From EBRT to IMRT to IGRT

Advances in Radiation Therapy

by
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Radiation therapy treatment planning and delivery systems have evolved tremendously over the past 10 to 15 years. Taking external beam radiation therapy (EBRT) for prostate cancer as an example, the treatment fields used to be hand drawn on anterior-posterior and lateral radiographic simulation films. We couldn't actually *see* the prostate, but based our field design on the visible bony landmarks. The next evolutionary step was to incorporate CT scans into the treatment planning process. This initially meant obtaining a CT scan and then, slice by slice and again by hand, translating the soft tissue anatomy (prostate gland and normal surrounding structures) now visible on the CT to the same type of anterior-posterior and lateral X-ray simulation films. This process was tedious and rather inaccurate. Once the target volume was defined, fields were drawn to encompass it with margin. In both of the above methods, molten metal (cerrobend) blocks were custom poured to shape the radiation beam to the drawn field. Later, multileaf collimators (MLCs) became available. These consist of a series of small metal leaves built into the head of the linear accelerator that could automatically create the necessary beam shape for each patient and each field. Over time, these MLCs became more and more refined.

Next came 3-D conformal radiation therapy, which allowed us to define the target volume on a computer monitor again using CT slice images. The treatment planning software could then determine the best MLC field shape using multiple beam angles (for prostate cancer, the beams often come from six directions). The MLC would have a different shape for each treatment angle, thus conforming the dose to the target.

Intensity-modulated radiation therapy (IMRT) was a further advance of 3-D conformal radiation therapy. With IMRT, multiple beam angles are again used but the shape and intensity of the radiation throughout each field vary during the actual treatment delivery. This technology allows doses to be even more conformal. In addition, it is the only technique that can create concavities in the dose distribution, an advantage when trying to wrap the high-dose region around a normal structure. For example, IMRT allows the dose to fall off posterior to the central portion of the prostate, further sparing the sensitive rectum.

IGRT: The Next Step in Radiation Treatment

Some of the newest radiation therapy technology centers around treatment margin—a very complex issue. Today, image-guided radiation therapy (IGRT) is optimally suited to improve treatment margin for many cancer patients. Again, using the example of prostate cancer, we need to account for a clinical or biological margin. We don't want the dose to fall off from 100 percent to 0 percent at the visible edge of the prostate gland, because we know microscopic disease can extend into this peri-prostatic area. Thus, as clinicians, we need to determine, again in each dimension, exactly how much margin beyond the visible structure we want to treat.

Once treatment margin decisions are made, issues of interfraction and intrafraction motion still remain. Interfraction motion refers to the prostate being in a slightly different position within the body each day, as well as inaccuracies in daily patient setup and positioning, which is typically done via external skin marks with a laser alignment system. Interfraction motion may be caused by the amount of stool or gas in the rectum and by bladder filling, which at times can cause the organ to shift by 1.5 cm or more. Intrafraction motion refers to movement of the organ during the time of actual treatment delivery. IMRT treatment delivery can easily span 20 minutes. Generally for prostate cancer, intrafraction motion is believed to be of significantly smaller magnitude than interfraction motion and setup error.

Until the development of IGRT, clinicians were unable to use the full capabilities of the modern linear accelerator and planning systems to design highly conformal treatment fields. The only way to use such tight fields is if there is a reliable and reproducible method of assuring the delivered dose precisely overlaps the actual target. Without this capability, clinicians would undoubtedly end up with a geographic miss. In other words, portions of the target area would be outside the volume of therapeutic dose (resulting in a decrease in the effectiveness of treatment), and areas of normal tissue would mistakenly end up in the high-dose region (resulting in increased complications).

The "ideal" external beam treatment for prostate cancer would deliver the full dose to the prostate gland and any surrounding cancerous cells, while minimizing dose to surrounding normal tissues. Two tissues of concern for both short-term and long-term toxicity are the rectum and bladder. There is dose response data showing improved tumor control with increasing total dose. We are limited, however, by how much radiation the normal surrounding tissues can safely tolerate. IGRT offers the possibility of increasing the dose delivered to the target, while simultaneously reducing the dose to the sensitive surrounding structures. If we can know with better accuracy and precision the position of the prostate before each treatment, we can eliminate the extra margin we previously added on to account for all of the interfraction uncertainties mentioned above.

IGRT: 101

Several IMRT manufacturers exist. The following real-world example focuses on SCI's IGRT system. In simple terms, SCI's Synergy system combines a state-of-the-art linear accelerator with robust imaging capabilities that are designed to work together in a single platform. Using Elekta XVI (X-ray volume imaging) cone beam CT on the Elekta Synergy system allows a rapid 3-D CT through the treatment site before each radiation treatment. Different image registration methods allow us to compare where the target is at the time of treatment to where the target was when we planned the now very tightly conformal treatment. The system provides a readout of the error in three dimensions (inferior to superior, right to left, and anterior to posterior) or up to six dimensions (adding pitch, yaw, and roll). This information is then fed back to the mechanical couch on which the patient lies for treatment. Using this information, we can correct for errors and then bring the target structure—in this case the prostate—back to the planned position.

The Synergy system also offers the ability to deliver stereotactic body radiotherapy. When combined with Elekta XVI cone beam CT, we will be able to deliver high-dose small-field radiotherapy to regions close to normal sensitive structures with confidence.

The benefit to patients is clear. Not only will more patients now be able to receive radiation therapy, the treatments themselves will be more accurate. Smaller margins translate into less radiation to normal structures, which, all things being equal, should translate into better tolerance and less side effects. Higher tumor doses generally translate into better results in terms of tumor control.

Body stereotactic treatment techniques also shorten the overall treatment course for some patients. Another exciting aspect involves IGRT for moving targets (such as a lung tumor that moves with breathing). The Synergy platform offers the potential to treat these patients without the need for surgically implanted radio-opaque markers or fiducials, which many other competing technologies require.

This technology is suitable for many tumor sites particularly those where we want to deliver high doses of radiation to a very conformal structure that is not easily imaged with standard x-rays. Prostate, lung, and head and neck are excellent examples.

In adopting this new technology, we have been able to staff our Synergy linear accelerators with the same number of people as our older equipment (without IGRT). We have not had to increase our radiation therapist staffing.

IGRT's promise is that it will allow clinicians to improve their ability to deliver high-dose precision radiation therapy with more accuracy and thus lower doses to surrounding normal tissues. Many patients whom in the past were deemed unsuitable for treatment will now be eligible.

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PHOTOGRAPH COURTESY OF ELEKTA, INC.

Three of SCI's four new linear accelerators are equipped with image-guided radiation oncology technology (IGRT). Pictured (left) is SCI's Elekta Synergy® linear accelerator.

Pictured below is a split view cross-sectional image of the pelvis with the prostate outlined.

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