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Positron Emission Tomography: History, Current Status, and Future Prospects

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Because of its high sensitivity, quantitative nature, and its ability to image deep into the body, positron emission tomography (PET) is arguably the most powerful technology for *in vivo* molecular imaging in humans. Although the broad impact of PET on routine clinical medicine is more recent than that of computed tomography (CT) and magnetic resonance imaging (MRI), its history started in the same era as the other cross-sectional imaging technologies.

The pioneers of positron imaging in the 1950s recognized that one of the powerful advantages of the technique would be the potential to use radioactive isotopes of the most important biological elements (carbon, nitrogen, oxygen) to probe physiology. Thus, even though anatomic cross-sectional imaging (CT and MRI) grew rapidly in importance, it did not displace PET. Rather, the complementary biological information provided by PET allowed it to also grow in importance.

A turning point in the growth of PET as a clinical modality in the U.S. came at the turn of the millennium with two events: the reimbursement (i.e., payment) for fluorodeoxyglucose (FDG)-PET imaging for clinical oncology imaging, and the large-scale introduction of hybrid dual-modality PET/CT (Fig. 1).

PET/CT is now one of the established tomographic clinical modalities, complementary to CT, MRI, and ultrasound. This utility and the quest for improvement is leading to a constant stream of innovations and refinements. Among the technical areas receiving significant attention are PET/MR, respiratory motion compensation, improved detector hardware, such as silicon photomultipliers (SiPMs) and effective digital electronics enabling time-of-flight (TOF) systems, new system design concepts for clinical and preclinical imaging, and algorithms for more efficient use of the measured data.

Despite the tremendous progress, the imaging performance of clinical PET (spatial resolution, temporal resolution, field of view, sensitivity) is still far from physical limits. Thus, more progress can be expected. An example is the effort to develop a total body PET system by the EXPLORER consortium. This system is expected to enable simultaneous dynamic imaging throughout the body while significantly increasing the system sensitivity. There are also opportunities for further technical development in preclinical PET and also for the development of application-specific instruments.

In this special section of the *Journal of Medical Imaging*, Jones and Townsend provide a review of the history of the development of PET, highlighting the many individuals and groups who made important contributions. They also peer into their crystal ball and provide a wise perspective into areas of potential future development. In addition to this historical

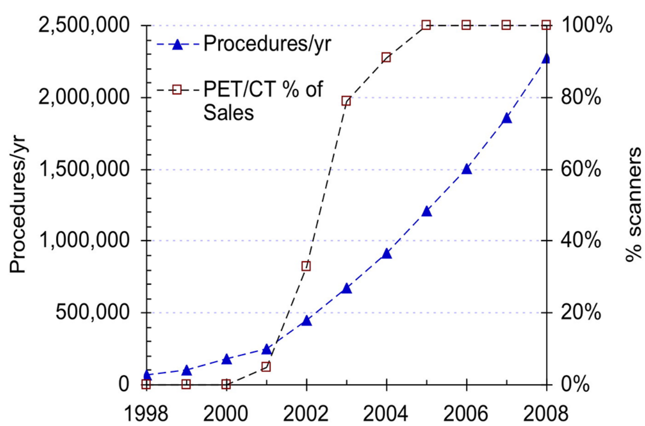

Fig. 1 The growth in the number of PET procedures per year (left axis) correlates with the beginning of reimbursement for clinical PET imaging in 1998, and the fraction of new PET systems sold that were hybrid PET/CT configurations (right axis) shows dramatic and immediate adoption of this technology. Data from multiple sources.

paper, the special section includes 11 manuscripts describing current research. The topics included in these papers are a sampling of the breadth of scientific exploration in PET research, filtered by the expertise of the readers of the *Journal of Medical Imaging*, i.e., more of a technical than biological nature. They include reports of new system architectures, components, system performance, and lesion detectability. We highly recommend careful review of these advancements in the field.

While the articles in this issue largely illustrate the impact of technical advances, we should emphasize the enormous power that PET gets from biologically relevant probes. This fundamentally provides potential and opportunities yet to be realized. Research into new probes or radiotracers, analysis methods for dynamic imaging, and the development of these into useful tools for clinical medicine and biomedical research are of great importance and represent areas of promise. Similarly, biological and medical investigation conducted with PET as a tool is a very active and important area of research. While there is, and should be, great interest in the development of PET/MRI technology, the impact of these systems in clinical medicine remains a work-in-progress. Research is needed to demonstrate the benefits of these and other advances. In addition, and appropriately, there is strong interest in the development and testing of new applications of PET. Specifically there is great need for improved assessment of many neurological and mental health conditions, and also biomarkers for the development of improved therapies for cancer and cardiovascular disease.

PET is an expensive modality because of the technical complexity, the need for short-lived radiopharmaceuticals, and the involvement of highly trained staff. However, the societal costs of neurological, oncologic, and cardiovascular conditions, and costs of some therapies, is enormous. If we are able to facilitate earlier detection based on modern risk factors, alter the management and improve the outcomes of these patients, PET imaging is cost effective when used appropriately, while remaining an outstanding quantitative biomedical imaging methodology for research.

PET is a technology with an interesting and rich history, a productive use currently, and a very fertile and promising future.

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Paul E. Kinahan is a professor of radiology and bioengineering at the University of Washington, and is the vice-chair for radiology research. He received BASc and MASc degrees in engineering physics from the University of British Columbia and a PhD in bioengineering from the University of Pennsylvania. He then became an assistant professor at the University of Pittsburgh. While there he was part of the group that built the first prototype combined PET/CT scanner.

Roderic I. Pettigrew has been the founding director of NIBIB since 2002, where he oversees the funding and development of biomedical technologies to improve the nation's health. A pioneer in 4-D cardiovascular MRI, he was previously professor of radiology and medicine (cardiology) at Emory University, professor of bioengineering at the Georgia Institute of Technology, and director of the Emory Center for MR Research at the Emory University School of Medicine.