Adaptive Radiation Therapy (ART) Strategies Using Helical Tomotherapy
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8.1 Introduction

Tomotherapy is intensity-modulated rotational radiotherapy utilizing a photon fan beam [1–6]. In helical tomotherapy the gantry and couch are in continuous motion and, from the patient’s point of view, the source describes a helical trajectory. Helical tomotherapy was designed around a ring gantry similar to a helical CT scanner. The constraints of a ring gantry are minimal since few patients are treated with non-coplanar radiation fields and IMRT diminishes the need for these types of field arrangements. Most importantly, a ring gantry is a very stable platform for CT scanning. The original helical tomotherapy concept had kV and MV beams for imaging and treatment respectively [1]. On the current version megavoltage photons from the treatment linac are used to generate the CT scans [7, 8]. The same detector can also be used to detect the exiting treatment beam in order to provide the data for dose reconstruction [9].

Figure 1 is a labeled photograph of the TomoTherapy (Madison WI) Hi-Art tomotherapy unit with its covers off. The helical tomotherapy beam line was designed for image-guided IMRT treatments.

The linac and gantry systems of the tomotherapy system are highly favorable for CT. The gantry sag of the tomotherapy system is negligible so that no sag corrections are required. The size of the electron beam on the target is about 1 mm so that the resolution is about 1.2 mm to 1.6 mm which is comparable to a conventional CT scanner for high contrast objects. Operating with typical patient doses of 1 cGy, the soft tissue contrast is about 2–3% which is higher than a modern CT scanner. Nevertheless, the images have sufficient quality for adaptive radiotherapy processes.

The tomotherapy unit’s xenon gas detector elements have tungsten septa separating ionization cavities. In addition to the ionization collectors, the tungsten plates are embedded photon converters intercepting the megavoltage photons and yet are thin enough to let an appreciable fraction of the electrons set in motion to deposit energy in the xenon gas. The interception of the beam by the tungsten means that the quantum efficiency of the system is about 25%, which is much more than the few percent collection efficiency of modern portal imaging systems, and decreases necessary imaging dose proportionally.

8.2 Treatment Plan Generation

Currently helical tomotherapy optimization is based on physical (dose-based) objective functions [10]. However, biological estimators to rank plans and biological optimization for treatment planning will be included in the future. The flexible delivery capabilities of tomotherapy will enable simple implementation of such novel techniques. Helical tomotherapy can deliver the complex radiation patterns that may result from biologically based optimizations. With helical tomotherapy, since all beam directions are available, it is not necessary to choose specific beam directions. A large number of beam directions are very beneficial to simultaneously achieving target dose uniformity and normal tissue...
II. Advanced Image-Guided and Biologically Guided Techniques

Fig. 1. Helical tomotherapy unit in a factory test cell. Major components are labeled sparing as well as possible. However, if desired, dose from any number of beam directions can be minimized, by partially or even completely blocking those beam directions to meet specific doses constraints.

Contributions from any beam direction and fluence intensities through the binary MLC are optimized for conformal dose distribution. However, the use of a binary MLC does not prevent the optimization of dose distributions in the superior-inferior direction. Due to the simultaneous couch motion, there is an effectively continuous range of beamlet positions in the S/I direction. Additional beamlet options can be added by using narrower jaw thicknesses and/or reducing the pitch, as this will allow the beam to pass through a particular point several times; the optimizer can then select the most appropriate beamlets given the beamlets at different angles and longitudinal positions that impinge upon the desired target. In practice, pitch values in the range of 1/4 to 1/2 commonly provide a good balance between delivery time and beamlet availability.

Figure 2 is an example of a head and neck case. The number of beamlet intensities that needs to be optimized for this type of case is on the order of 40,000. As can be observed, target dose conformity and uniformity are excellent. There are no hot spots in the target region. Both left and right parotid sparing is achieved, as can be seen in the DVH. Moreover, there are no hot streaks or other areas of high dose in the normal tissue regions.

8.3 CT-Based Patient Setup Verification

The verification CT serves as the basis for all of the patient-specific quality assurance processes; however, the patient setup verification may be the most important. The CT verification representation of the patient indicates the anatomy of the patient just minutes before the treatment begins. Setup verification directly com-

Fig. 2. Dose distribution and DVHs generated for a head and neck plan. The level of target conformity and sensitive structure sparing is very good. The number of beams directions as well as the modulation capabilities plays an important role in obtaining good quality plans for this type of case.