Radiation Dose Blurring Due to Tumor Motion During Respiration

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I. Motivation

A serious problem in clinical radiation therapy of lung and liver tumors is the change in target position during radiosurgery due to patient and physiological movement. Random patient movement is minimized using face masks and other apparatus that can be rigidly attached to the patient table. Physiological motion is dominated by respiration, peristalsis, and even the beating heart. The breathing cycle incorporates motion from the diaphragm, chest wall and muscles to acquire needed oxygen and expel waste byproducts. The movement of these organs greatly effects the shape and volume of the lung and other organs in the abdominal area. The deformation of the affected organ will greatly change the target tumor position and volume. Current treatment methods used to achieve a curative response require radiation oncologists to deliver a lethal dose to the tumor volume. As a result of physiological motion, the oncologist must treat an area encompassing the entire range throughout which the tumor travels. Thus, a large volume of healthy tissue is also exposed causing clinical repercussions such as fibrosis and pneumonia. Additionally, it is believed that tumor motion causes the radiation dose to be blurred over the volume and the dose to drop off slower than desired at the healthy tissue/tumor interface. Some measure of success has been achieved through the use of breath hold protocol. Using this method, the dose is delivered during an end inspiration or expiration breath-hold. However, the planned target volume (PTV) still exceeds the clinical target volume (CTV) by too large of a margin. By accurately tracking said motion, and gating the treatment beam as the tumor moves in/out of the beams eye view (BEV), a more accurate lethal dose will be delivered to the tumor volume, while sparing the surrounding healthy tissue.

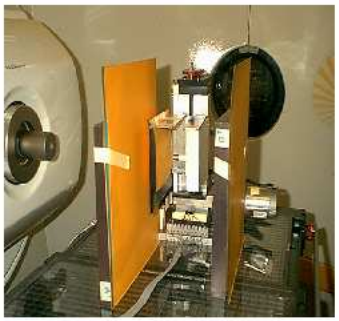
II. Objectives

We wish to model the motion of tumors by creating a respiratory motion phantom. This phantom will allow us address two main problems. First, the phantom will permit us to measure precisely the radiation dose delivered to the tumor and the changes in dose caused by target motion during radiotherapy. Second, we are developing a beam gating system to track tumor position and accurately deliver the dose to the tumor. The motion phantom is needed to create the gating system and verify the dose received by the tumor and surrounding tissues.

III. Methods

3D Motion Stage

A tumor phantom model and 3D motion system were constructed. The physical motion is performed by a 3D translation stage, powered by S57-83 stepper motors manufactured by Parker-Hanafin. Two phantom models were produced. The first consisted of a Styrofoam block with a 10mm rod inserted. This phantom was used to verify dose blur due to tumor position changes during a treatment plan mimicking the breath-hold technique. The phantom was moved to ten random off isocenter positions and irradiated at each. The second phantom is made from 6 x 6 x ½ pieces of Plexiglas assembled into a 6 inch cube. Film can be inserted into various levels within the block. This will be used in a continuous motion trial modeling tumor motion throughout the breathing cycle.



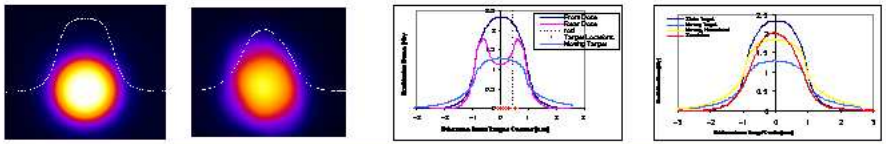
II. Methods Cont'd

Motion Programming

The motion programming is performed using a PC with LabView (LV) 6.1 software and the FlexMotion 7344 motion control board by National Instruments, Inc. This software is graphical user interface (GUI) based, and allows the user to design and build a "virtual instrument", which is then used to control the translation stage's motion. The front panel provides the user interface, and is simply an animated version of an actual instrument designed for the user's specific application. The block diagram contains the actual programming language in GUI form instead of text. It looks like an electrical circuit diagram. The ten movements of the first phantom were generated randomly to model position changes due to physiological motion. These positions were programmed into the FlexMotion control board to allow the engineer to perform the motion remotely from outside the treatment room.

III. Results

The left picture is a representation of the actual dose distribution seen by the front stationary film, while the second picture represents a computer simulation of the dose at the target. The first graph shows a comparison for the dose distribution seen between the front, back and moving films. The normalized dose for the front and back films are almost identical with the exception of the dip on the back caused by the shadow of the steel dowel pin. The second graph plots the dose received over the tumor volume. This verifies expectations of lower dose and dose broadening caused by tumor movement.



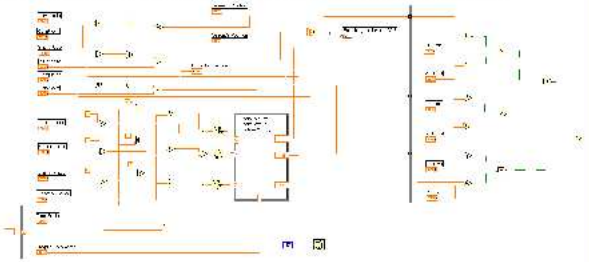
IV. Future Directions

3D Continuous Motion Programming

The system created will be used as a test bed for a respiratory motion system which will utilize real-time tracking to gate a radiation beam in order to provide accurate dose delivery to the target tumor. The next step is to use this system to model the continuous tumor motion seen during the respiration cycle. The equation used to model tumor motion due to respiration is:

$Z(t) = Z_0 - b\cos^{2n}(\pi t/T - \phi)$ where:

Z_0 = position at exhale
b = amplitude of motion
T = period of breathing cycle
n = shaping parameter of model
ϕ = starting phase of breathing cycle
(Lujan et al.
Med Phys 1999 May; 26(5): 715-2)



This equation has been programmed into the LV system and will be used to move the phantom continuously. A real-time tracking and beam-gating system will be developed which will track tumor movement and gate the beam when the tumor is in the optimal BEV position. This will allow the PTV to be shrunk to more closely represent the CTV, thereby saving healthy tissue and minimizing clinical repercussions.

Acknowledgments

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