A scientific first: Team engineers photograph radiation beams in human body through Cherenkov effect

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Long exposure image of Cherenkov emission and induced fluorescence from Fluorescein dissolving in water during irradiation from a therapeutic LINAC beam. Credit: Adam Glaser.

A scientific breakthrough may give the field of radiation oncology new tools to increase the precision and safety of radiation treatment in cancer patients by helping doctors "see" the powerful beams of a linear accelerator as they enter or exit the body.

We don't have X-ray vision. When we have an X-ray or mammogram, we cannot detect the radiation beam that passes through our bone or soft tissue, neither can our doctor. But what if we could see X-rays? When we use powerful X-rays for cancer treatment, we could see how they hit the tumor. If we were off target, we could stop and make adjustments to improve accuracy. Pinpoint precision is important. The goal of radiation is to kill cancer cells without harming healthy tissue.

Safety in Radiation Oncology

As a way to make radiation safer and better, Dartmouth began to investigate a scientific phenomenon called the Cherenkov effect in 2011. Our scientists and engineers theorized that by using Cherenkov emissions the beam of radiation could be "visible" to the treatment team. The ability to capture an X-ray would show:

- how the radiation signals travel through the body
- the dose of radiation to the skin
- any errors in dosage.

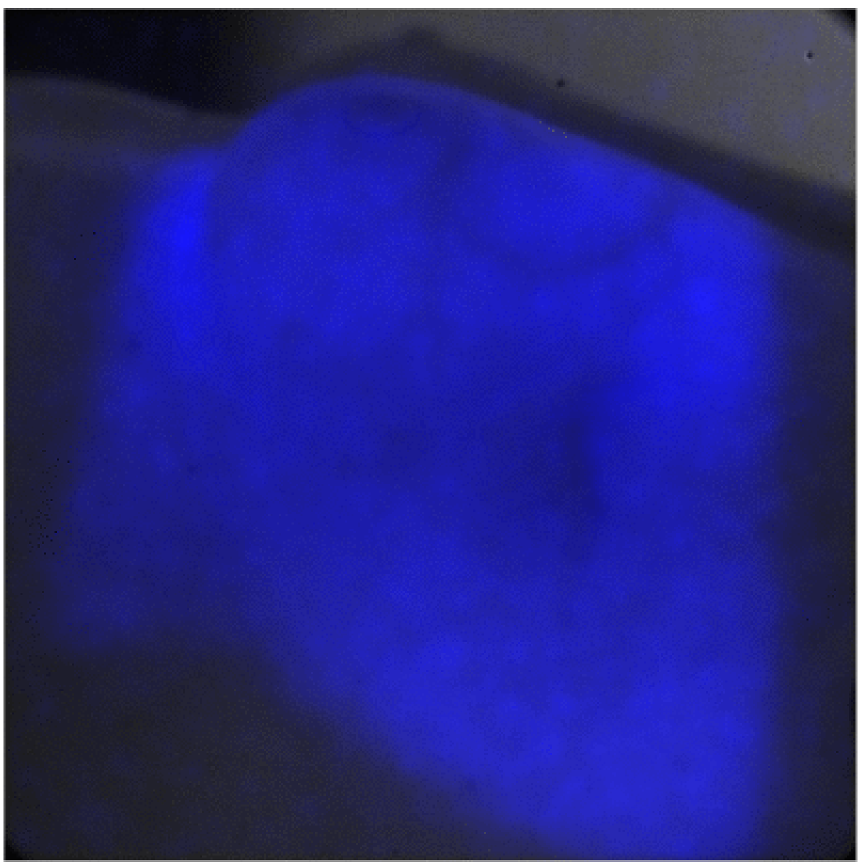
TV viewers may have seen images of sunken fuel rods from a nuclear power plant emitting a blue-green glow. That is the Cherenkov effect. When a particle with an electric charge travels faster than the speed of light through something that does not conduct electricity, like the human body or water, it glows. As the matter relaxes from polarization, it emits light. (Yes, for a brief period people glow during radiation.)

The Cherenkov effect in the laboratory

As a first step, engineers at the Thayer School of Engineering at Dartmouth modified a regular camera with a night vision scope to take photos of radiation beams as they passed through water. What appeared on the photos is the Cherenkov effect, a luminescent blue glow. (An engineering student, Adam Glaser, explains how it works in this video.)

To refine the approach for use in radiation treatment, scientists used a mannequin of the human body. They measured and studied the results to refine their ability to capture the luminescence, experimenting with beam size, position, and wavelength.

Cherenkov imaging used for first time in treatment setting



A radiation beam treatment is visualized here in the first in human use of the technique. The blue represents the treatment area. As the dose fades the treatment area becomes a dark gray shadow. The lingering blue in the lower right hand area of the image shows a "hot spot" in the treatment area where adjustments can be made to avoid skin irritation.

With the clinical aspects refined, Geisel School of Medicine researchers photographed luminescence during the routine radiation treatment of a dog with an oral tumor.

This was the first time Cherenkov studies came out of the laboratory and into a treatment setting. The scientists coined the approach Cherenkoscopy. As they anticipated, during the session they were able to see detailed information about the treatment field and the dose. The results were published in the November 2013 issue of the *Journal of Biomedical Optics*.

"This first observation in the dog proved that we could image a radiation beam during treatment in real time," said David Gladstone, ScD, chief of Clinical Physics at Norris Cotton Cancer Center. "The images verified the shape of the beam as well as intended motion of the treatment machine."

First image of Cherenkov emissions during treatment of human breast

Now ready to use the technology with a human patient, the team prepared to view radiation as it entered the body of a female breast cancer patient undergoing radiation in July 2013.

"Breast cancer is suited for this because the imaging visualizes the superficial dose of radiation to the skin," said Lesley A. Jarvis, MD, radiation oncologist, Norris Cotton Cancer Center. Skin reactions, similar to sunburn, are a common and bothersome side effect during breast radiation. "By imaging and quantitating the surface dose in a way that has never been done before," said Jarvis, "we hope to learn more about the physical factors contributing to this skin reaction."

By seeing the effect of radiation on the body, radiation oncologists and physicists can make adjustments to avoid side effects to the skin. Most radiation patients undergo somewhere between 8-20 sessions. The Cherenkov images of the breast cancer patient showed a hot spot in her underarm, which physicians and physicists could work to prevent in future sessions.

"The actual images show that we are treating the exact correct location, with the appropriate beam modifications and with the precise dose of radiation," said Jarvis.

Clinical use of Cherenkov emissions proves successful

This trial showed that the Cherenkov effect is feasible for use real-time during radiation. "We have learned the imaging is easy to incorporate into the patient's treatment, adding only minimal time to the treatments," said Jarvis.

"The time needed to acquire this information is negligible, even with our experimental, non-integrated system," said Gladstone. "Cherenkov images were found to contain much richer information than anticipated, specifically, we did not expect to visualize internal blood vessels."

Mapping blood vessels opens up opportunities for radiation oncology to use a person's internal anatomy to confirm precise locations. Skin tattoos on patients determine a preliminary alignment that is verified with X-rays, which show bony anatomy or implanted markers. Cherenkov imaging allow technicians to visualize soft tissue and internal vasculature.

A possible safety net for radiation treatment

By integrating Cherenkov imaging into routine clinical care, Gladstone says the technology could be used to verify that the proper dose is being delivered to patients, helping to avoid misadministration of radiation therapy, a rare, but dangerous occurrence.

Twelve patients are participating in a pilot study, which is almost complete. The research team plans to publish the results in a peer reviewed journal. The Cherenkov effect project team includes Lesley Jarvis, MD, assistant professor of Medicine, Geisel School of Medicine; Brian Pogue, PhD, professor of Engineering, Thayer School, professor of Physics & Astronomy, Dartmouth College, professor of Surgery, Geisel School of Medicine; David J. Gladstone, ScD, DABMP associate professor of Medicine, Geisel School of Medicine; Adam Glaser, engineering student; Rongxiao Zhang, physics student; Whitney Hitchcock, medical school student.

With each trial the team gathers more information on the utility of the approach. "Stay tuned, we are now planning more definitive studies to determine the impact of this new imaging technology to improve safety of radiation," said Jarvis.

Provided by Norris Cotton Cancer Center

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