biomedical research and clinical discipline. It aims to visualize and measure fundamental biological processes at the molecular, subcellular, and cellular levels. Molecular imaging promises not only to deepen our understanding of already-known biological processes but also to uncover still-unknown molecular and cellular events that are at the center of the initiation and evolution of disease. Compared with traditional in vitro tissue/cell culture and/or ex vivo animal studies, molecular imaging permits the noninvasive and repetitive imaging of targeted biological processes at both cellular and subcellular levels within living organs. Therefore, this offers a means for the specific targeting of abnormal biological processes for diagnosis and treatment.

In addition, molecular imaging has another important role; that is, in drug development, because molecular imaging may facilitate the understanding of pharmacokinetics in in vivo animal studies with the use of optical or radiolabeled pharmaceutical compounds. Furthermore, treatment effects may be more precisely and quantitatively assessed at molecular and cellular levels.

In the clinical setting, molecular-targeted drug therapy has been performed on the basis of tissue characterization. Molecular imaging, particularly positron emission tomography (PET), has recently been used for cancer treatment planning and for monitoring treatment effect. Thus, molecular imaging is a promising means for facilitating new drug development and for optimizing treatment strategy in individual cases (Fig. 1).

Methodological Issues

There are a number of molecular imaging techniques, including fluorescent or bioluminescent dyes for optical imaging, target-specific paramagnetic and superparamagnetic ligands for magnetic resonance imaging (MRI) and MR spectros-
copy, targeted radionuclide probes in nuclear medicine using PET/ single photon emission computed tomography (SPECT), and microbubbles for ultrasound imaging. Table 1 summarizes the characteristics of each molecular imaging technique. Optical imaging provides excellent spatial resolution and temporal resolution with high target-to-background activity. While this technique has been widely used at the molecular and cellular levels in experimental laboratory studies, it has inherent limitations for human use due to large attenuation through the body. The major advantage of MRI is high spatial resolution with no signal attenuation through the body. Because of its low sensitivity, human application with paramagnetic or superparamagnetic ligands remains limited. However, this limitation may be easily solved with the development of new and safe ligands and also imaging instruments in the near future.

Radionuclide imaging using either PET or SPECT has been most commonly used for human molecular imaging mainly due to quite high sensitivity for imaging radiolabeled ligands as compared with any other molecular imaging. Despite low spatial and temporal resolutions with high background activity and some radiation, wide clinical applications have been shown for the evaluation of various disease processes with safety. Another interesting molecular imaging is ultrasound with the use of microbubbles. This new technique holds promise for new treatment by optimizing drug delivery to the targeted lesions.