Advantages of Low-Field-Strength Magnet in MR-Guided Radiation Therapy with the MRIdian System

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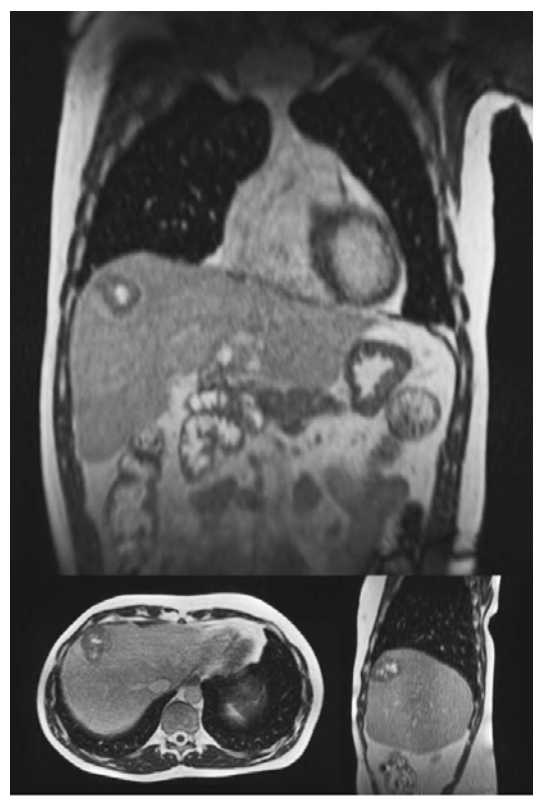
What is the benefit of low-field-strength MR in MRgRT?

In radiation therapy there are several key advantages to a low-field-strength magnet. First, low field strength allows the linear accelerator and the MRI to be in closer proximity. This can help increase the dose rate and reduce the penumbra. The second key benefit is the reduction in both image distortion and radiation dose distortion. A low-field-strength MR significantly reduces the impact of susceptibility artifacts and the electron return effect. The third point to consider is imaging sequence speed: at lower field strength, images can be acquired more quickly so you can complete a full 3D—or volumetric—setup scan within a single breath hold. Finally, low field strength enables real-time imaging, which MRIdian uses for tissue tracking and beam gating, so you are able to perform real-time MR imaging to directly track the tumor throughout the treatment.

How does a lower field strength magnet impact the system design and radiation delivery?

Using a lower strength magnet is what allows the linac and the MRI to be close together. When they're closer, you can provide a higher dose rate and a sharper beam. In terms of system design, basically, the linac and the MR really don't want to live in the same space. So, the lower field strength allows the magnet to be split, providing a clear path for the radiation beam by putting the accelerator itself right next to the patient. Why do we care about that? Well, that's going to improve the dose rate and increase the sharpness of the beam by having the MLC closer to the patient, reducing the penumbra. There are dosimetric advantages to placing the beam closer to the patient, which ultimately provides better plans and better treatments. This also makes the system more compact, allowing it to fit into a standard linac vault without having to remove a wall or ceiling.

A lot of people ask, "At 0.35 Tesla, can you really even see anything?" I think that's a reasonable question, but from our experience I can tell you, we see exquisite soft-tissue contrast. We can visualize a stratification of tissues more clearly and much better than we had otherwise hoped.



Improved Soft Tissue Image Quality:
MRIdian simulation scan of liver tumor (with contrast agent)

MRIdian clinical team spotlight

John Bayouth, PhD

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What impact does the magnetic field strength have on the electron return effect and how does that impact dose to tissues?

Electron return effect is directly proportional to the magnetic field strength. This is just basic physics. There is a centripetal force being created from the magnetic field that relates to the radius of curvature, which is inversely proportional to that magnetic field as well as the momentum of the electron. At higher field strength, for example 1.5 Tesla, there is a much tighter radius of curvature, around 5 millimeters. Many of the air cavities that the electrons are streaming through are larger than a 5-millimeter radius. As a result, those electrons are going to irradiate the tissues, turn around and re-irradiate the tissue, in effect increasing the exit dose. At a lower field strength, like on MRIdian, which is 0.35 Tesla, we're dealing in the order of a 40-millimeter radius and most of our air cavities are not that big, so the photons will undergo multiple Compton scattering and not have the same effect.

Can the electron return effect be "optimized out" through treatment planning?

While the multiple Compton scatter ameliorates this effect as you go through tissue, when you get to interfaces, like water and lung, or lung and water, there are dramatic differences in dose. You can see that they can differ by a good 20% or 30% or 40%. I can't help but note that I have heard people argue, "Well, this information can be used in your treatment planning and you can try to optimize it out." You can certainly try. If you're unsure about that, I encourage you to look at a publication from Bednarz , which explains that, "...Despite the helical nature of tomotherapy, it is clear that dose perturbations from magnetic fields are unavoidable, especially in cases where large, low-density heterogeneities exist in the treatment field such as in the lung." And I'm quoting that. Colleagues at the University of Wisconsin attempted to characterize out this effect. Yet, even with more degrees of freedom than are available on current delivery systems, they were unable to make this effect go away simply through planning approaches.

While the low field strength significantly minimizes the electron return effect, the MRIdian treatment planning system still uses Monte Carlo Treatment Planning to characterize the influence of the low magnetic field to provide the most precise dose calculations.

Does a lower field strength improve imaging speed? Why is it beneficial?

Lower field strength MR's allow for much faster imaging sequences. At lower field strength, there's a difference in how quickly a scan can be acquired and that's a key point. With the lower field strength, we're acquiring these images, not only daily, but we can acquire them in a very short amount of time. We are able to take a quality 3D scan in 17 seconds. The heat that's being transferred into the patient at the lower field strength is significantly less than that at higher field strengths. This allows you to get an image in a shorter period of time, which allows fast image acquisition during a single breath hold to remove respiratory motion.

Does the lower field strength magnet help with real-time imaging and radiation delivery?

Having the imaging during the treatment is a really important part of the process for us. We're getting cine images during the treatment delivery and we're using that information to analyze a lot of different things. For example, when the tumor is affected by respiratory motion, the system automatically tracks the tumor directly and the beam only turns on when it's inside the pre-defined boundary. We're able to visualize that, and not only have the system turned on in the event that the target's inside of its boundary, but we're also able to help coach the patient to put the tumor into the boundary. With this high frame rate imaging, we're able to help direct them, guide them, coach them, and target the tumor to within where we wanted it to be very accurately with a high-duty cycle. This allows us to significantly reduce margins, which should yield lower toxicities.

Which tumor sites benefit most from using a low-field-strength magnet?

We can treat lung lesions and at a lower field strength, you have less impact of susceptibility artifact, less chemical shift artifact and less spatial distortion. We can see cardiac motion and that's all really valuable information that allows us to do real-time tracking and reduce what would be our ITV into something much smaller with these smaller margins. Additionally, tumors adjacent to the bowel benefit because random bowel gas can have negative dose effect due to the electron return effect seen at higher field strengths.

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