GE Healthcare

4D CT gated acquisitions

The use and benefits in patient treatment and delivery —
especially those with lung cancer.

David Hinckley, MS (DABR)

David Hinckley, MS (DABR) is the Chief Medical Physicist at The Regional Cancer Center in Erie, Pennsylvania.

The Regional Cancer Center was one of the first free-standing community cancer care centers in the country. Today, it is also among the largest of such facilities, providing more than a half million services per year at five locations serving three states.

The physicians of The Regional Cancer Center were among the first in the nation to bring major treatment specialties — medical oncology, radiation oncology and hematology — together in a single location. In doing so, they pioneered a cooperative approach to treatment that is now becoming widely emulated. The achievements of the physician group in advancing cancer care have been recognized locally, regionally and nationally.

Each year, The Regional Cancer Center administers over 25,000 radiation therapy treatments, utilizing some of the most advanced imaging and treatment technology in the world, including:

- Image-guided radiation therapy (IGRT)
- Intensity-modulated radiation therapy (IMRT)
- Ultrasound imaging with robotic computer technology
- PET/CT imaging technology
- CT simulation-base treatment planning
- Stereotactic radiosurgery
- Gamma-knife procedures
- High dose-rate brachytherapy

At GE, we spoke with Mr. Hinckley on the use and benefits of 4D CT gated acquisitions in treatment planning and delivery for patients, especially those with lung cancer.

Why is motion correction needed in treatment planning?

"For too long we've been ignoring motion in the clinical world. We look at static CT images and believe that what we see is what we treat. But in reality, treatment is a lengthy process and the patient is a very dynamic organism — which all can lead to distortion in those static CT images we utilize.

"Also, considerable research points to the presence of motion, especially in the lung. In the superior/inferior direction this can be upwards of three centimeters (although less in the anterior/posterior and left/right aspects). Below the diaphragm, significant motion exists as well. We have to find more effective ways of dealing with motion during treatment planning and delivery in order to benefit our patients."

Why is motion in the lungs so critical?

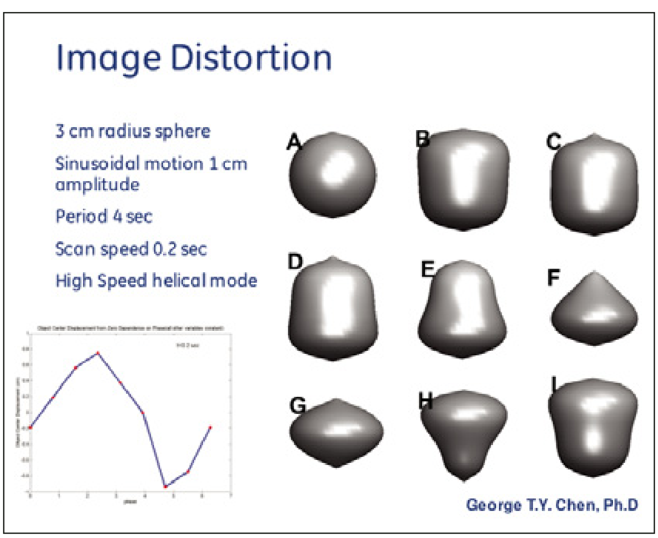
"Lung cancer is the most prevalent cancer in men and women in the United States. There are more than 170,000 new cancers diagnosed each year and, more devastatingly, there are 160,000 deaths per year. The reason we have been unable to make inroads into lung cancer treatment is dose limiting. In order to achieve a 50% local progression-free survival of even 30 months, you need to deliver greater than 85 Gray. Why do most of us feel uncomfortable delivering that high a dose? Because we are concerned about the side effects to the healthy lung tissue around the tumor.

"The question is: how do we solve that dilemma and what tools can help us deliver these high doses safely?"

What impact do helical CT scanners have on tumor motion?

"When you scan patients with today's ultrafast helical CT scanners, there is a considerable amount of tumor reconstruction distortion that is going to be inherent to any helical system. When you look at images acquired at different phases, not only is the tumor moving, but the structure and the shape of that tumor changes dynamically with the patient's respiration.

"In order to get a true reconstruction that represents the actual shape of the tumor, you need to consider advanced motion correction techniques. Several studies have taken a closer look at the characteristics of this distortion. Chen and colleagues[1] from Massachusetts General Hospital (MGH) reported that when performing fast helical scans, distortion along the axis of motion could result in a lengthening or shortening of the target. Additionally, the center of the target can be displaced by as much as the amplitude of motion of the target. Conversely, Wurstbauer and colleagues[2] have shown that a slow CT scan acquisition results in larger target volumes in comparison to fast scan techniques, while yielding an integral delineation of almost all positions of tumor motion. So slow scan techniques with slice acquisition times greater than the period of target motion should detect the range of tumor motion and shape throughout the normal cycle.[3] They concluded that non-gated spiral CT imaging of dynamic targets can lead to distortion of target shape and misalignment of the target's centroid, and loss of volumetric information and target motion.[3]"



Graphical depiction of tumor distortion during reconstruction. Portion A depicts a tumor with a 3 cm radius sphere, to approximate a lung tumor. When the tumor is scanned at a very high speed of about 0.2 seconds in a helical scanner and moved through a small amplitude of 1 cm to approximate a shallow respiratory phase period, the result is a variety of distortions depending on where the tumor is in the patient's respiratory cycle.

What techniques are available to solve the problem of respiratory motion?

"Let's look at the pros and cons of technologies that have been put forth to account for respiratory motion during imaging.

"**Slower image acquisition:** If fast scanning with a helical scanner contributes to distortion, how about slowing things down? Acquisition at reduced speeds does reduce distortion but at the expense of image definition. Less signal is captured so the image is blurred, making it more difficult to determine tumor edges. With slow image acquisition, motion blurs the image, just like in photography.

"**Breath-hold scanning:** With a helical CT scanner operating at high speed, it's easy for patients to hold their breath during the short scan duration. This allows you to temporarily freeze the tumor's location. Unfortunately the images, while good, are not always desirable for treatment. Treatments last a long time, upwards of 15 minutes, and patients cannot hold their breath for that long.

"**Breath control:** Some clinicians have tried abdominal compression to physically restrict the motion of the diaphragm and lung volume. But this procedure only restricts motion, and furthermore, is not well tolerated by patients, especially those with lung cancer.

"**Fiducial markers:** The use of internal fiducial markers has been explored. By implanting gold markers into a tumor, we can track and monitor the actual tumor. However, this is a very invasive procedure with potential complications and is not effective for small or non-solid tumors. The best technology available to us at this time is an external fiducial marker or surrogate that correlates to the internal tumor's motion — a respiratory gating system."

"For too long we have been ignoring motion in the clinical world."

What is a respiratory gating system?

"Ideally we want to acquire image data on a tumor through all phases of a patient's respiration and then rebin these images to specific phases. This allows us to analyze what the tumor is doing at each phase and determine whether there is a stable phase for treatment or whether we can create a composite tumor volume by summing all the different phases of respiration. In order to do this, we need a mechanism to monitor the patient's respiration and tie that into the imaging chain so we can tell exactly when an image was acquired in relationship to where the patient was in their breathing cycle."

What does respiratory gating require, in terms of equipment?

"Respiratory gating requires a CT scanner, a linear accelerator, and positioning technology — equipment that is fairly common in most cancer centers. We conducted our initial gating studies using a GE LightSpeed CT.

"While there are many different brands available, our cancer center currently uses:

- A GE Discovery ST PET/CT system to acquire the images
- A Varian Trilogy linear accelerator to treat the patient
- A Varian RPM (Real-time Position Management) computer system to serve as a bridge between the imaging and treatment modalities. This technology tracks the patient's respiration and triggers treatment at the appropriate time.

"You also need a mechanism to analyze and evaluate the images so you can make treatment decisions. We use GE Healthcare's AdvantageSim MD radiation therapy simulation and localization software with 4D motion management."

Gated study shows that in certain phases of patient respiration the tumor falls out of what would have been the traditional target volume using conventional simulation and contouring. Gating allows synchronization of the image and radiation delivery with respiratory motion, which means margins can be shrunk down around the tumor and be more conformal.

How does the process work?

"The patient is placed into treatment position and a plastic surrogate marker is placed somewhere between the umbilical cord and the xiphoid process. The camera system is turned on and the patient is moved into the imaging position. The technologist then performs the CT scan with the table pausing incrementally during each phase of the respiratory cycle, based on data from the RPM system. During each cycle you can see the patient's chest rise and fall, and then the CT scanner moves on to the next bed position and acquires the next set of images.

"This information goes to the AdvantageSim workstation where the data is rebinned into different breathing phases for the clinicians. Typically the physicist, the dosimetrist, and the radiation oncologist review this data and make the treatment decisions regarding volume contouring and phases of treatment.

"That information is fed into the treatment planning computer and a treatment plan is generated. If a gated delivery of treatment is recommended, the patient is positioned in the linear accelerator and the RPM data is fed into the system to tell the accelerator when to turn the treatment beam on and off."

What is the decision tree for gated imaging studies and gated respiratory treatment at the center?

"Any patient who comes to the center with a lesion in the thorax immediately gets a gated CT or a gated PET/CT imaging study. We also are using gated imaging to explore other disease sites outside the lung, predominantly below the diaphragm. The team evaluates the gated study on the Advantage workstation to make a decision. The vast majority of our patients will get nothing more than a composite tumor volume drawn and incorporated into their treatment plan. For the remainder, we find the most stable phases of respiration, where the tumor holds still, and we'll deliver this in a gated fashion on the linear accelerators."

Is 4D gating helpful for ungated treatments?

"Regardless of the severity of tumor motion, the ability to collate and view images with the 4D software gives us an enhanced clinical picture. 4D allows us to see where the tumor is going to move and where it's not going to move and what the critical structures around it are doing as well. This data enables us to contour the tumor and determine the appropriate margins with accuracy, and thus, escalate the dose with a higher degree of confidence. We believe patients benefit from gated image acquisition even when they don't need gated treatments. In fact, upwards of 85% of our patients who receive gated image studies do not go on to gated treatment.

"Even with tumors that don't move a lot, a gated image study gives you the data to accurately define the planning treatment volume with confidence knowing that the tumor is going to be stable in the radiation field."

How does 4D gating and treatment help with significant tumor motion?

"We've found that when you have a tumor with significant motion, a conventional simulation simply isn't adequate. We've compared contours drawn on volumes based on conventional simulation and then repeated the scan with respiratory gating. In many cases the tumor drops out of the proposed target volume during certain phases of respiration. We could have contoured the tumor in all phases and come up with a composite, but that would have meant a large portion of healthy lung would have been unnecessarily irradiated as the tumor bounced in and out the treatment window."

“Respiratory gating technology allows you to synchronize the image and the radiation delivery with respiratory motion.”

How did the Center incorporate 4D CT scanning into the treatment planning process?

“We built our confidence through a phased adaptation process. First, we started acquiring gated images and watching the movie loops to get a feel for tumor movement. This helped us decide what margins to place, which quickly led us to create differential tumor volume margins and incorporate them into our treatment plans.

“Next, we started contouring the tumor at all phases of respiration and blending the contours together to create a composite tumor volume. This led to using differential margins based upon the direction and extent of motion to determine the phase with optimum stability.

“Since most of our patients are in the 40 to 60% respiratory phase range, we contour the tumor in the 40, 50, and 60% phases and create a composite tumor volume. We feed this data into the treatment planning computer, and at the time of treatment we only turn the beam on during those corresponding phases.

“Recently, we have moved into the gated respiratory IMRT stereotactic arena. I wouldn’t recommend starting here, but as you build your confidence you can work up to this.”

What advice would you give to other oncology treatment centers considering respiratory gating technology?

“According to the AAPM Task Group 76 Report, if the target motion of a tumor is greater than 5 mm, the facility has a method of respiratory management, and the patient can tolerate the procedure, then a respiratory gating protocol should be followed.

“Respiratory gating technology allows you to synchronize the image and the radiation delivery with respiratory motion. You can shrink the margins down around the tumor, be more conformal, and in doing so, deliver higher doses with the hopes of having better control and better outcomes for the patient.

“Is current respiratory gating technology perfect? No, but it is certainly mature enough to be incorporated into an oncology practice.”

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GE Healthcare
3000 North Grandview
Waukesha, WI 53188
U.S.A.

www.gehealthcare.com

ONC-0138-10.07-EN-US