Evolution of External Beam Radiation

Medicine has a long-established history of using external beam radiation therapy to treat cancerous tumors. This specialty involves the use of ionizing radiation from either X-rays or proton beams to kill or control malignant cancer cells. X-rays and protons are equally effective at killing tumors. The biggest difference is that proton radiation stops where the tumor stops, while X-ray radiation travels beyond the tumor and affects more healthy tissues and organs. Below are brief historical overviews of how technology has evolved in the United States for the two major forms of external beam radiation: proton therapy and X-ray therapy.

Proton Therapy Technology: History at a Glance

In 1946, American physicist and former Manhattan Project group leader Robert Wilson laid the groundwork for the field of proton therapy with the publication of his landmark paper, "Radiological use of Fast Protons." In this paper, Wilson suggested for the first time that protons could be used clinically, describing how protons could spare normal tissue and allow for the maximum placement of the radiation dose inside the tumor.

The first proton treatments were performed in the mid-1950s using a particle accelerator built for physics laboratory research at the University of California, Berkeley, and later at the Harvard Cyclotron Laboratory. These were busy physics labs, and a very limited number of patients could be treated. The nation's first hospital-based proton therapy center opened in 1990 at the Loma Linda University Medical Center in Southern California. Since then, 14 more patient-focused proton therapy centers have opened in the United States.

The technological centerpiece behind proton therapy is the superconducting cyclotron, where the proton beam is generated using hydrogen and oxygen to create a plasma stream. Protons are extracted and accelerated to roughly 100,000 miles per second. They are then sent to a beam transport system, which uses a series of electromagnets to steer the beam and transport it to each treatment room using a vacuum line.

The traditional method for delivering proton therapy is the "passive scatter" approach, in which the shaping of the beam to conform to the tumor takes place just outside of the treatment nozzle. When the proton beam exits the nozzle, it runs through a scattering filter to broaden the beam, and then travels through a hole in an aperture that matches the height and width of the tumor. Next, the beam runs through a tissue compensator, which is custom designed to direct the beam to the specific depth of the tumor in the body.

The latest advance in proton delivery is "pencil-beam scanning." Instead of using physical devices outside of the treatment nozzle to shape the beam, pencil-beam scanning utilizes computerized data files, developed based on 3-D models of the patient's tumor. Pencil-beam technology configures the height and width of the tumor with a computer that uses electromagnets inside the nozzle to sweep the beam across the tumor, building up the dose layer by layer. The penetrating depth of the beam is controlled by an energy selection system (located near the cyclotron), which varies the energy of the protons.

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Pencil-beam scanning offers a number of advantages compared to the passive scatter method. It spares more normal tissue and enables doctors to treat larger and more irregularly shaped tumors. Pencil beam also allows for changes in treatment planning to be implemented more quickly, as the size of tumors can change during weeks of treatment. And pencil beam produces about one-tenth as many highly carcinogenic neutrons as passive scatter, which further reduces the probability of secondary malignancies.

Scripps Proton Therapy Center is the only U.S. facility to deploy pencil-beam scanning in all of its treatment rooms. Pencil-beam scanning was first used in the U.S. at MD Anderson Cancer Center in 2009 and is now used on a limited basis at a handful of centers nationwide.

X-ray Therapy Technology: History at a Glance

In 1895, German physicist Wilhelm Roentgen discovered the existence of X-rays. Their effect on growing cells was immediately evident, as human skin exposed to X-rays reddened and peeled. Despite limited knowledge about how X-rays work, in 1896 Emil Grubbe became the first American physician to irradiate a cancer patient, using high doses of low-energy X-rays. Many early X-ray therapy patients endured severe skin burns, due to the high skin dose of the low-energy X-rays being utilized.

Treatment approaches changed with the introduction of fractionation (a more gradual delivery of radiation in smaller doses, spread out over time), which was shown effective in a 1934 report. Fractionation remains a key part of many radiation treatment programs today.

Technology slowly progressed during the first half of the 20th century, as X-ray machines grew more energetic, enabling doctors to treat tumors slightly deeper in the body. But even at approximately 400,000 electron volts, these ortho-voltage X-rays were still relatively low in energy.

World War II brought the development of powerful nuclear reactors that could generate synthetic radio isotopes, including cobalt 60. Cobalt emits a gamma ray with an energy of 1.25 million electron volts, which could penetrate slightly deeper in the body and spare more of the skin from excessive damage. But using cobalt to treat at greater depths created too much collateral damage for patients to tolerate. Because it was simple to manufacture and maintain, cobalt technology went into widespread clinical use in America for the next few decades.

The next evolution in X-ray therapy technology was the medical linear accelerator, which came into general clinical use in the mid- to late-1970s. Early linear accelerators could produce X-rays in the energy of 6 million electron volts and by 2000, they could produce up to 25 million electron volts. The planning of X-ray therapy has also evolved to help better define and treat tumors. An example is 3-D conformal radiation therapy, in which data from CT or MRI images of the tumor are used with a multi-leaf collimator (a computer-controlled blocking device) to shape each beam to match the tumor. The latest advancement in X-ray therapy has been widespread adoption of intensity-modulated radiation therapy in the early 2000s. This approach involves treating the tumor from multiple angles with X-ray beams of varying intensity, depending on the amount of normal tissue that is in their path.

Media Contact: Steve Carpowich
858-356-7476
carpowich.stephen@scrippshealth.org
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