MRI/CT is the future of radiotherapy treatment planning

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(Received 11 August 2014; accepted for publication 13 August 2014; published 7 October 2014)
[http://dx.doi.org/10.1118/1.4894495]

OVERVIEW

Use of magnetic resonance imaging (MRI) in radiotherapy planning has rapidly increased due to its exquisite high contrast, high resolution soft tissue visualization and functional imaging modalities that rival PET/CT in tumor visualization capability. These features, in combination with CT’s freedom from spatial distortion, have led some to suggest that the future of radiotherapy lies more with MRI/CT than with either CT or MRI alone. This is the premise debated in this month’s Point/Counterpoint.

Arguing for the Proposition is Carri K. Glide-Hurst, Ph.D. Dr. Glide-Hurst obtained her Ph.D. in Medical Physics from Wayne State University in 2007, focusing her efforts on breast ultrasound tomography and utilizing acoustic parameters for breast density evaluation. She then spent two years in postdoctoral training in the Department of Radiation Oncology at William Beaumont Hospital, Royal Oak, MI, with an emphasis on motion management techniques in lung cancer, and is now Senior Staff Physicist at Henry Ford Health Systems in Detroit. Dr. Glide-Hurst is certified in Therapeutic Radiologic Physics by the American Board of Radiology. Her current interests include a hybrid of teaching, clinical duties, and translational research and, relevant to the topic of this debate, she is the Principal Investigator for a Henry Ford Health System Grant on optimizing MRI simulation (MR-SIM) for breast cancer radiotherapy.

FOR THE PROPOSITION: Carri K. Glide-Hurst, Ph.D.
Opening Statement

Over the past few decades, CT simulation (CT-SIM) has been the primary modality used for radiotherapy treatment planning (RTP). CT offers excellent spatial resolution, high geometric integrity, short exam times, and accurate electron density information to enable dose calculation.

Arguing against the Proposition is Daniel A. Low, Ph.D. Dr. Low obtained his Ph.D. in Physics from Indiana University, Bloomington and, after a postdoctoral fellowship at M. D. Anderson Cancer Center, Houston, TX, moved to Washington University Mallinckrodt Institute of Radiology, St. Louis, MO, where he eventually became Professor in Radiation Oncology. In 2010, he moved to his current position at UCLA, where he is Professor in Radiation Oncology and Vice Chair of Medical Physics. Dr. Low is certified by the American Board of Medical Physics in Radiation Oncology Physics. He has been very active in both the AAPM and ASTRO and currently serves as Chairman of the NIH Clinical Trials Committee of ASTRO, the AAPM Audit Committee, the AAPM Working Group for Radiation Oncology National Event Reporting System, the AAPM Working Group on Radiation Oncology Incident Learning System, and the AAPM Science Council. He is the current Treasurer of the AAPM Southern California Chapter. Dr. Low’s major research interests include 4DCT, modeling respiratory motion, and applications of PET in radiotherapy. He is a Fellow of the AAPM and has published over 170 papers in refereed journals.

FOR THE PROPOSITION: Carri K. Glide-Hurst, Ph.D.
Opening Statement

Over the past few decades, CT simulation (CT-SIM) has been the primary modality used for radiotherapy treatment planning (RTP). CT offers excellent spatial resolution, high geometric integrity, short exam times, and accurate electron density information to enable dose calculation.
Implementation of thinner slices, larger fields of view, and 4DCT has further improved spatial and temporal resolutions. Iterative reconstruction and dose modulation have yielded ~70% dose savings while maintaining comparable image quality. One disadvantage of CT, however, is the lack of the soft tissue contrast which is essential for delineation of low contrast interfaces. To address this limitation, MRI is used as an adjunct to CT when soft tissue contrast is advantageous (e.g., abdomen, brain, and pelvis).

Compared with CT, MRI provides superior contrast resolution that can be further optimized by varying parameters. MRI can resolve tumor boundaries and differentiate between normal tissue and surgical beds. In addition, functional MRI offers potential for identifying dominant lesions or serving as a biomarker of tumor/organ at risk (OAR) response. However, the geometric accuracy of MRI can be hindered by magnetic field distortion and gradient nonlinearity, resulting in spatial distortions as large as 3–4 mm for gradient and spin echo acquisitions and ~20 mm for echo planar imaging. Furthermore, patient-induced field distortions (e.g., chemical shifts and susceptibility) may introduce distortions of 3–4 mm due to different magnetic field susceptibilities between interfaces. Given the high degree of accuracy and high dose per fraction required for stereotactic radiosurgery and body radiotherapy, even small errors in target localization may cause >20% undertreatment of the tumor while overdosing adjacent OARs. Thus, the synergistic effects of CT and MRI combined yield the most complete tumor delineation with the highest geometrical accuracy afforded by CT-SIM.

Recently, MR-SIM platforms have been introduced with added components (e.g., flat tabletops and laser systems) that will undoubtedly improve image registration accuracy between MR-SIM and CT-SIM. Nevertheless, MR-SIM for single modality simulation is being explored via generation of synthetic/pseudo CT-SIM datasets, but low signal intensity of cortical bone on MRI remains a limitation. Caution must be exercised when using only MRI for delineation. Evaluating MRI prostatic tumor volumes revealed only 2 of 20 estimates were within 10% of actual volumes determined via prostatectomy, while 11 were underestimated. Most importantly, excellent outcomes have already been observed for CT-based delineation. To justify implementing MRI-alone simulation, large prospective trials spanning decades would be necessary for evaluating outcomes and survival.

Currently, MRI is not indicated for all anatomies. MRI has shown limited clinical advantages in the thoracic region, where low proton density, respiratory/cardiac artifacts, and magnetic susceptibility artifacts pose challenges. Not all patients are candidates for MRI due to contraindications such as implanted devices. Finally, ~25% of cases are designated as palliative intent, thereby making it difficult to justify MRI’s high cost and long examination times. Overall, CT-SIM will maintain its prominent role in RTP. MRI will continue to complement CT-SIM and provide soft tissue contrast for delineation, but only when indicated for a subset of qualified patients.

### AGAINST THE PROPOSITION: Daniel A. Low, Ph.D.

**Opening Statement**

There is no controversy that MRI provides superior image quality when compared against CT for almost all treatment sites. There are two options for integrating MR into the clinical workflow: to acquire images using both modalities or replace the CT simulator with a MR simulator and develop a strategy for replacing the data we currently receive from CT.

One of the important considerations when determining whether to replace an existing paradigm with a new one is cost. For most treatment sites and regimens, the current billing structure reimburses only for a single simulation modality. Broad implementation of MR + CT planning would require a significant increase in cost to payers or would require clinics to subsidize uncompensated imaging costs. This would be especially challenging given the high cost of MR scanners and the need to have specially trained staff to operate them. Not only do such simulations require two acquisitions but also they require the planner to fuse the image datasets to allow structures from one image dataset to be used on the other. This fusion adds additional workload to the clinic.

The capital and operational costs could be reduced by using MR-only simulation. Challenges to this include questionable spatial integrity, the need to develop robust methods for obtaining electron densities from the images, the need to develop robust methods for obtaining digitally reconstructed radiographs for comparison against radiographic and fluoroscopic patient positioning imaging methods, and the need to develop adequate 4DMR image sequences for lung and upper abdominal tumors.

A second consideration is benefit. MRI imaging for cervical cancer brachytherapy is common in some countries, and MR has long been used for planning treatments of brain lesions. However, there is little evidence that the improved soft tissue imaging of MRI actually leads to improved outcomes. Easier segmentation does not necessarily relate to dose distributions that more accurately conform to tumor volumes. In the current and future medical economic climate, the prospect of increased cost with uncertain, if any, benefit is unlikely to lead to substantial acceptance.

Given the unknown benefits of MRI-based simulation outside of its current limited uses, the unmet challenges of implementing MR-only simulation, the lack of credible evidence as to the benefit of the improved image contrast and flexibility, and the degrading medical economic climate that is unlikely to improve in the near future, it is unlikely that MR/CT simulation will be a dominant imaging modality for radiation therapy in the future. It has its place, even in the current paradigm, but broad adoption in the long-term future is at best uncertain, at worst nonexistent.

**Rebuttal: Carri K. Glide-Hurst, Ph.D.**

Dr. Low and I agree on many issues regarding the role of MRI/CT in radiation oncology, including that the benefits of MRI will apply to a subset of patients and that MRI poses many technical challenges, particularly with image...
distortion. While Dr. Low is correct that we currently bill for a single simulation modality, it is important to note that the standard of care is constantly changing as technology evolves. For example, in 2014, a Current Procedural Terminology (CPT) code (77293) was introduced for respiratory motion management simulation. This CPT code came eight years after TG-76—The Management of Respiratory Motion in Radiation Oncology—was first published and long after 4DCT and other motion management approaches were integrated into most clinics. Despite the technical costs (specialized equipment and management of hundreds of “uncompensated” images) and significant personnel burdens (extended imaging times and physician review/delineation) associated with 4DCT acquisition, we did not forgo 4DCT for patients who may have benefited from motion management just because a procedure code was not available.

When MRI is critical for target delineation and the patient is being treated with curative intent, the workload and expense of MRI in addition to CT are justified. This practice has, and will continue to be, well supported by clinical trials and cooperative groups.14 While a direct association between MRI utilization for delineation and improved outcomes is currently unproven, preliminary studies suggest that functional MRI (i.e., diffusion-weighted and dynamic contrast-enhanced) can identify dominant lesions and elucidate early tumor response.15

Having this noninvasive, nonionizing imaging feedback may facilitate adaptive dose escalation strategies and personalized treatment selection, thereby offering potential to improve therapeutic ratios. Given MRI’s unparalleled soft tissue contrast and functional information that cannot be obtained via CT alone, MRI/CT will play an even greater role in radiotherapy treatment planning in the future.

**Rebuttal: Daniel A. Low, Ph.D.**

My esteemed colleague had an excellent point that I had failed to mention, that CT iterative reconstruction and dose modulation have yielded a large dose savings while maintaining comparable image quality. This work has been prompted by public health concerns about the increasing medical radiation burden on the population, which has climbed a factor of 6 from 1980 to 2006.17 However, the doses delivered by CT scans to most radiation therapy patients pale in comparison to even the scattered and leakage doses from their treatments. Therefore, we can and should be pursuing the uses of these techniques not to lower the dose but to improve CT image quality by reducing the effects of noise and consequently increasing the CT soft tissue contrast. In fact, Sheng et al.18 presented at the 2014 AAPM Annual Meeting their work on improving CT soft tissue contrast with postprocessing. Finally, phase-contrast CT has the potential for greatly improving image quality and has only recently been investigated for clinical imaging.19

CT scanners are ubiquitous, relatively inexpensive, provide outstanding spatial integrity, deliver essentially inconsequential doses, and have the potential for further improvements in soft tissue contrast. What’s not to love?

**ACKNOWLEDGMENTS**

C.K.G.-H. would like to acknowledge Joshua Kim and Indrin Chetty for their valuable feedback and that Henry Ford Health Systems holds research agreements with Philips Healthcare.

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