Compact proton therapy for fight against cancer

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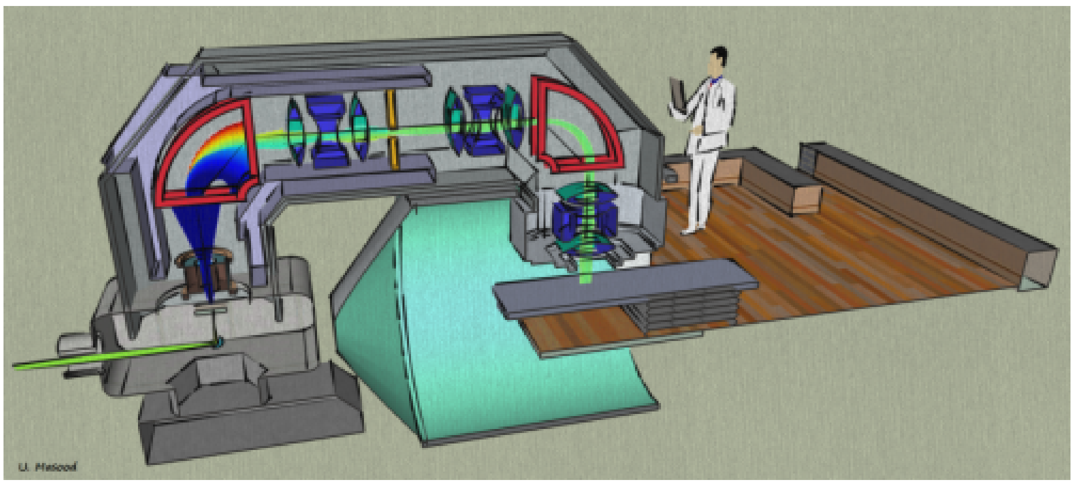

Dresden cancer researchers are looking to cut the overall size of the facility for cutting-edge proton therapy against cancer in half -- and to cut costs by doing so. Credit: Umar Massod

The future face of modern-day anti-cancer therapy based on charged particles like protons could potentially involve using laser accelerators. However, these facilities will need to be reduced in terms of both size and cost compared to conventional ones. In the scientific journal, *Applied Physics B*, Dresden medical physicist Umar Masood is the first to present a new design for the entire complex machine – from the accelerator to the radiation site. In the process, he has successfully cut the facility's size in half.

In the fight against cancer, proton therapy is especially precise and is better able to spare healthy tissue compared to established, high-level, hard X-ray based radiation therapy. A conventional proton radiotherapy facility typically consists of a ring accelerator plus a gigantic steel construction called a gantry with 360-degree rotational ability. In-between, protons are sent flying through a long beamline where heavy electromagnets keep them on track.

In Germany, only two universities – Heidelberg and Essen – are currently offering proton therapy as a treatment option; Dresden is on the cusp of starting operation of its own brand new facility. Professor Michael Baumann, Director of the new University Proton Therapy Dresden and of OncoRay – National Center for Radiation Research in Oncology sheds light on the reason behind this: "On the one hand, the application of proton beam therapy in different types of cancer has yet to be studied in more depth; for 15 to 20 percent of all radiotherapy patients, proton beam therapy will most likely be a considerable advantage compared with the established form of radiation therapy. On the other hand, the necessary facilities are quite large and costly. Thus, this treatment option will become more widely accepted, the more compact and the less expensive the available equipment becomes."

For this, it is necessary to shrink the three main components – the accelerator, the beamline, and the gantry – and Ph.D. student Umar Masood has succeeded at doing just that in his design study. Initially, he went ahead and replaced the conventional ring accelerator with a novel kind of laser accelerator, where the distance along which the particles are accelerated to high energy levels is on the order of millimeters. As part of his design study, and working closely with fellow researchers at the Helmholtz-Zentrum Dresden-Rossendorf (HZDR), the Technische Universität Dresden (University of Technology), and the University Hospital Dresden – together, these parties constitute the OncoRay Center – Masood was the first to markedly decrease the size of the individual components that lie beyond the accelerator.

"We will have to redevelop all of the various components from scratch over the next few years," says Masood. This is because laser-based particle beams exhibit properties that are distinct from those produced by ring accelerators. They exhibit a far greater energy distribution. At first glance, this seems to be a clear disadvantage. Established radiotherapy methodology is based on the premise that a tumor is scanned piecemeal using a pencil-shaped beam with a narrow energy window, starting with a higher energy, which is subsequently gradually lowered. As such, the proton beam is able to target every single place within the tumor's total mass. Since it gives off the vast majority of its energy only at the end of the distance traveled, the healthy tissue that lies beyond the tumor is spared.

Greater tumor volume targeted in a shorter amount of time

Given the wide energy window during radiation using laser-accelerated protons, a large portion of protons has to be eliminated from the beam to reach a comparatively narrower energy window. This compromises efficiency. However, Umar Masood has come up with an innovative solution to this dilemma: Not only does he use the wider energy distribution but also the proton beam's naturally larger diameter, which thus emits its dose within a larger volume. This translates to a larger number of cancer cells that are simultaneously irradiated within the same unit of time. Technische Universität München is currently in the process of developing a special kind of software to help with calculating dose deposition in the patient during planning of the treatment optimized for laser-accelerated proton beams.

Another property of laser-accelerated protons lies with the fact that we are not looking at a continuous particle beam here but instead at individual particle pulses. In the case of pulsed beams, more powerful magnets can be used to guide the beam from accelerator to patient – an important prerequisite for decreasing the beamline's and, more importantly, the massive gantry's overall size. Dresden is banking on pulsed magnets since the HZDR's Dresden High Magnetic Field Laboratory has extensive experience with these.

Staying on track using pulsed magnets

Umar Masood had to run tests on a number of different incarnations of his idea in order to be able to come up with a concept for guiding laser-accelerated proton beams in the first place. First, a magnetic coil fashions a beam from protons that were accelerated directly inside the gantry using intense laser light. Thereafter, a dipole magnet directs the beam around a 90-degree curve while ensuring that protons with an unsuitable energy window are cut off. A group of focusing magnets called quadrupoles, which are also only switched on for about 100 milliseconds at a time, keep the beam on track. Transport of a pulsed beam with a wide energy distribution can be tricky as there are at least six dimensions to be taken care of. A second dipole magnet redirects the beam in a direction opposite to the original acceleration towards the patient table located at the center of the gantry.

In spite of the fact that now, for the first time ever, an entire facility was modeled on the basis of a laser accelerator, there are yet many obstacles to be overcome before this kind of a facility can become a reality. As such, the various pulsed magnets have to first be developed and tested. Also, at this time, the laser-accelerated protons' energies are falling short of targeting deeper-lying tumors within the patient's body. Which is why the HZDR's own laser DRACO is currently undergoing an upgrade and is also getting a new big sister, PENELOPE, which, at a performance of 1 petawatt will take its place among the World's most powerful lasers.

Professor Ulrich Schramm, head of the HZDR laser-particle acceleration group, is quite certain that "following some five years of intense research using DRACO we're thinking we will at last be able to realize the necessary parameters for patient radiation therapy."

More information: U. Masood et al.:A compact solution for ion beam therapy with laser accelerated protons, in *Applied Physics B, Lasers and Optics*, link.springer.com/article/10.1007%2Fs00340-014-5796-z%20 (DOI: 10.1007/s00340-014-5796-z)

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