4D Treatment Optimization and Planning for Radiosurgery with Respiratory Motion Tracking

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25.1 Abstract

The CyberKnife® Robotic Radiosurgery System (Accuray Incorporated, Sunnyvale, CA) can treat targets that move with respiration using the Synchrony® Respiratory Motion Tracking System or the Xsight™ Lung Tracking System (Accuray Incorporated, Sunnyvale, CA). Alignment of each treatment beam with the moving target is maintained in real time by moving the beam dynamically with the target. The challenges of treatment planning for mobile targets are different for dynamic respiratory motion tracking than for conventional approaches such as motion-encompassing and respiratory gating methods that are common on gantry-based delivery devices. Internal motion during respiration is not rigid, and thus positions of critical structures relative to the target and hence to the beam can change during respiration. The 4D Treatment Optimization and Planning feature, which recently became available in the MultiPlan® (Accuray Incorporated, Sunnyvale, CA) Treatment Planning System, is a new approach to four-dimensional (4D) treatment planning for motion tracking. It uses a 4D-CT image study to measure respiratory tissue motion and deformation and to account for the effect of motion and deformation on dose. The individual 3D-CT images are aligned so that the target coincides in each image. A tissue motion model is computed by performing nonrigid registration of the individual 3D-CT images. Using the target-centric alignment and the deformation model, it is possible to calculate a dose distribution that takes into account both beam movement and soft tissue deformation. This dose distribution may be calculated before plan optimization and hence used to determine the desired beam geometry and weighting, or it may be calculated after plan optimization in order to review the effects of respiration on the dose isocontours and statistics for a given plan.
### 25.2 Introduction

Planning for radiation therapy is typically performed using a static 3D-CT image of the patient. However, during treatment delivery, the anatomy can undergo substantial tissue motion and deformation. The inclusion of organ deformation and motion in treatment planning is growing in importance, especially in thoracic and abdominal applications where breathing has a large effect on target position and shape and the positions of critical structures relative to the target [1].

Numerous approaches have been developed to address the effect of respiratory motion [2]. One straightforward approach is to enlarge the target by a margin within which the target should move during the breathing cycle [3]. A related motion-encompassing approach is the slow scanning method, in which the CT scanner is operated very slowly, or multiple CT scans are averaged such that multiple respiration phases are recorded per slice [4]. The image of the tumor should show the full extent of the respiratory motion that occurs during the scanning process, provided the acquisition time at each couch position is longer than the breathing cycle. The disadvantage of slow scan methods is the loss of resolution due to motion blurring, which potentially leads to larger observer errors in tumor and normal organ delineation, as well as estimated dose delivered to the patient. Another related approach is to acquire CT images during the end-exhale and end-inhale phases of a breathing cycle. The pair of images provides the range of target motion, which is used to provide an anisotropic enlargement of the target. All of these motion-encompassing approaches ensure that tumor motion during breathing will not affect the dose delivered to the target, but they also lead to increased dose delivered to normal tissues, which can be a particular problem when the lesion is located close to organs at risk.

Another natural approach is to add a temporal component to the process using a gated strategy, which can be based on either breath holding or free breathing. Breath-hold techniques can use simple voluntary breath holding or more sophisticated approaches such as active breathing control [5]. Treatment is delivered during the breath hold period, which can be at end-exhale or end-inhale. These methods provide higher accuracy of dose delivery than motion-encompassing methods, but breath hold repeatability and patient compliance are challenges, especially for elderly patients or patients with lung cancer or other pulmonary disease. For respiratory gating approaches, the patient continues breathing normally. The treatment delivery system tracks respiratory motion, for example, using optical tracking, and turns the radiation beam on only when the respiratory position falls within a specified range of the complete breathing cycle. The delivery of radiation during a limited portion of the breathing cycle can substantially reduce the duty cycle and prolong treatment time. Lesion motion and gating model stability are also challenges for gating methods.

Recent advances in CT imaging have led to the development of high-quality 4D-CT or respiration-correlated CT scanning methods [6, 7]. Most major CT scanner vendors offer 4D-CT capability on their currently available equipment. A 4D-CT image study consists of a set of 3D-CT images, each one of which represents a different phase of the patient’s breathing cycle (Fig. 25.1). The number of phases present in a study varies, but ten is a common number. The availability of 4D imaging has led to efforts to include organ motion and deformation in the treatment planning process.

### 25.3 4D Planning System for Respiratory Gating

With traditional gantry-based radiation delivery systems in which the treatment beams are not moved during treatment to compensate for respiratory motion, the term “4D planning” is generally used to refer to the process of finding a compromise between the size of the Planning Target Volume (PTV) and the width of the gating window, i.e., the portion of the respiratory cycle during which the beams are turned on (Fig. 25.2).

Clearly, the wider the gating window, the greater the volume of normal tissue that must be treated in order to ensure target coverage; however, a narrow gating window significantly lengthens treatment