

# High-contrast imaging for cancer therapy with protons

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Dr. Aswin Hoffmann and his team installed an open MR scanner in the experimental room at the National Center for Radiation Research in Oncology -- OncoRay. Conducting various experiments, the HZDR researchers were able to demonstrate that MRI can be combined with a proton beam. Credit: HZDR / R. Weisflog

Medical physicist Dr. Aswin Hoffmann and his team from the Institute of Radiooncology—OncoRay at the Helmholtz-Zentrum Dresden-Rossendorf (HZDR) have combined magnetic resonance imaging (MRI) with a proton beam, thus demonstrating for the first time that in principle, this commonly used imaging method can work with particle beam cancer treatments. This opens up new opportunities for targeted, healthy tissue-sparing cancer therapy. The researchers have published their results in the journal *Physics in Medicine and Biology*.

Radiation [therapy](#) has long been part of the standard oncological treatment practice. A specific amount of energy is deposited into the tumor tissue, where it damages the cancer cells' genetic material, preventing them from dividing, and ideally destroying them. The most commonly used form of radiation therapy today is called photon therapy, which uses high-energy X-ray beams. Here, a substantial portion of the [beam](#) penetrates the patient's body, depositing a harmful dose in healthy tissue surrounding the tumor.

## **Atomic nuclei as weapons against cancer**

An alternative is radiation therapy with charged atomic nuclei such as protons. The penetration depth of these particles depends on their initial energy. They release their maximum dose at the end of their trajectory. No dose will be deposited beyond this so-called "Bragg peak." The challenge for physicians administering this kind of therapy is to control the [proton beam](#) exactly to match the shape of the tumor tissue and thus spare as much of the surrounding normal tissue as possible. Before the treatment, they conduct an X-ray-based computed tomography (CT) scan to select their target volume.

"This has various disadvantages," Hoffmann says. "First of all, the soft-tissue contrast in CT scans is poor, and secondly, the dose is deposited into healthy tissue outside of the target volume." On top of this, proton

therapy is more susceptible to organ motion and anatomical changes than radiation therapy with X-rays, which impairs the targeting precision when treating mobile tumors. At present, there is no direct way of visualizing tumor motion during irradiation. That is the biggest obstacle when it comes to using proton therapy. "We don't know exactly whether the proton beam will hit the tumor as planned," Hoffmann explains. Therefore, physicians today have to use large safety margins around the tumor. "But that damages more of the healthy tissue than would be necessary if radiation were more targeted. That means we are not yet exploiting the full potential of proton therapy."

## **First prototype for MR-guided particle therapy**

Hoffmann and his team want to change that. In cooperation with the Belgian proton therapy equipment manufacturer IBA (Ion Beam Applications SA), his research group's objective is to integrate proton therapy and real-time MR imaging. Unlike X-ray or CT imaging, MRI delivers excellent soft-tissue contrast and enables continuous imaging during irradiation. "There are already two such hybrid devices for clinical use in MR-guided photon therapy; but none exists for particle therapy."

This is mainly due to electromagnetic interactions between the MRI scanner and the proton therapy equipment. On the one hand, MRI scanners need highly homogeneous magnetic fields in order to generate geometrically accurate images. The proton beam, on the other hand, is generated in a cyclotron, a circular accelerator in which electromagnetic fields force charged particles onto a circular trajectory and accelerate them. The proton beam is also steered and shaped by magnets, whose magnetic fields can interfere with the MRI scanner's homogeneous magnetic field.

"When we launched the project three and a half years ago, many

international colleagues were skeptical. They thought it was impossible to operate an MRI scanner in a proton beam because of all the electromagnetic disturbances," Hoffmann explains. "Yet we were able to show in our experiments that an MRI scanner can indeed operate in a proton beam. High-contrast real-time images and precise proton beam steering are not mutually exclusive." Many experts predicted another difficulty to occur from proton beam behavior: when electrically charged particles move in the magnetic field of an MRI scanner, Lorentz forces will deflect the beam from its straight trajectory. However, the researchers were able to demonstrate that this deflection can be anticipated and thus corrected for.

To explore these mutual interactions, Hoffmann and his team used the experimental room at the National Center for Radiation Research in Oncology—OncoRay.

"Our mission is to individualize proton therapy biologically and to optimize it technologically towards its physical limits," says Hoffmann, head of the research group on MR-guided [radiation therapy](#) at the HZDR. OncoRay has its own cyclotron to deliver the proton beam into the therapy room as well as into the experimental room. Hoffmann and his colleagues used the latter for their research activities. With the support of IBA and the Paramed MRI Unit of ASG Superconductors SpA, they installed an open MRI scanner in the path of the proton beam, realizing the world's first prototype of MR-guided particle therapy. "We are lucky to have an experimental room that is large enough to accommodate an MRI scanner. That is one of OncoRay's unique features."

## **Knee phantom, mixed sausage and predictable diversion**

For their experiments on this first prototype, they initially used what is called a knee phantom, a small plastic cylinder filled with an aqueous contrast liquid and a variety of differently shaped plastic pieces. Hoffmann and his team used it to conduct quantitative analyses of image quality. In a second series of experiments, the researchers used a piece of Dresden mixed sausage. "When the Dutch research group studied imaging for their MR-guided photon therapy device in 2009, they used pork chop," Hoffmann says. "In 2016, Australian researchers demonstrated their MR-photon therapy device on a Kangaroo steak. Since we also wanted to go regional for our prototype in MR-guided particle therapy, we used Dresden mixed sausage." Both the series of experiments with the phantom and with the sausage showed that the magnetic fields from [proton](#) therapy did not distort the image. They merely caused minor shifts in the MR image, which can be corrected for.

The project is currently entering its next phase. The goal is to develop the world's first prototype for MR-guided particle therapy that is applicable for clinical use.

**More information:** Sonja M Schellhammer et al, Integrating a low-field open MR scanner with a static proton research beam line: proof of concept, *Physics in Medicine & Biology* (2018). [DOI: 10.1088/1361-6560/aaece8](#)

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