MRI TUMOR-TRACKED CANCER TREATMENT

In a project that is truly breaking the boundaries of what was thought possible, a team from the Cross Cancer Institute in Canada is combining the superb quality of magnetic resonance imaging with the power of a linear particle accelerator to enable ultraprecise radiation therapy.

By **JENNIFER HAND**

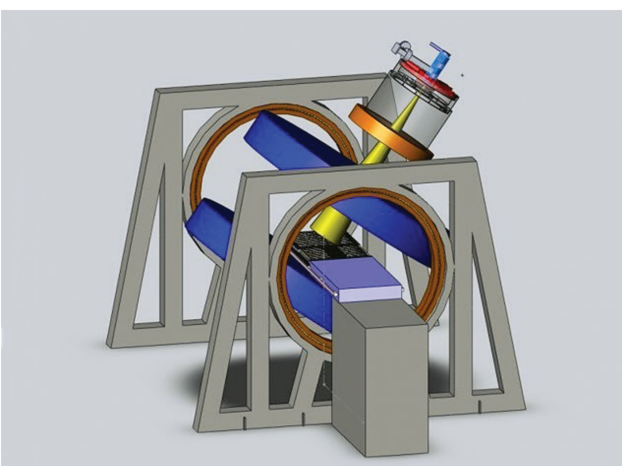


FIGURE 1: Configuration of the Linac-MR system.

A RATHER UNPALATABLE truth is that the targeting of radiation therapy for cancer involves significant uncertainty in accurately targeting tumors. On the other hand, magnetic resonance imaging (MRI) may be used to help by accurately identifying the location of a tumor in soft tissue, but it has to be carried out totally independently of radiation treatment delivered by a linear particle accelerator (Linac) because the two techniques conflict.

MRI scanners need to receive extremely faint radio frequency (RF) signals from the patient to produce an image. The electrical needs of the Linac produce very large RF signals, however, that interferes with the process of collecting faint signals. On the other hand, electrons from the Linac need to be directed precisely onto a target to produce cancer-killing X-rays, but the stray magnetic fields from the MRI deflect the electrons, impairing the Linac's function.

If the two systems could be combined, they would form an ideal treatment system that could pinpoint any tumor at all times during treatment, in particular, tumors within the thorax or abdomen that move with breathing. This has until recent years been regarded as an impossible undertaking. Now, a team based at the Cross Cancer Institute in Edmonton, Canada, has proved that it is not.

» ONE CHALLENGE AFTER ANOTHER

PROFESSOR GINO FALLONE of the University of Alberta, also in Edmonton, established a task force to attack the problem in 2005. Since then, he and his team have been knocking down barriers previously regarded as insurmountable. They achieved proof of concept in 2008 when they built a fully operational prototype designed for the head (see Figure 1).

"It would be difficult to overstate the different engineering and physics issues within the Linac-MR Project," Fallone says. "We have had to consider the design of the MRI system, the Linac, the optimal combination of both, and the room in which the new installation would be housed." Simulation plays a vital role in the progression towards clinical use of real-time, MRI-guided radiation, and team members have been using COMSOL Multiphysics since 2006.

"One of the earliest projects we did with a magnetostatic simulation was to establish a means of shielding the Linac from MRI's magnetic fields," says team member Stephen Steciw, an Associate Professor at the University of Alberta. "Having resolved that problem, we moved on to other issues, such as simulating and optimizing the structure of the MRI scanner, which has to incorporate a hole for the beam of X-rays to pass through. We had previously investigated the impact on the image quality when a Linac rotates around an MRI. We therefore studied angle-specific field heterogeneities and different ways to circumvent these. We verified that designing the Linac and the scanner to move together as one whole system resolved this issue."

» PROTECTING THE LINAC

WITH REGARD TO shielding the Linac, the initial aim was to shield down to 0.5 gauss, the magnitude of Earth's magnetic field. To accomplish this, the steel plate of the shielding wall was initially set at a thickness of 5 centimeters and a dimension of 200 cm by 200 cm. Joel St. Aubin, a former medical physics PhD graduate student who worked on the project picks up the story. "Using COMSOL Multiphysics, we were able to verify the tolerances of the Linac to the magnetic field and reduce the shield to a radius of 30 cm with a thickness of 6 cm. The new shield was more than three times lighter than the original, much more practical from an engineering design point of view. This new shield also dramatically reduced the MRI's field inhomogeneities—by more than three times—which is important for producing a distortion-free MRI image."

In addition to the passive shielding of the Linac, the team also investigated active shielding, running an electromagnetic simulation of a counter magnetic field.

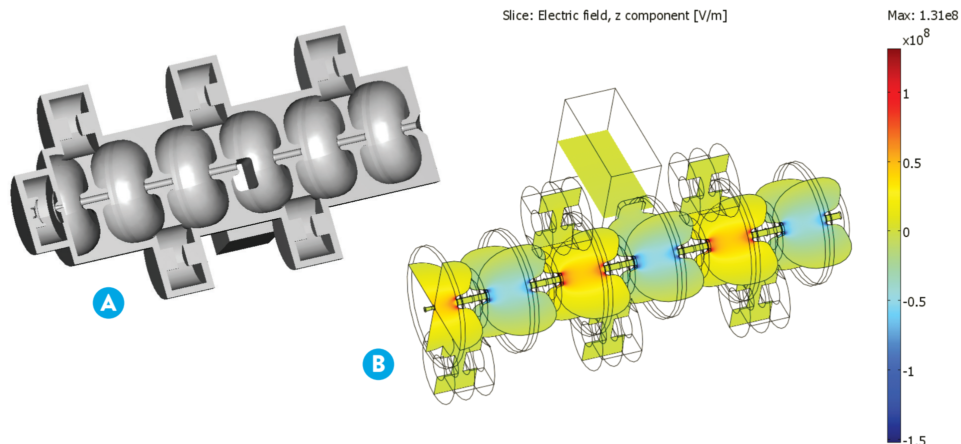


FIGURE 2: Cutaway view (a) and electric field distribution (b) of the short 10-MeV waveguide.

» HIGH ENERGY WITH A SHORT WAVEGUIDE

"**WE WANTED THE** Linac MR to generate a 10-megaelectronvolt (MeV) electron beam," explains Steciw (see Figure 2). "Given current sizing options, that would have meant buying a waveguide that was actually capable of generating 22-MeV electrons and measured 150 cm, too much and too long for our needs. We estimated that we needed 70 cm in length, but by using COMSOL Multiphysics we found out that we could take the waveguide right down to 30 cm. Now we are designing a new S-band waveguide. This reduction in length is of major importance because it means that the room we are constructing to take the Linac MR can be significantly smaller."

COMSOL Multiphysics was also used to establish whether this special room needed to be magnetically shielded (see Figure 3). The results showed that it did, and further simulations determined the thickness of the special steel lining. The first whole-body Linac MR is being constructed inside this room and is expected to be in public use by 2016.

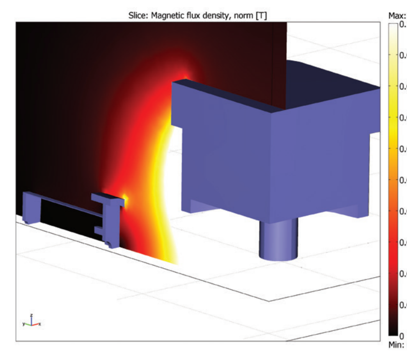
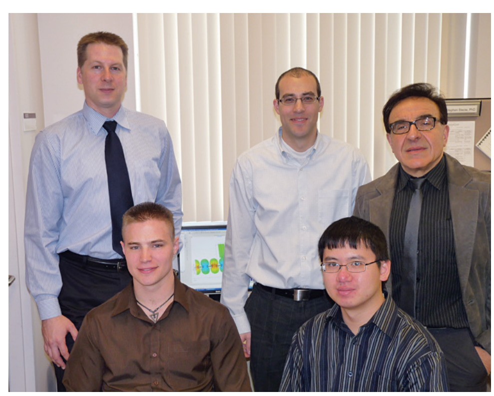


FIGURE 3: Passive shielding for a perpendicular Linac MR orientation (magnetic field lines perpendicular to electron trajectories).

» TIGHT TARGETING

THE PROTOTYPE IS being used for fundamental research on the engineering of the system's critical component, and the team is now preparing the documentation required to seek government approval for a Linac MR to be used as an investigational device for humans in clinical trials.

"COMSOL Multiphysics is an extremely practical and helpful tool which is enabling us in this important work", says Fallone. "Cancer patients currently have to undergo irradiation of the whole area around a tumor and some internal organs are particularly difficult to treat because they are so difficult to see. The Linac MR is set to transform radiation therapy." ◎



The team. Back row: Stephen Steciw, Joel St. Aubin, Gino Fallone. Front row: Devin Baillie, Dan Michael Santos.