Dosimetry of double orbit cone beam computed tomography (CT) as applied to image guided radiotherapy (IGRT)

Ariel Jefferson, Dandan Zheng

Department of Radiation Oncology

Division of Medical Physics

VCU Medical Center

BBSI Summer 2008

This summer our research centered on the use of the Varian Trilogy Systems linear accelerator for image-guided radiotherapy. What is special about this device is that it has an integrated cone-beam CT imaging system that has only recently been developed for application in treating cancer patients. The system works in tandem with the gantry head that delivers the radiotherapy via two arms connected laterally that consist of an x-ray source and flat panel detector. The two arms complete a single axial rotation about the patient, and the pulsed x-rays pass through the subject before they are collected on the detector. We use computer software to reconstruct the images produced by the x-ray pulses into to a 3D representation of the patient's anatomy. While providing complete axial coverage, this method of image acquisition is limited longitudinally by the size of the detector. Currently, our linear accelerator is equipped with a detector that produces an image that is about 14cm longitudinally, which is adequate for most IGRT applications.

There are other applications, however, that require a greater longitudinal area, such deformable registration or simulated dose calculation. For these applications, here at the Department of Radiation Oncology we have developed a method of increasing the longitudinal area that involves multiple orbits of the cone beam CT system during image acquisition. The method involves completing one rotation scan, then translating the couch on which the patient is laying, and taking another scan in series with the first. Results have shown that doubling the number of scans basically doubles the longitudinal coverage of our images.

A few problems arise with this method. First, it is a locally developed method, so the manufacturer, Varian Systems, did not intend the device for this application, and any

application beyond its intended use requires extensive research. Second, the two scans cannot be performed precisely in series; there is a slight overlap called an abut region. The abut region is essential for two things: it accounts for patient movement between scans and is used in 3D to 3D registration which is a method of aligning the two scans into one volumetric image. At this point we have a protocol for acquiring these multiple scans and we have a method of registering the scans together into one image set. The next obvious question is: how does this procedure affect the patient? We sought to answer this question in terms of absorbed radiation dose, and the most comprehensive way to do that is to obtain a geometric distribution curve along the central and peripheral axis of the irradiated field.

There are various tools used in dose calculation in this field, but for our purposes, a CTDI phantom and thermoluminescent dosimeters were ideal. CTDI phantoms are used frequently in quality assurance of CT imaging devices for dose measurement. Their acrylic, water-like substance is analogous to the human body. Thermoluminescent dosimeters (TLD) are small lithium fluoride chips that react to given amounts of radiation. They are very useful because they can be used to measure points of dose absorbance, and their response provides us with a latent measurement of that dose.

However useful, TLDs do have their limitations when it comes to radiation dose response. Limitations on that response include radiation energy dependence and the non-uniformity of response between individual chips. To account for these limitations in our experimental procedure, we spent much of the summer analyzing the characteristics of the batch of TLDs we planned to use for data acquisition. Three characteristics were of particular interest to us: uniformity, linearity, and reproducibility. Uniformity refers to the deviation of response from chip to chip when exposed to the same radiation. Linearity is concerned with the relationship between response and dose. We wanted to ensure that the response would change proportionally with the dose. Reproducibility refers to how consistently the TLDs respond from one trial to the next. We wanted to ensure that the TLDs do not lose sensitivity with each test, and that their sensitivity is not random or fluctuating.

There several steps involved in processing the chips for every trial as well as during the actual experiment. First is a process called annealing, which basically sets the

chip response to zero before irradiation. Irradiation involves exposing all the TLDs to a uniform x-ray beam to which the molecules in each TLD will react. The reaction is measured one chip at a time by placing them inside a specialized TLD reader which heats up the chip and measures the resulting light emission (hence the term thermo-luminescent). This light emission is the latent measurement preserved after irradiation and indicates the amount of radiation absorbed by each chip.

These preliminary tests indicated several things pertinent to our investigation. First, while examining the uniformity, we made note of the fact that higher dosages resulted in larger TL readout numbers. Statistically larger numbers have smaller standard deviations. This characteristic of large doses was applied later during data acquisition because given that that we cannot use the same TLD with its same characteristics in each point in our geometric experiment, anything we can do to make our tools as uniform and consistent as possible will make our experiment that much more accurate.

As mentioned above, the TLD reader measures the amount of light emitted from each TLD and outputs a number that is proportional to the amount of radiation absorbed. This number, however, is in Coulombs, a unit of charge. The next step now that we understand the behavior of our TLDs is to quantify their TLD readings in terms of absolute dose. To this end we used an ion chamber to calibrate our TLD readings.

Ion chambers are frequently used with CTDI phantom measurements, but it is impractical to use for our purposes because it cannot perform point measurements. We placed the ion chamber inside another acrylic water-phantom, same as our CTDI phantom, and also placed 5 TLDs inside adjacent to the chamber. One double cone beam CT was performed on the apparatus. The TLDs were read and averaged, and the ion chamber was connected to an electrometer which output a separate reading. The American Association of Physicists in Medicine (AAPM) provides a protocol for absolute dose calculation from ion chamber measurement. Using this protocol we converted the electrometer reading to a dose measurement of 10.29 cGy for one double cone beam CT. The TLD average reading was 51.94 nC, and from this we generated or calibration factor for nC of light emission to Grays of absolute dose.

After establishing the characteristics of our TLD response and relating that response to the absolute dose, the next step is actual data acquisition. The CTDI phantom

we employed has two separate parts: a head phantom and body phantom. They are usually not used together, but because neither of them individually is long enough to cover our scan, we aligned their central axes and made them into one full head and neck phantom. This unconventional use of TLDs in the CTDI phantom and unconventional setup of the phantom itself required custom designing our own TLD holders to fit inside the phantom's axial and peripheral channels. Three holders were made: one long one to span the central axis length through both phantoms; one to fit the peripheral channel in the head; another to fit the peripheral channel of the body. The holders have wells spaced 1 cm apart, and in each well we placed two TLDs.

For our image acquisition, we placed the isocenter of the beam 12 cm from the top of the head phantom for the first scan. The couch was shifted 12.3 cm down the axis for the second scan, and in this way 4 double cone beam CT acquisitions were performed. The reason for so many orbits is that as mentioned above, we want our results to be as close as possible to using the same TLD for each position in the phantom, and large dose exposure accomplishes that.

The results of our dose curve were obtained after converting the TLD readout of each chip to absolute dose. The curve represents a geometric distribution of absorbed dose down the length of the irradiated field. The curve indicates that the dose at the periphery and central axis are not very different, which can be attributed to the way the scan was acquired. While the x-ray source passes on the same side as the peripheral TLD holder, the dose should increase, but as the source continues to rotate to the opposite side, more attenuation occurs because the beam passes through more of the phantom before it reaches the TLDs. We conclude that the overlap in the abut region caused a marked increase in absolute dose, as expected. What is not clear is whether this extra dose is warranted for the information we obtain from this data acquisition. Also, the dose in this region is higher than a conventional CT, so the next step is to investigate ways of lowering that dose. Some possibilities are reducing the size of the abut region and perhaps using 3D to 2D image registration instead of 3D to 3D when aligning the two scans.