Preface

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Biographical notes: Yulin Song received a BS in Laser Physics from Beijing University and an MS in Accelerator Physics from Sam Houston State University. Supported by a US Department of Defense Breast Cancer Research Pre-doctoral Fellowship, he obtained another MS and a PhD in Biomedical Engineering from the University of Texas Southwestern Medical Center at Dallas. Subsequently, he completed a Post-doctoral Fellowship in the Department of Radiation Oncology at Stanford University School of Medicine. He is now a faculty member in the Department of Medical Physics at Memorial Sloan-Kettering Cancer Center. His research interests include medical imaging, tumour tracking, and 4D radiation therapy.

Radiation therapy and medical imaging have been in use for more than a century. Formally known as radiation oncology or therapeutic radiology, the evolution of radiation therapy has been closely linked to the advances in medical imaging. The discovery of 2D x-ray imaging by Röntgen in 1895 gave birth to the earliest form of 2D radiation treatment planning using special x-ray tubes in 1922. The invention of computed tomography (CT) by Hounsfield and Cormack in 1972 led to the formation of the initial concept of 3D Conformal Radiation Therapy (3D-CRT) in the late 1970s after computers were introduced to radiation treatment planning. The introduction of on-board mega-voltage (MV) portal imaging in the mid-1990s speeded up the development of intensity modulated radiation therapy (IMRT) in the late 1990s. The invention of cone-beam computed tomography (CBCT) in 1999 led to the development and clinical implementation of image-guided radiation therapy (IGRT) in 2003 and, later on, the image-guided adaptive radiation therapy (IGART) in 2006. CBCT, a true 3D volumetric imaging modality, has revolutionised the practice of modern radiation oncology. Its widespread adoption in radiation oncology has been considered another milestone after IMRT.

The latest breakthroughs in imaging technology, particularly 4D medical imaging (three spatial dimensions plus time), have injected new momentum into radiation oncology. At present time, the main stream 4D medical imaging modalities include time-resolved volumetric CT, Magnetic Resonance Imaging (MRI), Positron Emission Tomography (PET), PET/CT, Single Photon Emission Computed Tomography (SPECT), and Ultrasound (US). Broadly speaking, the time information required for organ and tumour motion characterisation in 4D imaging can be obtained in two ways: prospectively and retrospectively using either respiratory gating or various motion

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tracking techniques. In the former approach, snapshot image projections are acquired at a specified phase in the breathing cycle. The reconstruction of these projections produces a motion-free 3D image with identical phase. In the latter approach, continuous image projections and time information are recorded simultaneously while the patient breaths freely. The correlation between time and respiratory phase information is established through external surrogates, such as a pressure sensor or a light reflecting marker block placed on the patient chest. The acquired projections are sorted into either phase bins or amplitude bins prior to reconstruction. The 4D reconstruction yields a cyclical series of 3D images. In general, these methodologies can be applied to all imaging modalities with slight modifications in implementation.

4D medical imaging led to the creation of a new form of radiation therapy, 4D Radiation Therapy (4DRT) in 2007. Many concepts in 4DRT were adopted from IGRT and IGART. 4DRT introduces the time dimension into 3DRT in order to compensate for patient motion/changes occurring either during a single fraction (intra-fractional) or between successive fractions (inter-fractional). A complete 4DRT procedure should integrate 4D medical imaging into each of the key steps in 4DRT. These include 4D patient simulation, 4D treatment planning, and 4D treatment delivery. The primary objectives of 4DRT are

- to correct for daily patient setup errors
- to track target motion
- to compensate for dose deficit
- to correct for overdose.

The major advantages of 4DRT are high-precision dose conformity, minimised normal tissue complication probability, and possible further dose escalation to the target. To maximise the potential benefits of 4D medical imaging and promising improvements in patient survival and quality of life, an integrative and systematic approach to 4DRT is essential. Without such an integrated multi-disciplinary strategy, 4DRT would only remain as an ideal concept.

Although still in its infancy, 4DRT has already been implemented at a number of major academic cancer centres in the USA. Thus, we feel that it is necessary to put together a special issue on 4D medical imaging and 4D radiation therapy to reflect this increasing interest and demand. Contributors of this special issue are the leading 4DRT experts from prestigious cancer centres in the USA, including Dana-Farber Cancer Center and Brigham and Women’s Hospital of Harvard University Medical School, Duke University Medical Center, Fox Chase Cancer Center, Memorial Sloan-Kettering Cancer Center, National Cancer Institute, and the University of Texas Health Science Center at San Antonio.

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