Laser Accelerated Radiotherapy: Is It On Its Way to the Clinic?

By Mike Martin

One of the newest candidates for delivering radiotherapy may be largely unknown to the world of oncology.

Laser accelerated subatomic particles for the treatment of superficial tumors may afford the tissue-sparing precision of proton therapy—another fledgling technology—without the unwieldy size or cost. “Thank most clinicians have never heard of laser accelerated radiotherapy, the technology is promising enough that we spent four years investigating it,” said Eric Horwitz, M.D., acting chairman and clinical director of the Fox Chase department of radiation oncology.

Budget cuts have put the Fox Chase program on hold, but studies in Europe, Japan, and elsewhere continue. In Germany, Christoph Keitel, Ph.D. led a group from the Max Planck Institute for Nuclear Physics in Heidelberg that recently concluded several types of laser beams could accelerate protons “to the energies required for cancer therapy.”

And in recent papers for the journal Physical Review Letters, Italian physicist Antonio Giulietti, Ph.D. and colleagues at the Institute for Physical Chemistry Processes in Pisa, Italy showed that tabletop lasers could replace the room-sized particle accelerators now standard for electron therapy as well.

These and other studies have generated excitement about the potential of laser acceleration—what Shalom Kalnicki, M.D., a radiation oncologist at New York’s Albert Einstein College of Medicine, calls “a radiation oncologist exploits a proton beam characteristic called the Bragg peak. A Bragg curve plots how ionizing radiation loses energy as it travels through matter, in this case, tissue. For accelerated protons, the energy curve peaks sharply as the particle stops, releasing its power like a well-placed punch.

This so-called Bragg peak effect provides “normal tissue sparing superior to other radiotherapies,” said Albert Einstein’s Kalnicki.

Despite the potential benefits, until recently only two cancer centers—Loma Linda and Boston’s Massachusetts General Hospital—have operated the huge subatomic particle accelerators that proton therapy requires.

“Cyclotron accelerators are monsters. They’re the size of a house,” Horwitz said. “A single cyclotron takes up an entire building and costs between $150 to $250 million.” What’s more, the rotating gantry that positions the proton beam around the patient “not only weighs a ton but takes up a ton of room,” he added.

Cost, size, and unwieldiness are driving smaller, less expensive lasers as accelerator alternatives, and a way to use protons in techniques like image guided radiotherapy (IGRT) or intra-operative radiotherapy (IORT), where extra equipment and space considerations presently rule protons out.

In the operating room, IORT destroys cancer cells surgeons may have missed shortly after tumor resection. IGRT couples an intensity-controlled radiation beam with an image guidance system like 3-D computed tomography (CT), to deliver precise doses to specific areas that conform to the tumor’s three-dimensional shape.

“Laser acceleration promises the benefits of proton radiotherapy at a fraction of the cost and a fraction of the space,” Horwitz said. “A laser accelerator might run between $5 million to $10 million and you could actually put a PET (positron emission tomography) imaging system in the room with the gantry. Clinically and financially, lasers make much more sense.”

From Physicist to Physician

Physicists conducted the first laser proton acceleration experiments at the Lawrence Livermore National Laboratory in 2000, and until recently, used mathematical models to show what lasers might do for cancer.

A model from the Ecole Polytechnique Intense Laser Laboratory in Paris, for instance, focused a laser to strip protons off metal. Described in the January 2006 issue of the journal Nature Physico, the stripped protons reached 60 MeV—the minimum energy required for medical applications, but far below the 250 to 300 MeV required to reach denser, deeper tissue.

Recent research promises more energy and more precision. In an April 2008 paper for Physical Review Letters, the Max Planck Institute’s Keitel joined Yousef Salamin, Ph.D. from the American University of Sharjah in the United Arab Emirates to assert, “direct laser acceleration of ions is an appealing alternative for cancer therapy.”

They also added some new caveats, suggesting that so-called radially polarized laser beams are preferable to linearly polarized beams and may be the best way to get laser accelerators up to speed. Not yet available for medical applications, radially polarized beams radiate in all directions, providing what Salamin calls “a more favorable energy spread.” Linear polarization, on the other hand, directs light in one direction, reducing the energy spread. In both instances, however, Keitel and team discovered that “linearly and radially polarized laser beams...”
Giulietti, who heads the intense laser irradiation laboratory at the Institute for Physical Chemistry Processes in Pisa, Italy.

In radiotherapy, monochromatic, collimated high-energy beams are the stuff of perfect worlds, at least in theory. Consisting of near-single wavelength radiation and well-bundled rays, the beams don’t disperse much as they move through tissue, delivering an energized wallop to their intended target.

“IORT has seen limited use in the past, due to the challenges of either moving a patient during surgery to a shielded bunker, or performing the actual surgery in a shielded operating room,” said Wink Jones, whose firm Intraop Medical in Sunnyvale, Calif. manufactures a mobile, self-shielded linear accelerator used for unshielded radiotherapy. “Electron beam technology for IORT has gained wider clinical adoption—especially in Europe—because it allows greater flexibility for delivering radiation in the operating room.”

Offering even safer electron delivery, “the laser could stay in a hospital room with no radiation safety restrictions,” Giulietti explained. “Its beam could also serve several operating theaters.” In the operating room, Giulietti envisions the laser beam entering an air-evacuated 50 by 20 by 20 cm metal box with focusing optics and a helium gas jet. Using remote control and precision pointers, the radiotherapist would direct electrons extracted from the box to the patient’s tumor “the same way they would using a traditional accelerator," Giulietti said, except that laser acceleration is far less expensive and shrinks the system’s footprint by a factor of about 100.

Still, Giulietti does worry about stability and reliability and says laser accelerated electrons need plenty of engineering before a usable prototype will emerge. Fox Chase’s Horwitz agrees. “Laser accelerators haven’t yet generated a clinically useful beam, regardless of the particles they’re being used to accelerate,” he said. However, he remains optimistic: “Though lasers don’t yet generate energetic enough particle, it’s certainly feasible, and there are a lot of very talented people working on it,” he said.

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