Theme Symposium

IMAGE GUIDED RADIATION THERAPY

S. Hukku*, S. Halder#

Senior Consultant in Radiation Oncology*, Consultant in Radiation Oncology#,
Apollo Cancer Institute, Indraprastha Apollo Hospitals, Sarita Vihar, New Delhi-110044, India.

Correspondence to: Apollo Cancer Institute, Indraprastha Apollo Hospitals,
Delhi-Mathura Road, Sarita Vihar, New Delhi-110044, India.

HIGH precision radiation therapy is based on the fact that the tumor and normal surrounding structures have to be delineated in all three dimensions before the radiation oncologist plans the treatment for the patient. The three dimensional computerized treatment planning system then generates a plan in which the tumor gets a high dose and the normal tissues around it get a very low dose of radiation. The radiation is then delivered using a linear accelerator with a multi leaf or micro multi leaf collimator. This methods results in higher cure rates and minimal normal tissue complications. Based on this premise the modern radiation therapy techniques viz. stereotactic radiotherapy, stereotactic radiosurgery, 3 dimensional conformal radiation therapy (3D CRT), and intensity modulated radiation therapy (IMRT) have been developed and have become standard of care in modern radiation therapy departments around the world, including India. Such treatments are planned using CT/ MRI imaging.

Till a decade ago the planning techniques were different because the planning was done based on fluoroscopy and not on CT/MRI images. This resulted in two and not three dimensional delineation of tumor and normal tissues and therefore the radiation portals were large so that there was no geographical miss of the tumor. This, however, resulted in inclusion of a larger volume of normal surrounding tissues and the radiation oncologists had to keep the total dose to a lower level in order to keep the complication rates low, but the lower tumor doses were not sufficient enough to result in higher cure rates.

When the intention is to spare the normal tissues and the delineation is in three dimensions, the radiation oncologist uses a very tight margin around the tumor which helps in escalating the total tumor dose. This philosophy is utilized in all the modern treatment techniques mentioned above.

It has been observed and documented over the last few years that all the organs in the body move during the radiation treatment and also over a period of 4-6 weeks over which all the radiation therapy treatments are delivered. This observation has led us to think that if the margins around the tumor are very tight, the tumor motion may result in tumor going out of the treatment field and normal tissues coming in the radiation field thus defeating the whole purpose of three dimensional treatment planning with extremely tight margins.

Efforts are on the way to track the tumor everyday during treatment and adjust the radiation fields accordingly. This is called image guided radiation therapy (IGRT).

IGRT protocols are still in development and will become standard of care with in the next few years.

Organ motion

Intrafraction tumor motion can be of two types: stochastic (random in time and direction) and systematic. The later can consist of slow, quasi-static changes in position due to effects viz., muscle fatigue, and rapid cyclical changes caused by respiration and heart beat. Conventional radiotherapy uses a short time per fraction everyday and techniques like radiosurgery uses long time per fraction delivered. The treatment delivery time also influences both the effect of motion and the techniques for tracking it.

If patient movement is slow or intermittent, the response time of tracking and beam positioning systems is not important. If the motion is fast relative to the speed of beam adjustment (like respiration) then it becomes important to recognize and accommodate the delay in beam repositioning by predicting the future position of the target. This is only possible if the movement is systematic; fast random motions cannot be effectively predicted. Therefore, large and rapid stochastic movements cannot be effectively compensated by real time tracking.

Organ motion because of physiologic function can be substantial. The liver moves upto 5 cm in the caudal cranial direction during free breathing. Although breathing is most often the largest source of organ motion in the upper abdomen, organ motion due to cardiac function, stomach filling, rectal filling, and swallowing is also of importance.

Effect of motion on imaging, treatment planning, and dose delivery

Precise treatment of the tumor begins with an accurate three dimensional images taken by CT imaging. Significant distortions of the true shape of an object can be introduced when imaging is performed in the presence of object motion. Distortion along the axis of motion could result in either a lengthening or shortening of the object. This could result in under irradiation of the target or an un necessary irradiation of normal tissues if adequate margins are not allowed for the motion.

Geometric uncertainties have to be recognized and accounted for in the planning and delivery of treatment otherwise the advantages of 3D CRT/IMRT may be lost and risk of unsatisfactory treatment increases. The ICRU 50/62 methodology does allow the treating physician to address these issues and should be used.

Organ motion and set up errors lead to a blurring of dose distribution, just as taking a picture of a moving object leads to a blurred image. The amount of blurring depends on the amplitude and the characteristics of the motion and not on the specific delivery technique.

Strategies to deal with organ motion

A lot of strategies have been examined to deal with organ motion due to respiration but the two most commonly studied techniques are a) deep inspirational breath hold (DIBH), and respiratory gating [4].

In DIBH, the patient with nose clamped, breathes through a calibrated pneumotach spirometer and is coached through a modified slow vital capacity maneuver, consisting of tidal breathing, a maximum inspiration, maximum expiration, and a second maximum inspiration with breath hold. Because most patients can maintain DIBH for 15-20 seconds, daily dose of radiation can be delivered in a single breath hold at a maximum linear accelerator dose rate (500-600 MU/min). The main disadvantage of this technique is that the need for active participation and compliance severely limits the number of patients who can benefit from it.

In respiratory gating treatment, a device monitors patient breathing and allows delivery of radiation only during certain time intervals, synchronous with the patients respiratory cycle. Respiratory gating with the patient breathing normally is potentially less demanding and thus more generally applicable. There are systems that rely on respiration monitors external to the patient to infer the position of internal target organs and systems that use real time imaging of patient internal anatomy.

Dimensional computed tomography, imaging, and treatment planning

Intrafraction motion is significant for lung, liver, and pancreatic radiotherapy and to a lesser extent breast, and prostate radiotherapy. A method to account for intrafraction motion is to temporarily adjust the treatment beam based on the tumor position with time such that the motion of the radiation beam is synchronized with the tumor motion. This addition of time into the three dimensional treatment process is termed 4-dimensional radiotherapy [5]. This modality may allow safe clinical target volume planning , target volume margin reduction to achieve the goals of raised tumor dose and decreased normal tissue dose. Detailed clinical studies are presently under way at various institutions. It is still in its infancy and much research and developments are expected in this area within the next few years. It relies on deformable image registration, which is slowly becoming more available to the radiation oncology community. Linear accelerators are capable, in principle, of delivering 4D radiotherapy, but they will require predictive software and feedback from the patient's respiration signal to the linear accelerator.

REFERENCES

1. Goitein M. Organ and tumor motion: An overview, Seminars in Radiation Oncology. 2004; 14: 2-9,.
2. Shirato H, *et al*. Real time tumor tracking radiotherapy. Lancet 1999; 353: 1331-1332.
3. George TY, *et al*. Artifacts in computed tomography scanning of moving objects. Seminars in Radiation Oncology 2004;14:19-26.
4. Mah D, *et al* . Technical aspects of the deep inspirational breath hold technique in the treatment of thoracic cancer. International J Radiation Oncology Biology Physics, 2000; 48: 1175-1185.
5. Keall P. 4-dimensional computed tomography imaging and treatment planning. Seminars in Radiation Oncology, 2004; 14: 81-90.