MReadings: MR in RT

11th Edition, ESTRO 2025

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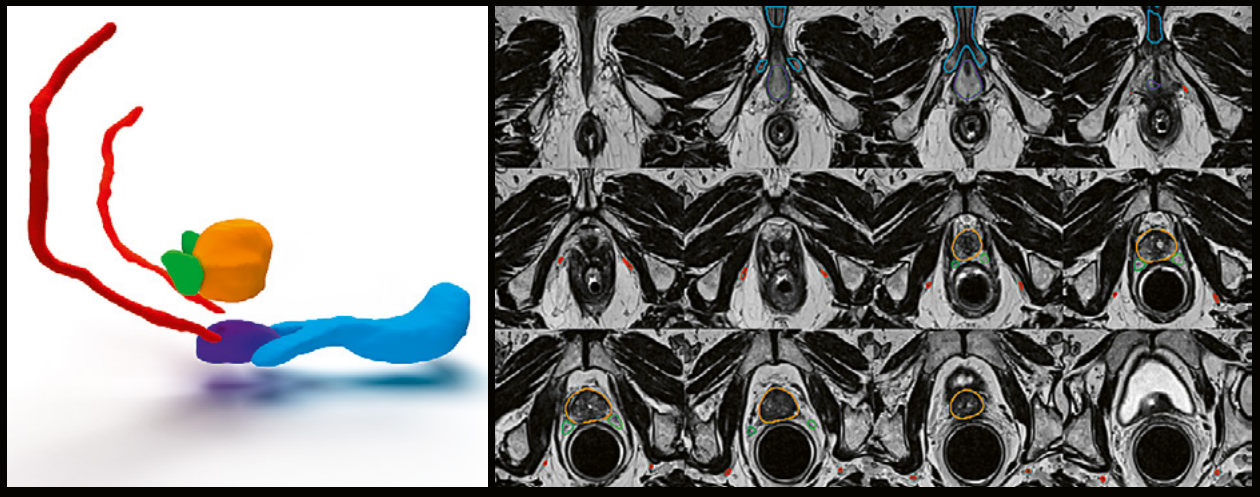

Deep learning neurovascular OAR autocontouring* on high-resolution T2w SPACE

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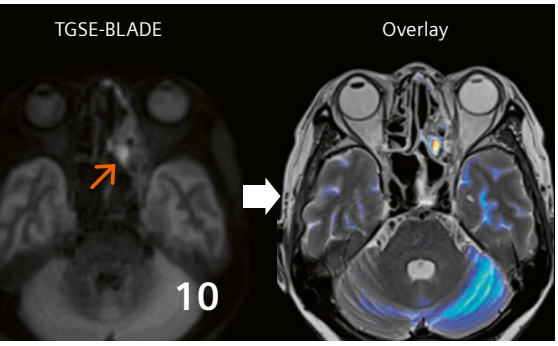
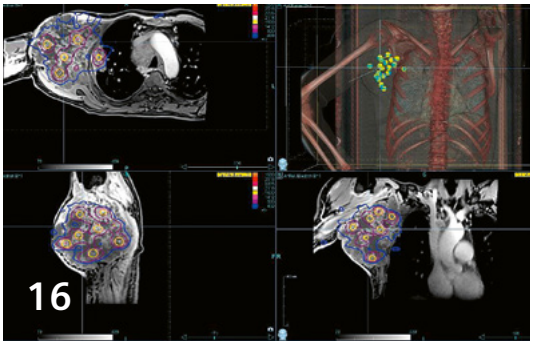


TGSE-BLADE DWI and overlay image



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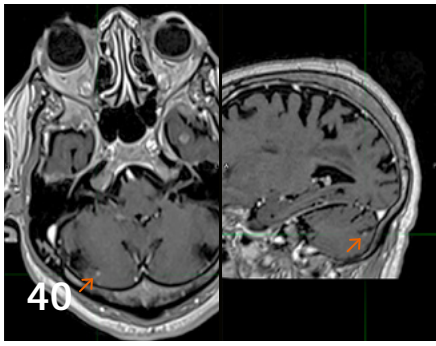


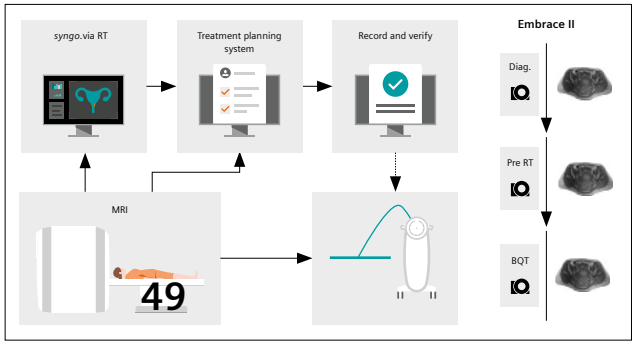
Metastatic lesion on 0.55T MAGNETOM Free.Max

Editorial Comment

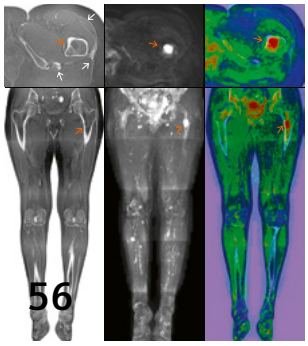
Radiation Therapy

Radiation Therapy at Lower-Field MRI

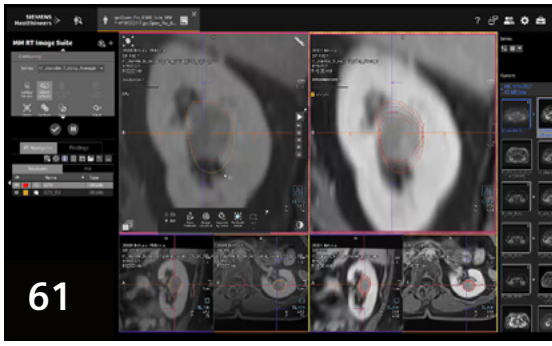
Work in progress. The application is currently under development and is not for sale in the U.S. and in other countries. Its future availability cannot be ensured.



IGABT process harmonized with Embrace II protocol



Whole-body evaluation of the bone



4D MRI-RT respiratory self-gating workflow

Brachytherapy

Spotlight

Product News

Meet Siemens Healthineers

Universitätsklinikum Tübingen / Beate Armbruster

Professor Daniela Thorwarth, Ph.D., is head of the Research Section for Biomedical Physics in the Department of Radiation Oncology at the University of Tübingen, Germany.

After earning a diploma in physics and general engineering from the University of Stuttgart and École Centrale Paris, she went on to earn her Ph.D. in medical physics at the University of Tübingen in 2007. Dr. Thorwarth followed this with a postdoc in medical physics at Tübingen, before completing her habilitation in medical physics in 2013.

Since 2015, she is full professor and research group leader for biomedical physics at the University of Tübingen, Germany.

Dr. Thorwarth has received several prestigious awards: the ESTRO Physics Award, a Behnken-Berger Award, the Science Prize from the German Society of Medical Physics, and a European Research Council Starting Grant for a project on individualized radiation therapy.

Photograph: Wiebke Peitz

Professor Daniel Zips, M.D., is medical director of the Department of Radiation Oncology and Radiotherapy at Charité – Universitätsmedizin Berlin.

Between 2010 and 2012, Dr. Zips was deputy director of the Department of Radiotherapy and Radiation Oncology at TU Dresden, and head physician for radiotherapy at the University Cancer Center Dresden. In 2012, he moved to Tübingen, serving as medical director of the Department of Radiation Oncology at Universitätsklinikum Tübingen and as a professor of radiation oncology at the University of Tübingen until 2022. In 2007 he received the DEGRO Holthusen and ESTRO Varian Clinical Research award.

Dr. Zips has been principal investigator on numerous studies. His current clinical and research interests include biologically individualized high-precision radiotherapy, experimental radiation oncology, and image-guided radiotherapy.

Quantitative MRI with High Potential for Response-Adaptive Radiotherapy

In recent years, magnetic resonance imaging (MRI) has become increasingly important in radiotherapy in a number of ways. In addition to providing high-resolution anatomical information that allows more accurate delineation of tumor volumes and organs at risk, MRI has been shown to be useful as a single simulation image input for treatment planning in MR-only workflows. In the context of offline and online adaptive radiotherapy, the value of MRI for monitoring positional changes in tumor volumes and adapting treatment accordingly has been extensively investigated by the scientific community over the last decade. In addition, MRI allows us to assess quantitative and biological characteristics of the tumor that are related to the tumor microenvironment and possibly to the underlying radiation sensitivity, which can be captured by diffusion-weighted (DW) MRI, dynamic contrast-enhanced (DCE) MRI, or other quantitative imaging techniques such as relaxometry.

Recent studies investigating quantitative imaging biomarkers (QIB) in the field of radiotherapy have highlighted the potential of these techniques to realize biology-guided radiotherapy approaches by assessing biological characteristics and monitoring these parameters throughout the course of radiotherapy, allowing response-adaptive interventions to either maximize tumor control or reduce radiation side effects.

As a potential QIB for radiotherapy, DW-MRI has recently been investigated in several studies. Lawrence et al. [1] showed that DW-MRI can identify tumor subvolumes with low apparent diffusion coefficient (ADC) values that are inversely correlated with overall survival and local control. In this study, the outcome correlation of low ADC volumes was higher than the classical contrast-enhancing gross tumor volume and may therefore be suitable for future dose-painting approaches in radiotherapy. Similarly, Winter et al. [2], inspired by results from a preclinical animal study [3], identified a tumor sub-volume defined by a band of low ADC values as prognostic for outcome after radiotherapy in head and neck cancer (HNC).

The beauty of ADC as a QIB for radiotherapy is its high availability and accessibility across centers and MRI scanners, without the need to use contrast agents. As a result, clinical implementation for radiotherapy planning and offline or online adaptation appears feasible and cost-effective.

In addition to pragmatic approaches based on ADC alone, complex preclinical and clinical studies supported the hypothesis that hypoxia imaging could be performed using quantitative MRI [4, 5]. Results were presented in prostate and cervical cancer, where MRI-based hypoxia imaging – consisting of a combination of DW-MRI as a surrogate for oxygen consumption and perfusion MRI with intra-voxel incoherent motion (IVIM) or DCE-MRI to account for oxygen delivery – significantly correlated with outcome after radiotherapy [4, 5]. As an alternative strategy to assess tumor hypoxia, oxygen-enhanced MRI has recently been proposed [6], and clinical feasibility has been demonstrated on diagnostic MRI scanners and on combined MR-linac systems [7].

The assessment of early radiotherapy response using changes in QIBs during treatment may add a very important and potentially powerful dimension to response-adaptive radiotherapy: namely, time. The optimal time for adaptation or intervention may be more accurately estimated by monitoring response during treatment. A recent prospective study showed that ADC changes after two weeks of initial radiotherapy were a strong predictor of radiotherapy outcome in HNC patients [8]. Patients with increasing mean tumor ADC had a higher chance of locoregional control than patients with no ADC increase.

To advance promising QIBs based on DW-MRI and on other quantitative MRI techniques into routine clinical use for biological and response-adaptive radiotherapy planning, they must be thoroughly validated from both a technical and clinical perspective [9]. Future clinical use of QIBs will only occur if adequate levels of repeatability and reproducibility can be achieved to ensure robust measurement of relevant changes and transferability of QIB assessments to other centers and scanners [10–13] Clinical validation of QIB candidates is equally important for a biomarker to cross the translational gap into broad clinical use. Therefore, clinical research in radiation oncology and medical physics should focus on the technical and clinical validation of promising MRI-based QIBs. As a next step, large prospective multicenter trials are needed to provide definitive proof of the utility of QIBs.

In conclusion, we see immense potential for quantitative MRI biomarkers such as ADC assessed by DW-MRI to serve – after successful technical and clinical validation – as future targets for dose-painting approaches, and for adaptive radiotherapy interventions driven by early response monitoring.

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Magnetic Resonance Imaging and Radiotherapy: A Transformative Alliance in Modern Oncology Seeking the Best Results with the Best Quality of Life

Dr. Federico Bakal I.

Oncological Coordinator, Digital Hospital, Ministry of Health of Chile
Medical Coordinator, CARE Oncology Foundation
Bradford Hill Clinical Research (Centro de Investigación Clínica Bradford Hill), Santiago, Chile

Recent decades have witnessed a revolution in oncology, marked by unprecedented advances that have radically transformed the cancer treatment landscape. This progress has not only extended patients' survival but has also significantly improved their quality of life, enabling them to live fuller and more active lives [1]. The two main pillars behind this are the development of increasingly sophisticated imaging technologies and the emergence of new, more precise, and effective therapies.

From the dawn of radiography to the rise of magnetic resonance imaging (MRI) and positron emission tomography/computed tomography (PET/CT), diagnostic imaging has allowed physicians to delve into the complexity of cancer with unprecedented clarity. In parallel, minimally invasive surgery, targeted therapies, and intensity-modulated radiotherapy have opened new avenues to combat cancer with increasing precision, minimizing damage to surrounding healthy tissue [2].

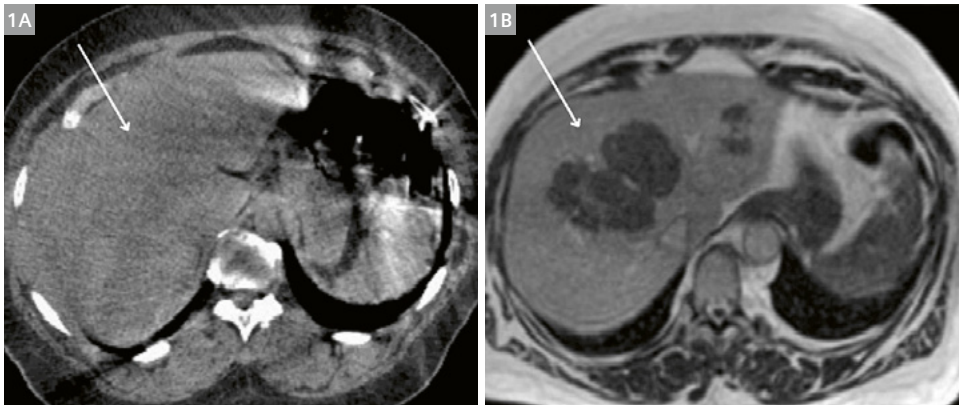
However, progress is not limited to technological innovation. A true transformation is born from the synergistic integration of these technologies with therapies, in the creation of an oncological ecosystem where interdisciplinary collaboration and efficient resource management are fundamental pillars. Today, more than ever, it is evident that the success of cancer treatment depends on a holistic approach that encompasses diagnostic precision, therapeutic personalization, rational resource management, and patient-centered care [3].

In this context, MRI emerges as a key player, a transversal element that permeates every stage of cancer treatment. Its ability to provide high-resolution images with exceptional tissue contrast makes it an indispensable tool for clinical decision-making, from initial tumor staging to long-term patient follow-up, offering unique possibilities that simply could not be achieved without it [4].

This article demonstrates the current impact of MRI in different phases of cancer management where radiotherapy plays a fundamental role. It will focus on how MRI provides detailed anatomical and functional information that optimizes decision-making to maximize efficacy and minimize the side effects of treatments where it has an impact.

Cancer staging and radiotherapy planning: Millimetric precision for personalized treatments

Cancer staging is the process of determining the extent of the disease, a crucial step in selecting the most appropriate therapeutic strategy. MRI, with its ability to precisely visualize the location and extent of the tumor and its invasion of



1 Comparison of CT imaging **(1A)** and MRI **(1B)** with gadolinium in liver tumors. *Reprinted with permission from [18].*

neighboring structures, plays a fundamental role in this process.

In the context of radiotherapy, MRI allows the creation of detailed maps of the tumor and surrounding tissues, which is essential for designing personalized treatment plans. By using these high-resolution images, radiation oncologists can accurately define the tumor volume that should receive radiation, while minimizing exposure of nearby healthy tissues (Fig. 1).

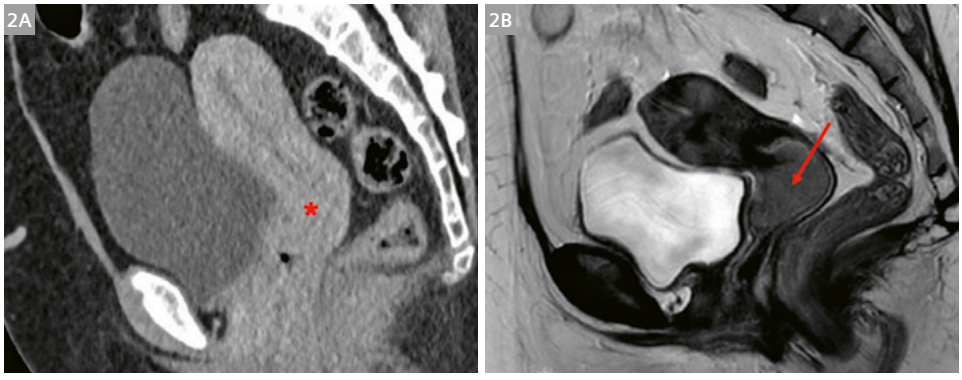
Selecting the best treatment for cervical cancer

Identifying the precise extent of the tumor is one of the main elements in defining the best curative treatment for a patient. MRI is fundamental to determining tumor extent and therefore to defining whether a patient should be managed with surgery in cases of early-stage disease or with a combination of radiotherapy and chemotherapy when the disease has advanced [5] (Fig. 2).

In scenarios where MRI is not used and where traditional methods (CT imaging and physical examination) do not detect advanced disease, there is a high risk that futile surgeries will be performed, leading to patients having to continue with complementary radiotherapy [6]. Published data from the EMBRACE study demonstrates that restaging with MRI identified 30% of cases, originally considered surgical, as inoperable [7]. The impact is enormous: greater treatment toxicities (severe non-hematologic toxicities are reported in 26% of surgery-plus-radiotherapy cases, compared with 12% in exclusive chemoradiotherapy cases) [8], greater expenditure of resources in health centers, and less availability of places for other patients who may already be on the waiting list [9].

Planning curative radiotherapy in the central nervous system

MRI allows the identification of risk areas beyond the visible tumor. This is especially important to avoid tumor recurrence in areas adjacent to the primary tumor [10]. Today, all modern radiotherapy guidelines define MRI as indispensable: It is essential to include the results of T1, T2w FLAIR, and diffusion-weighted sequences in the planning [11]. Centers that do not have adequate equipment can only plan palliative management, even for patients who can opt for a cure (Fig. 3).



2 Comparison of CT imaging **(2A)** and MRI **(2B)** in cervical tumors.
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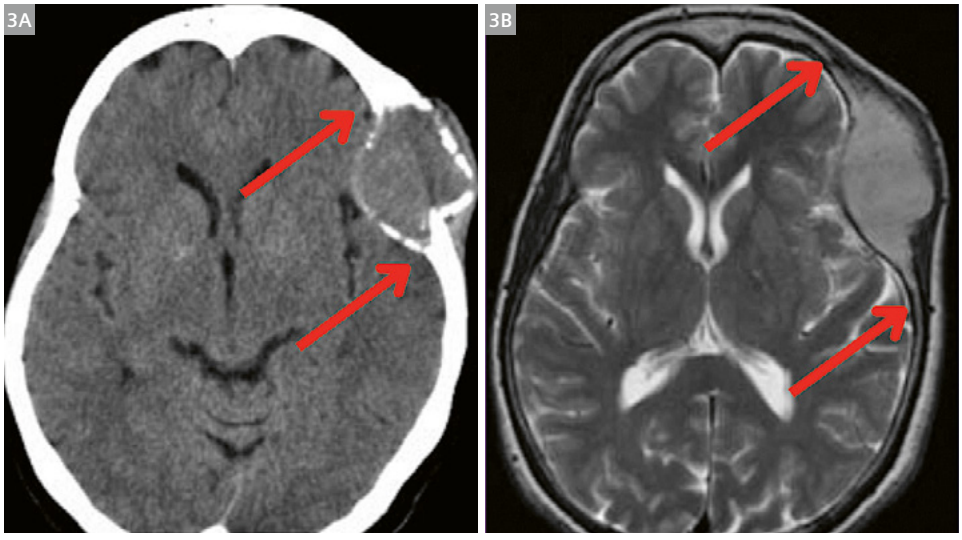

3 Meningioma limits on CT imaging **(3A)** vs. MRI **(3B)**, which is fundamental when planning radiotherapy.
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Adaptation of ongoing treatments: MRI as a guide to initial responses

In some cases, the early response of the tumor to treatment can determine the therapeutic strategy to follow. Thanks to its ability to discriminate between different tissues, MRI allows the evaluation of the response of certain tumors in real-time, making it an invaluable tool to define certain crucial steps of ongoing treatments, especially when less aggressive management alternatives are desired.

One in five advanced rectal cancers can be cured without surgery, but only if response is confirmed with MRI [12]

One of the most complex scenarios when treating rectal cancer is the need to undergo surgery that leads to permanent use of a colostomy bag (for the elimination of feces).

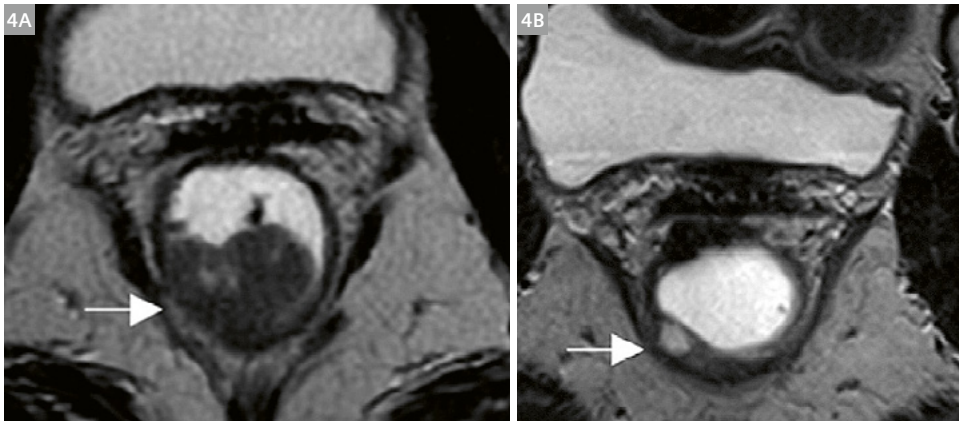
Currently, MRI helps to evaluate the response to neoadjuvant treatment (chemotherapy and radiotherapy before surgery) [13]. This allows for a more precise decision on whether to perform sphincter-preserving surgery, with the possibility of opting for a reconstruction of the intestinal transit in the future – or even, in highly experienced centers, opting for modern protocols that avoid surgery without losing the chances of a cure and of maintaining a quality of life at levels never seen before [14]. It is simply not possible to carry out this therapy without MRI at the indicated times (Fig. 4).

Follow-up and early detection of recurrences: MRI as a vigilant sentinel

Long-term follow-up of cancer patients is essential for many reasons, one of which is to detect recurrences early and administer timely rescue treatments without losing the curative intention in as many cases as possible. MRI, with its ability to detect subtle changes in tissues, is an invaluable tool for this purpose and is already standard in a growing number of tumors.

Follow-up in specific subtypes of breast cancer, the last chance to opt for a cure

MRI is undoubtedly the imaging modality of choice in patients who have the most aggressive breast cancers: carriers of certain genetic mutations, young patients, and



4 Complete response **(4B)** of rectal tumor **(4A)** after neoadjuvant chemoradiotherapy.
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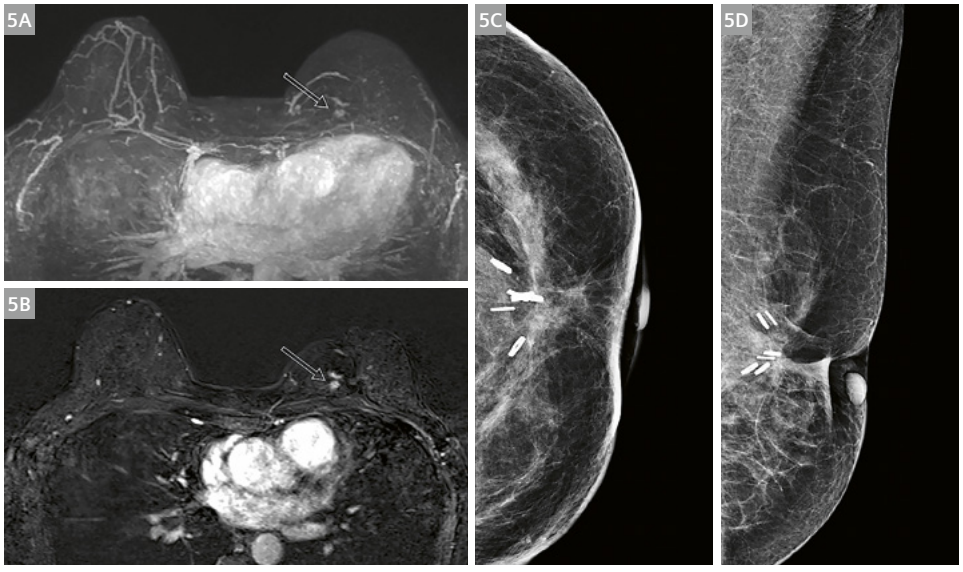

5 Early recurrence of breast cancer on MRI **(5A, 5B)**, not visible on mammography **(5C, 5D)**.
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those who received radiation during childhood (often for another cancer, such as Hodgkin's lymphoma) [15]. Not having access to MRI substantially increases the risk of later detecting diseases in advanced stages that could have been cured after early detection with MRI [16]. As an example, in a study of follow-up MRI in patients treated for breast cancer, only 60% of recurrences detected with MRI could have been diagnosed with mammography alone, 60% with ultrasound alone, and 81% with the combination of both [17] (Fig. 5).

Conclusion: Toward precision oncology driven by MRI

The integration of MRI in the planning and administration of radiotherapy has transformed the landscape of modern oncology. By providing high-resolution images and precise anatomical and functional details, MRI allows for more personalized, effective treatments with fewer side effects.

As technology continues to advance, we can expect MRI to play an even more important role in the fight against cancer. New MRI sequences and image analysis techniques will allow us to obtain even more detailed information about the tumor and its environment, which will allow us to design even more precise and personalized treatments. The task today is to recognize its value and to work on the design of protocols that allow us to deliver the best healthcare that each of our patients deserve.

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Contact

Dr. Federico Bakal I.
Bradford Hill Research Center
Palestina 343 - Recoleta
Santiago de Chile
Chile
fbakal@gmail.com

Application of TGSE-BLADE DWI in Radiotherapy Treatment Planning

Yutaka Kato[1], Mariko Kawamura[2], Shunichi Ishihara[2], Shinji Naganawa[2]

[1]Department of Radiological Technology, Nagoya University Hospital, Nagoya, Japan
[2]Department of Radiology, Nagoya University Graduate School of Medicine, Nagoya, Japan

Introduction

In recent years, radiotherapy has become increasingly localized and customized, enabling the precise delivery of high radiation doses to tumors while sparing adjacent healthy tissue. Techniques such as intensity-modulated radiation therapy and stereotactic radiation therapy exemplify this advancement [1, 2]. Consequently, magnetic resonance imaging (MRI) has gained prominence in radiotherapy treatment planning (RTP) because of its superior soft-tissue contrast compared to computed tomography (CT) [3, 4]. Our center installed a dedicated MRI system with an external laser control system (DORADOnova MR3T, LAP GmbH Laser Applikationen, Lüneburg, Germany) for RTP in 2018. Since then, imaging has been performed with patients positioned identically to their planning CT scans and irradiation, using a thermoplastic mask and vacuum cushion (Fig. 1). In RTP, precise geometric information about tumor shape and location as well as organs at risk is crucial for accurate targeting. However, spatial information obtained from MRI can be inaccurate due to various factors, potentially compromising its reliability in RTP.

Diffusion-weighted imaging (DWI) is highly effective for lesion detection due to the high tissue contrast between tumors and surrounding healthy tissues [5, 6]. However, a major limitation of DWI in RTP is the deterioration of spatial accuracy caused by distortion. The standard technique of single-shot echo-planar imaging (SS-EPI) is susceptible to B_0 inhomogeneity, often leading to severe geometric distortions that can render images undiagnostic. To address this limitation, we used a turbo gradient- and spin-echo diffusion-weighted pulse sequence with a non-Cartesian BLADE trajectory (TGSE-BLADE DWI)* in clinical situations, which was provided as a work-in-progress prototype developed by Siemens Healthineers. In this article, we describe the clinical utility of TGSE-BLADE DWI and share our preliminary experience with its application in RTP at our center.

Work in progress. The application is currently under development and is not for sale in the U.S. and in other countries. Its future availability cannot be ensured.

1 Our center introduced a dedicated MRI system with an external laser control system (DORADOnova MR3T, LAP GmbH Laser Applikationen, Lüneburg, Germany) for RTP in 2018 **(1A)**. Imaging has been performed with patients positioned identically to their planning CT scans and irradiation, using a thermoplastic mask and vacuum cushion **(1B, 1C)**.

Features of TGSE-BLADE DWI

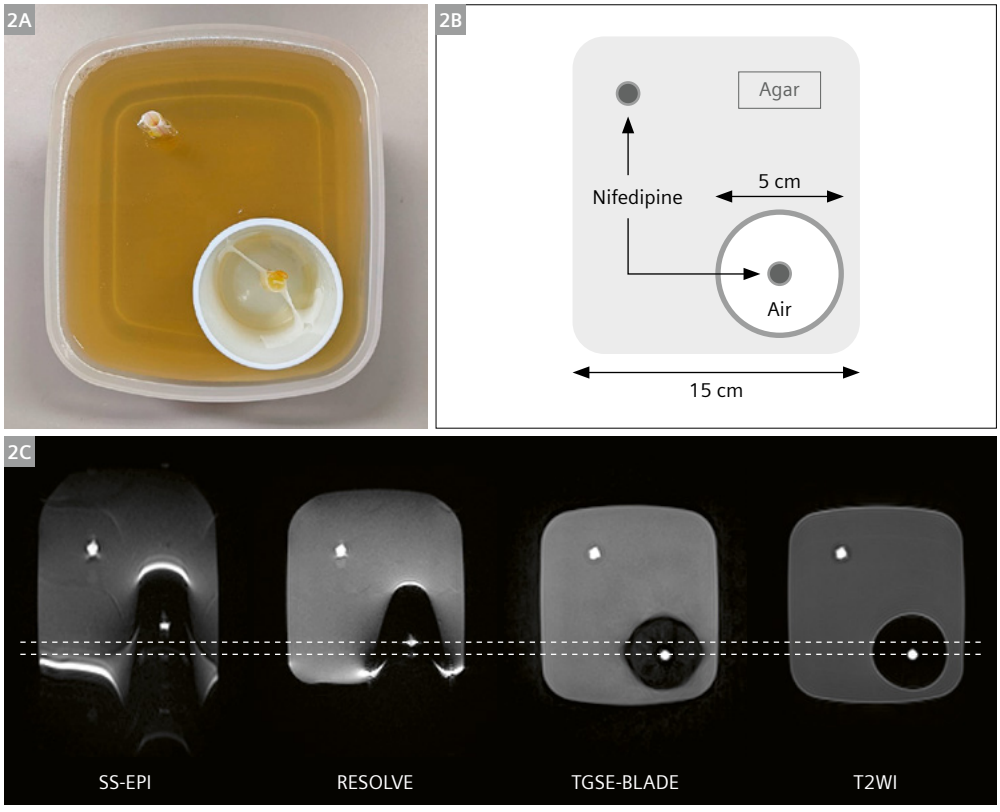
DWI is a powerful clinical technique for detecting and evaluating lesions without the need for contrast media. The widely used SS-EPI DWI offers the advantages of rapid scanning and efficient signal acquisition. However, it also has severe geometric distortions and susceptibility-induced artifacts. To mitigate image distortion, readout-segmented EPI (RESOLVE) has been introduced, which divides *k*-space into multiple segments in the readout direction for data acquisition [7]. However, despite these improvements, geometric distortions cannot be completely eliminated with EPI-based DWI. On the other hand, turbo spin-echo (TSE)-based DWI was developed to produce distortion-free images [8, 9], but its routine clinical use is limited due to significantly prolonged acquisition times. To address this trade-off between image quality and acquisition speed, Siemens Healthineers developed TGSE-BLADE DWI. The basic principles were introduced by Li et al. [10]. This technique is based on the TSE method but incorporates gradient echoes for data reconstruction, substantially reducing acquisition time compared to conventional TSE-based DWI. Additionally, it employs a non-Cartesian trajectory (BLADE) for *k*-space filling [11].

Phantom study

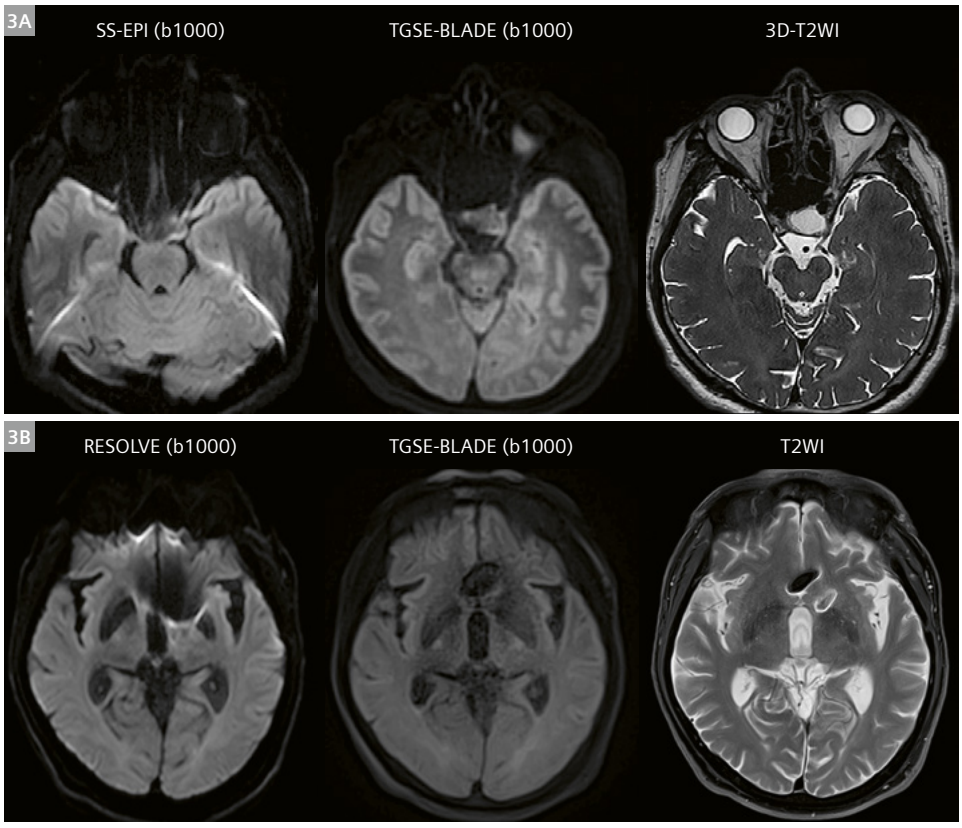
We conducted phantom experiments to evaluate misalignment caused by B_0 inhomogeneity and susceptibility artifacts near air interfaces in TGSE-BLADE DWI. Figure 2 shows images of a custom-made phantom acquired using SS-EPI, RESOLVE, and TGSE-BLADE DWI, compared with a reference T2-weighted image (T2WI). In SS-EPI DWI, the high-signal substance (nifedipine) placed at the center of the circular cavity exhibits considerable displacement. Although RESOLVE DWI reduces this distortion, displacement remains evident compared to T2WI, and the boundary between the circular cavity and the surrounding agar appears severely altered due to susceptibility-induced artifacts. Conversely, TGSE-BLADE DWI shows no noticeable positional displacement compared to T2WI, and artifacts at the cavity boundaries are not conspicuous.

Clinical images

The top row of Figure 3 shows DWI and T2WI of a 56-year-old male patient with a pituitary tumor. The lesion is difficult to identify on SS-EPI DWI due to susceptibility artifacts, whereas it is clearly visualized using TGSE-BLADE DWI. The bottom row of Figure 3 shows DWI and T2WI of a 79-year-old male patient who underwent cerebral aneurysm clipping. Signal pile-up artifacts caused by the metal implant are prominent even in RESOLVE DWI. However, TGSE-BLADE DWI effectively minimizes these artifacts.



2 **(2A)** A photograph of a custom-made phantom, **(2B)** a schematic diagram, and **(2C)** images of the phantom acquired using SS-EPI, RESOLVE, and TGSE-BLADE DWI, compared with a reference T2-weighted image (T2WI). TGSE-BLADE DWI shows no noticeable positional displacement compared to T2WI (dotted line).

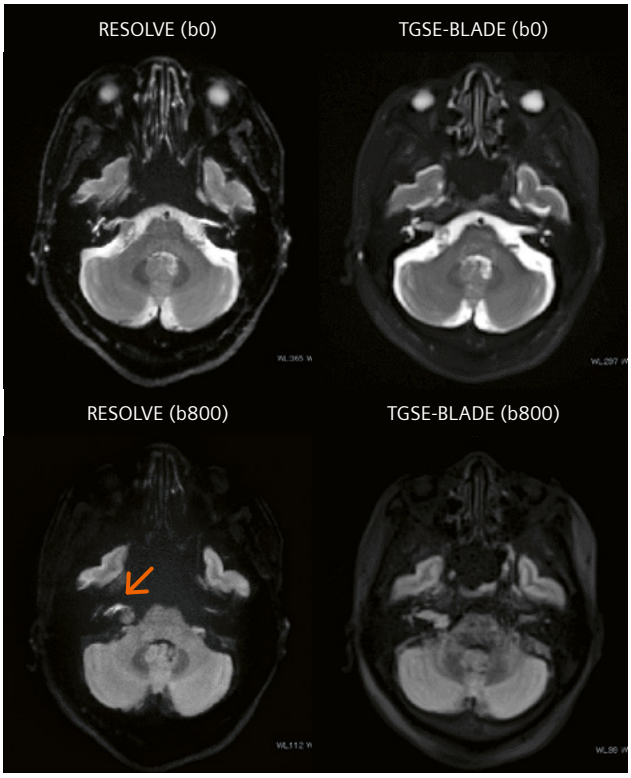


3 **(3A)** Clinical images of a 56-year-old male patient with pituitary tumor. **(3B)** Clinical images of a 79-year-old male patient who underwent cerebral aneurysm clipping.

Figure 4 shows clinical images of a 72-year-old female patient with a right vestibular schwannoma. Even with RESOLVE DWI, the mass within the internal auditory canal appears severely distorted, and signal pile-up artifacts are evident. Conversely, TGSE-BLADE DWI produces high-quality, distortion-free images. Although the acquisition time remains relatively long (6 min 59 s) to achieve high spatial resolution (1.4 × 1.4 × 2.0 mm^3), TGSE-BLADE DWI provides critical imaging details that cannot be obtained with EPI-based DWI.

Using TGSE-BLADE DWI for head and neck RTP

TGSE-BLADE DWI offers the greatest advantage for RTP as it is free of distortions commonly associated with EPI-based techniques. This is particularly beneficial for head and neck tumors, for which MRI is preferred due to its superior soft-tissue contrast and its ability to minimize dental metal artifacts. However, the complex anatomy of the neck is highly susceptible to B_0 inhomogeneity, leading to severe geometric distortion. Additionally, image quality can be compromised by motion artifacts caused by swallowing. From a patient comfort perspective, shorter acquisition times are desirable, as wearing a thermoplastic mask during imaging can be burdensome. Given these considerations, we implemented TGSE-BLADE DWI at our center,



4 Clinical images of a 72-year-old female patient with right vestibular schwannoma. RESOLVE DWI exhibits signal pile-up artifacts (arrow).

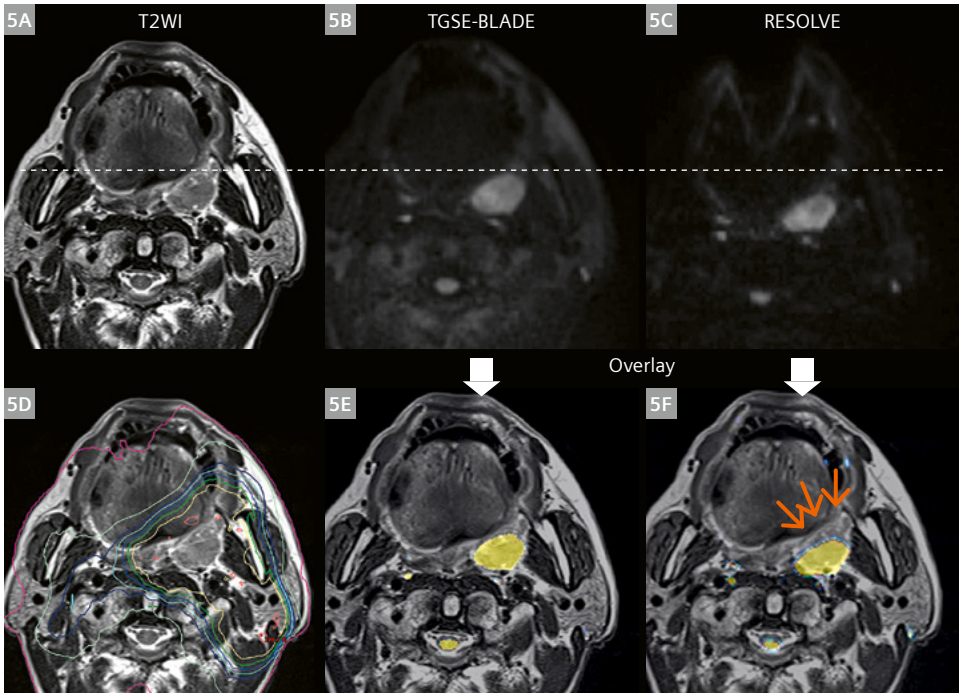
recognizing its potential as a powerful tool for RTP. In the following, we present clinical cases of patients scheduled for radiotherapy of head and neck tumors, for whom MRI was performed at our center.

Case 1

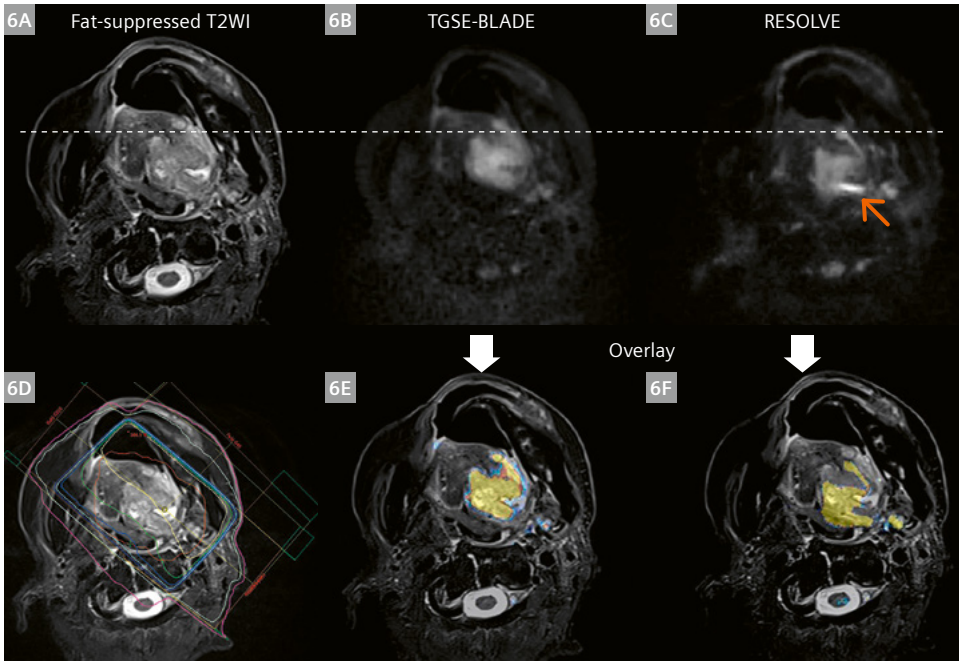
Figure 5 shows the case of an 84-year-old male patient with oropharyngeal carcinoma. RESOLVE DWI shows displacement of the tumor and alterations in its shape compared to T2WI. Conversely, TGSE-BLADE DWI demonstrates excellent anatomical agreement with T2WI, without the need for misalignment correction or deformable registration.

Case 2

Figure 6 shows the case of an 84-year-old male patient with tongue cancer. RESOLVE DWI shows significant misalignment and signal pile-up artifacts. Conversely, TGSE-BLADE DWI demonstrates excellent agreement with fat-suppressed T2WI.



5 A 84-year-old male patient with oropharyngeal carcinoma. RESOLVE DWI shows displacement of the tumor and alterations in its shape in the overlay image (dotted line and thin arrows).
(5A) T2-weighted image (T2WI),
(5B) TGSE-BLADE DWI,
(5C) RESOLVE DWI,
(5D) dose distribution,
(5E, 5F) overlay images.



6 A 84-year-old male patient with tongue cancer. RESOLVE DWI shows significant misalignment (dotted line) and signal pile-up artifacts (thin arrow). Conversely, TGSE-BLADE DWI demonstrates excellent agreement with the fat-suppressed T2-weighted image (T2WI).
(6A) Fat-suppressed T2WI,
(6B) TGSE-BLADE DWI,
(6C) RESOLVE DWI,
(6D) dose distribution,
(6E, 6F) overlay images.

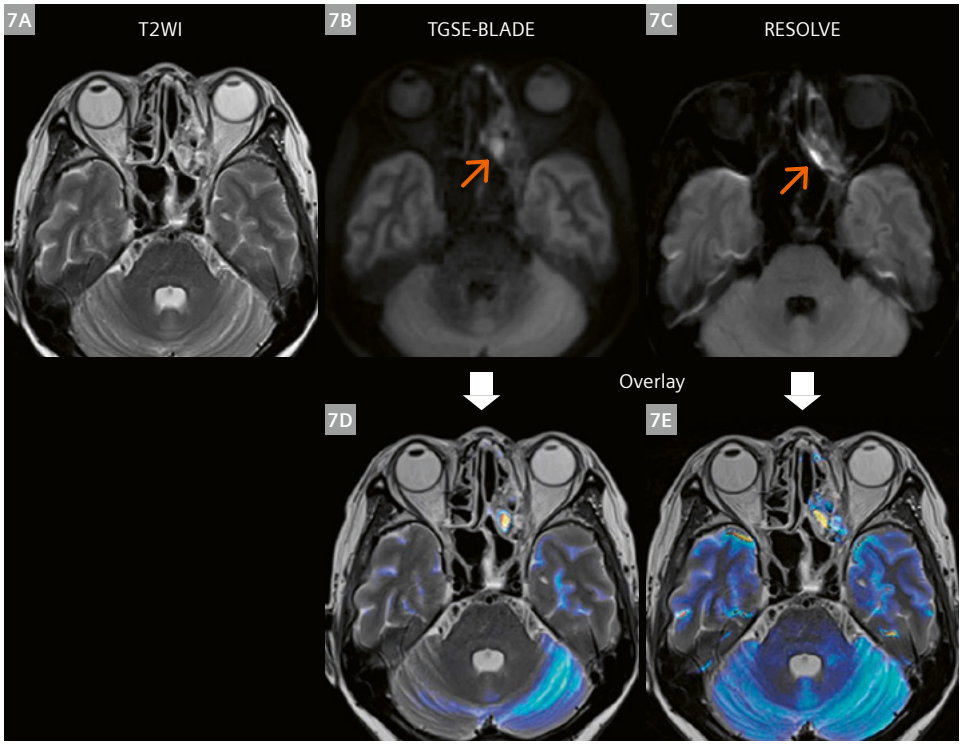
Case 3

Figure 7 shows the case of a 60-year-old female patient with olfactory neuroblastoma, a tumor located at an air–tissue interface. This anatomical complexity makes it difficult to distinguish the lesion from artifacts, even with RESOLVE DWI. However, TGSE-BLADE DWI clearly delineates the tumor.

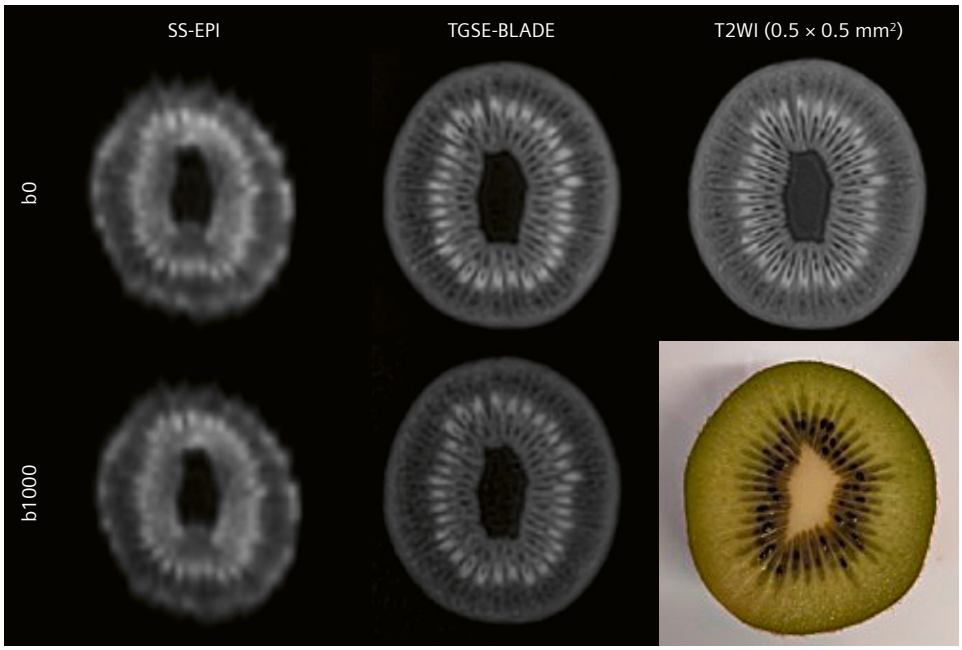
Although RESOLVE DWI is valuable enough for lesion detection as a diagnostic examination, it may not fully meet the requirements for RTP. In such cases, TGSE-BLADE DWI serves as a powerful alternative. However, one current limitation of TGSE-BLADE DWI is its lower SNR compared to EPI-DWI. Notably, head and neck examinations for RTP are performed using plastic masks and vacuum pillows, making it impossible to use a dedicated receiver coil (Fig. 1B). This presents a disadvantage in terms of SNR. In the future, we hope to develop a highly sensitive receiver coil specifically designed for radiotherapy planning, capable of flexibly adhering to a plastic mask. Additionally, SNR improvements are expected through the integration of deep learning-based reconstruction, a technology that has advanced in recent years [12].

High-resolution imaging instead of shorter acquisition times

Figure 8 shows images of a kiwi fruit. Here, the parameters were adjusted to improve spatial resolution rather than shorten acquisition time. The result is an impressive image with super-high spatial resolution with an in-plane resolution of less than 1 mm, free of distortion, obtained in approximately 6 minutes. There is potential to employ b0 images as morphological images for capturing anatomical information because of their comparable quality to T2WI, with an in-plane resolution of 0.5 × 0.5 mm^2. If morphological and functional images without misalignment can be acquired simultaneously in a single scan, this would present a significant advancement for RTP. Additionally, the use of simultaneous multislice technology [13] could further reduce acquisition time and enable thinner slice thickness imaging. Until now, the primary focus of DWI has been lesion detection and characterization, with b0 images acquired mainly for ADC map calculation. However, the era of compromising spatial resolution in DWI has ended. We are now opening the door to the next stage, where anatomical information can be obtained alongside functional data in a short time by integrating various technologies.



7 A 60-year-old female patient with olfactory neuroblastoma. A tumor located at an air–tissue interface (arrows).
(7A) T2-weighted image (T2WI),
(7B) TGSE-BLADE DWI,
(7C) RESOLVE DWI,
(7D, 7E) overlay images.



8 Kiwi fruit images. TGSE-BLADE DWI provides an image with super-high spatial resolution with an in-plane resolution of less than 1 mm, free of distortion, obtained in approximately 6 minutes.

Conclusion

This article described the clinical utility of the prototype TGSE-BLADE DWI, focusing on its use for RTP at our center. This is a novel technique that effectively overcomes geometric distortion, a critical limitation of conventional DWI. Additionally, it enables faster scanning or higher spatial resolution than conventional techniques. The current understanding that "DWI inherently has distortion" and that "long acquisition times are necessary to reduce distortion" is likely to be changed by the implementation of TGSE-BLADE DWI.

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Contact

Yutaka Kato
Medical Radiation Technologist
Nagoya University Hospital
Department of Radiological Technology
65 Tsurumai-cho, Shouwa-ku,
Nagoya, Aichi 466-8560
Japan
kato.yutaka.k3@f.mail.nagoya-u.ac.jp

Exploring the Role of Magnetic Resonance Imaging in Lattice Radiotherapy: A Case Study

Chun-yu He, Bing Li, Yao-yao Du, Wei Guo

Department of Radiation Oncology, the Affiliated Cancer Hospital of Zhengzhou University & Henan Cancer Hospital, Zhengzhou, Henan, China

The therapeutic dilemma of bulky and complex tumors

Advanced refractory bulky tumors present significant treatment challenges due to their extensive lesion range and rapid growth rate, often rendering them inoperable at initial diagnosis. Additionally, the bulky tumor volume, which contains substantial hypoxic regions, makes traditional radiotherapy techniques less effective. The constraints imposed by surrounding organs at risk (OARs) further limit the delivery of high-dose radiotherapy, while chemotherapy and immunotherapy also show limited efficacy, making treatment extremely challenging. Conventional fractionated radiotherapy and high-dose hypofractionated radiotherapy involve whole-tumor irradiation, but these approaches are often impractical for bulky tumors due to severe radiation-induced damage. Spatially fractionated radiotherapy (SFRT), with its highly modulated dose distribution, enables precise delivery of high-dose radiation to specific regions within the tumor. The highly heterogeneous dose distribution reduces damage to OARs and creates unique biological effects, such as the bystander effect (BE) and the abscopal effect (AE). Lattice radiotherapy (LRT), a standard SFRT technique, achieves dose sculpting by establishing high-dose "vertices" within the tumor, enabling three-dimensional dose distribution that spatially couples with the tumor's anatomical structure. This approach simultaneously achieves tissue protection and dose escalation in the treatment of complex lesions, such as lung cancers. However, current SFRT techniques rely on computed tomography (CT) guidance, which struggles to accurately distinguish between active and necrotic tumor regions, leading to a disconnect between dose distribution and immune microenvironment modulation, potentially compromising therapeutic efficacy.

The role of magnetic resonance imaging in tumor characterization

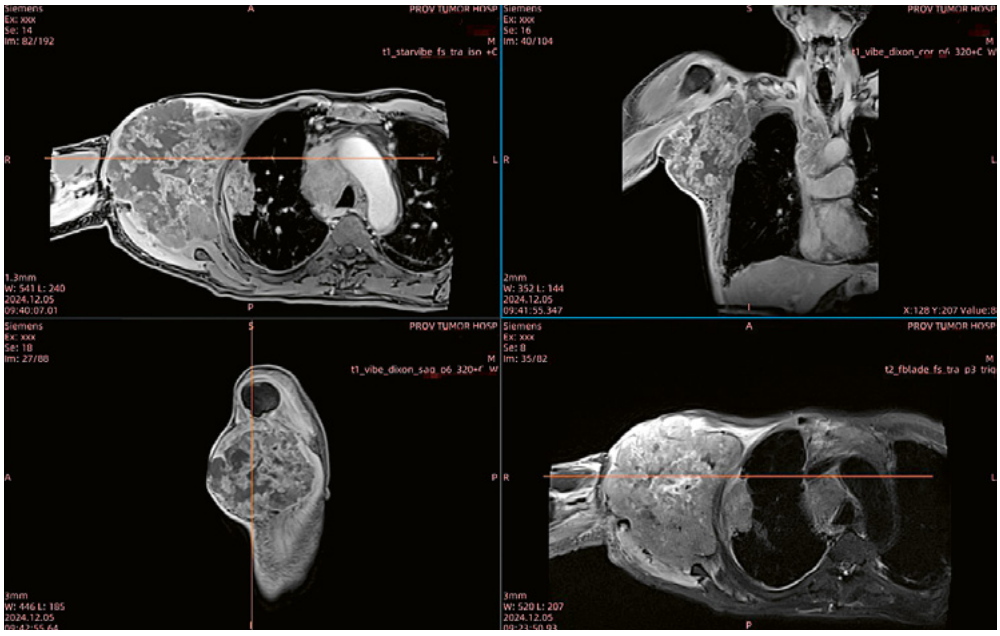
Magnetic resonance imaging (MRI), through multiparametric imaging techniques such as T1/T2-weighted imaging, diffusion-weighted imaging (DWI), and dynamic contrast-enhanced MRI (DCE-MRI), can precisely differentiate between solid tumor components and necrotic regions. Compared to the limited soft-tissue resolution of CT imaging and the metabolic heterogeneity interference of positron emission tomography (PET), DWI achieves a sensitivity of over 90% by quantifying cellular density (apparent diffusion coefficient (ADC) values). Furthermore, histogram parameters from DWI and DCE-MRI are significantly correlated with HIF-1α expression. We are using a 3T MAGNETOM Vida RT Pro Edition with software version *syngo* MR XA20 for this procedure.

Case study: Successful application of MRI-guided SFRT

At our center, we successfully treated a patient with a massive metastatic lung cancer lesion in the chest wall by leveraging the advantages of MRI in soft-tissue resolution and functional imaging (e.g., DWI and DCE-MRI) to precisely deliver SFRT, achieving excellent therapeutic outcomes.

Patient history

A 62-year-old male patient with right lung adenocarcinoma (cT2N3M1c, Stage IV), driver-gene-negative, and a PD-L1 tumor proportion score (TPS) of 25%, presented with comorbidities including chronic obstructive pulmonary disease (COPD) and coronary artery disease, status post coronary stent implantation. The patient had previously received multiple lines of treatment, including pemetrexed, carboplatin, albumin-bound paclitaxel, docetaxel, anlotinib, and PD-1 inhibitors, but experienced disease progression again. An MRI exam revealed an enlarged mass in the right upper lobe of the lung and progression of mediastinal



1 The MR imaging before LRT.

lymph node metastases. Additionally, a large mass was observed in the right chest wall, invading the skin and ribs (Fig. 1). The patient reported severe pain in the right chest wall and upper limb, with a Numeric Rating Scale (NRS) score of 8. MRI-guided LRT was performed to treat the bulky metastatic lesion in the right chest wall and the right upper lobe lesion, achieving favorable therapeutic outcomes without adverse reactions.

Radiotherapy planning

Based on the functional MRI, the volume of the solid component within the gross tumor was pre-defined as spherical regions with diameters of 1.2–1.5 cm (Fig. 2), longitudinally distributed throughout the gross tumor volume (GTV). The diameter of the vertices was adjusted according to the solid component displayed on MR images. However, the following guidelines must be adhered to:

1. The spheres must be placed exclusively within the GTV.
2. The distance between the centers of any two spheres must be at least 3 cm in any direction.
3. Any sphere must be ≥ 1 cm away from the tumor edge.
4. As many spheres as possible should be filled within the GTV without violating any of the above guidelines.

A total of 19 spheres were placed within the GTV, with a prescribed dose of DT 16 Gy/1 fraction. The radiotherapy was delivered using the CyberKnife system (Accuray, Madison, WI, USA), incorporating multi-leaf collimator (MLC) technology and fixed collimator pencil beam (FSPB) algorithms. Spine tracking was employed to ensure precise localization during treatment.

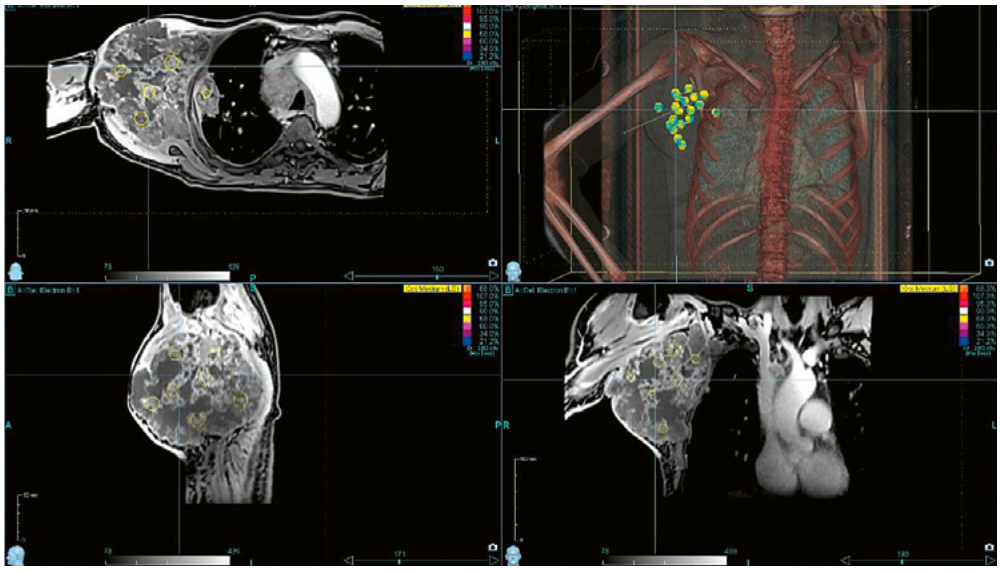
During the optimization of the radiotherapy plan, a three-center ring structure was used to confine the highest dose to the center of the target area while maximizing the sparing of surrounding OARs. Through optimization, the dose distribution across the GTV was significantly improved, achieving a peak-to-valley ratio of 4:1. Additionally, the flattening filter-free (FFF) mode was used to efficiently deliver the treatment plan, with the entire treatment process typically completed within 50 minutes. The final dose distribution of the treatment plan is illustrated in Figure 3.

Post-radiotherapy follow-up

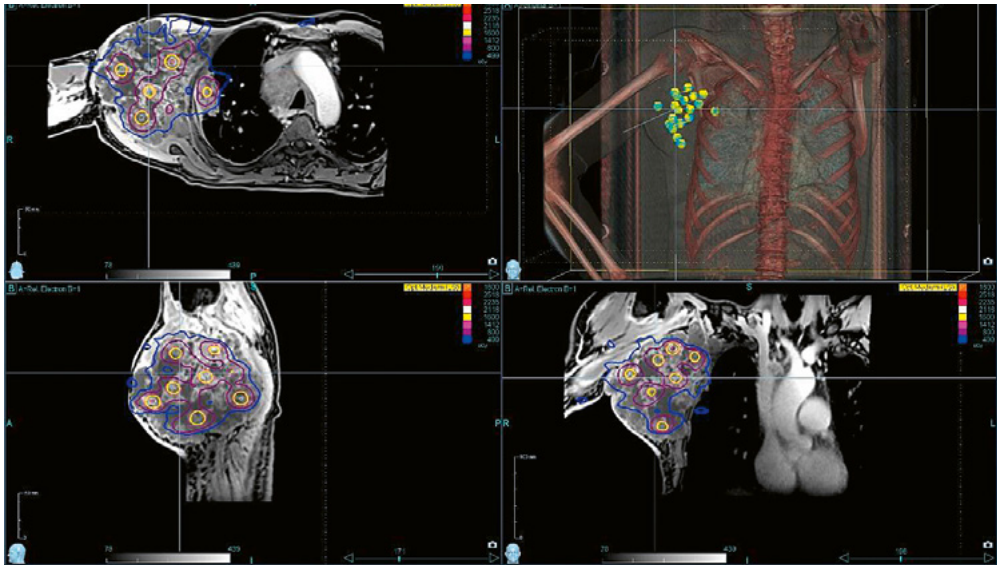
Following LRT, regular follow-up assessments were conducted using MRI to monitor treatment response. Follow-up imaging was conducted at 24 and 43 days post-treatment. The post-treatment MRI images are shown in Figure 4. According to the MRI findings, the tumor exhibited significant shrinkage 43 days after LRT, with a volume reduction of 44.4% (from 1,244 cc to 692 cc). The NRS score decreased from 8 to 2. Additionally, the irradiated mediastinal and supraclavicular lymph nodes showed a marked reduction in size, as illustrated in Figure 4 (red circles).

Discussion

LRT uses modern radiation delivery systems with IMRT/VMAT-focused photon beams. Its objective is to deliver a series of high-dose spheres (apexes) within the GTV, forming a peak-valley-shaped and highly heterogeneous dose distribution. Three-dimensional LRT can effectively reduce the dose outside the GTV, thereby achieving superior toxicity control. In this case of MRI-guided LRT, portions of the GTV containing the apexes received a higher biologically effective dose (BED), while the valley dose was only



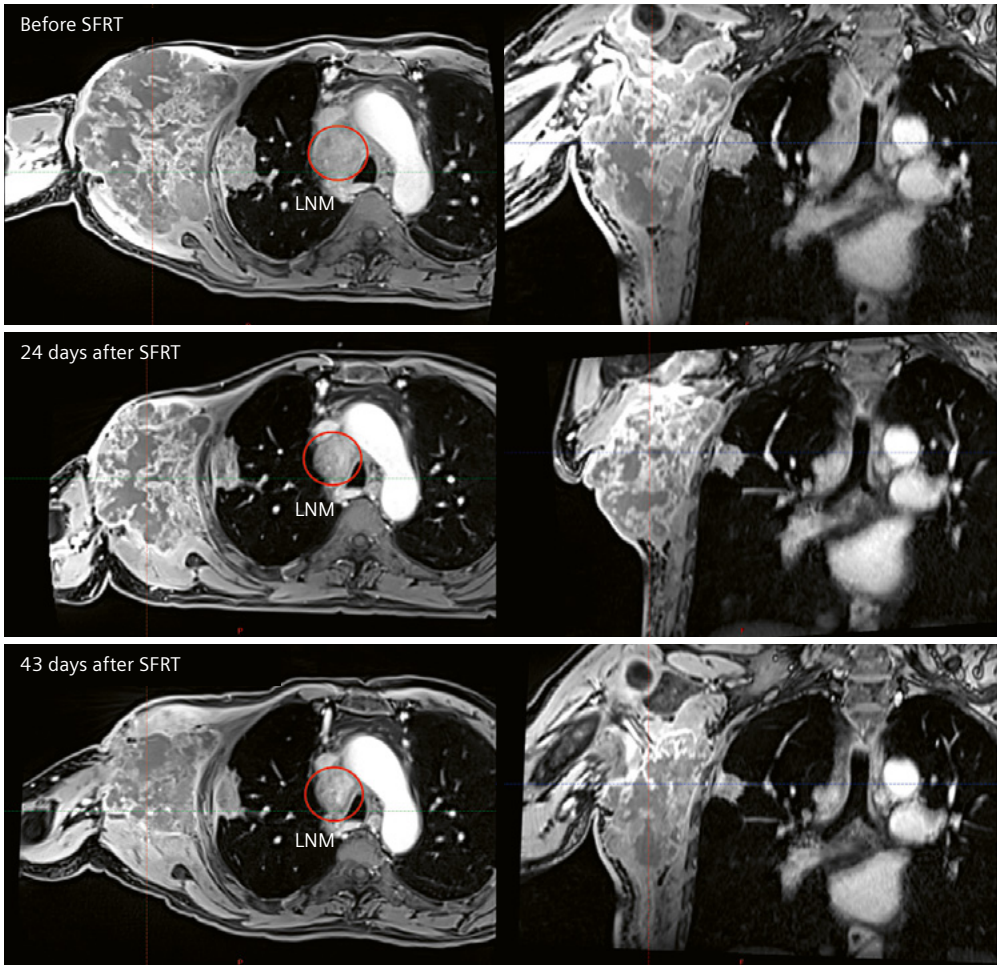
2 The arrangement of spherical vertices.



3 The dose distribution diagram of a patient.

approximately 30% of the prescribed dose, with a peak-to-valley ratio of 7–8. This highly heterogeneous dosimetry not only provides therapeutic advantages, but also exerts a synergistic effect on tumor control by triggering certain radiobiological and immune pathways. The bystander effect was observed in both the valley region and the non-irradiated areas (mediastinal and supraclavicular metastatic lymph nodes), and no adverse reactions of grade ≥ 2 were noted.

Compared to CT imaging, MRI provides a far higher resolution in soft-tissue imaging. It clearly delineates tumor boundaries and morphology, and the relationship with surrounding tissues. With MRI, it is possible to identify intratumor heterogeneity, including necrotic areas and hypoxic regions. It can also better assess the peritumoral immune microenvironment. Moreover, MRI can assist in evaluating the blood flow status and cell density of the tumor. It can capture in real time the changes of the tumor during treatment that result from physiological activities (such as breathing) or post-treatment responses (such as tumor shrinkage or expansion), thus providing a more precise GTV delineation for SFRT and optimizing the dose distribution of SFRT. Through dynamic MRI monitoring, doctors can track post-treatment tumor changes, especially tumor volume reduction and necrotic area formation. MRI can effectively monitor radiotherapy-induced side effects, particularly for deep-seated tumors or those close to vital organs. Doctors can identify the damage to OARs caused by radiotherapy (such as radiation pneumonitis and spinal cord injury) at an early stage and carry out timely interventions. By means of specific MRI techniques (such as DWI and DCE-MRI), the status of peritumoral immune cells can



4 MRI comparison of 5 days before SFRT, 24 days after SFRT, 43 days after SFRT. LNM: Lymph Node Metastasis

be evaluated in real time, enabling doctors to better understand the intensity of the immune response and its therapeutic implications. In the future, with the integration of multimodal imaging techniques, the enhancement of real-time monitoring, and the introduction of artificial intelligence, MRI-guided LRT will offer more precise individualized treatment plans for large-volume tumors. Advanced refractory bulky tumors pose significant treatment challenges due to their extensive lesion range, rapid growth rate, and the presence of substantial hypoxic regions which limit the effectiveness of traditional radiotherapy. In addition, current CT-guided SFRT techniques have limitations in accurately distinguishing between active and necrotic tumor regions. With this in mind, MRI-guided LRT holds great promise in addressing these issues and improving treatment outcomes.

Bing Li, Ph.D.
Associate Senior Medical Physicist
The Affiliated Cancer Hospital
of Zhengzhou University & Henan
Cancer Hospital
Department of Radiation Oncology
No. 127, Dongming Road
Zhengzhou, Henan, 450008
China
zlyylibing4127@zzu.edu.cn

Contact

Chun-yu He, Ph.D.
Chief Physician in Radiation Oncology
The Affiliated Cancer Hospital
of Zhengzhou University & Henan
Cancer Hospital
Department of Radiation Oncology
No. 127, Dongming Road
Zhengzhou, Henan, 450008
China
15003883759@163.com

Integrating MRI into Radiotherapy: Insights from Clinical Implementation of an MRI-Guided Workflow for Prostate Cancer

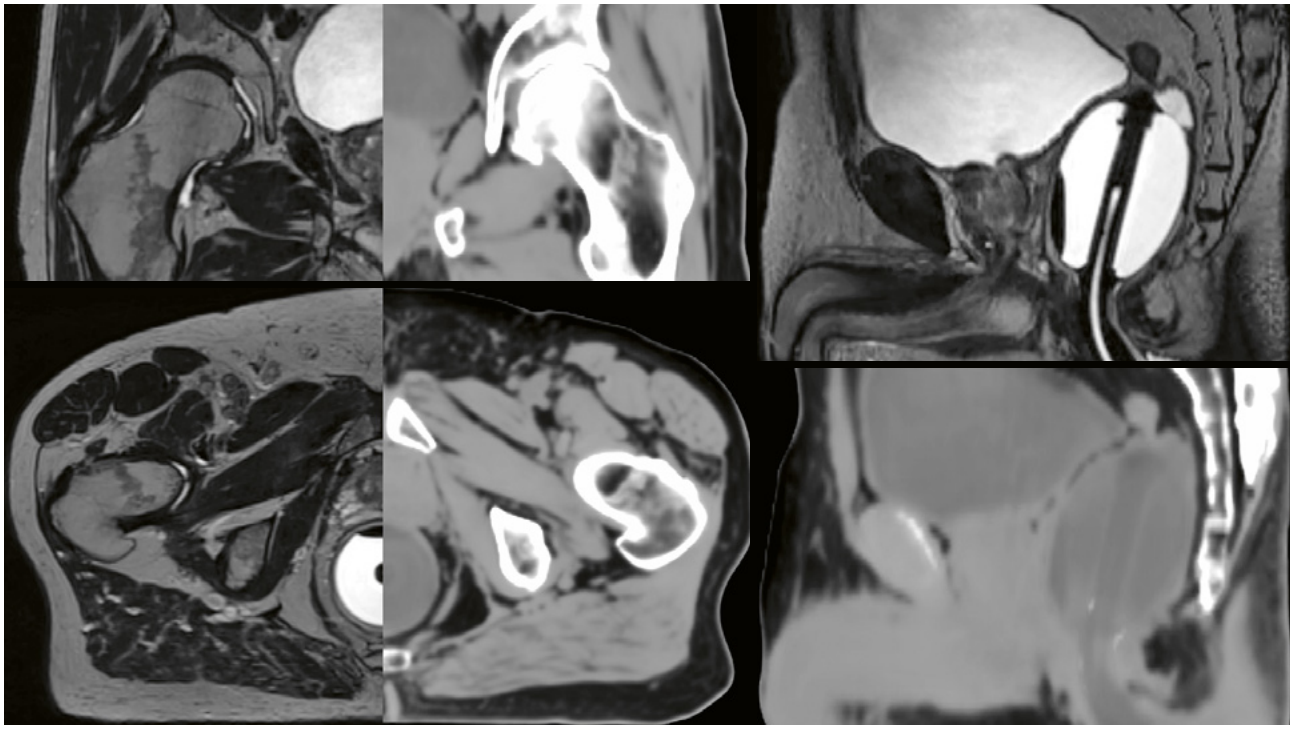
Philipp Schubert, M.D.; Juliane Szkitsak, Ph.D.; Rainer Fietkau, M.D.; Christoph Bert, Ph.D.; Florian Putz, M.D.

Department of Radiation Oncology, Universitätsklinikum Erlangen, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany

Introduction

Since 2019, the Department of Radiation Oncology at Universitätsklinikum Erlangen has had a dedicated magnetic resonance imaging (MRI) in radiotherapy (RT) program. To facilitate optimal integration of MRI into MR-guided RT protocols, a 1.5T MAGNETOM Sola RT Pro Edition was installed in our department. An interdisciplinary team consisting of radiation oncologists, medical physicists, and radiation therapy technologists (RTTs) collaboratively manage all MR imaging related to RT treatment planning. This specialized approach enables the implementation of RT-optimized imaging setups, tailored protocols, and streamlined imaging-to-treatment workflows designed explicitly to meet RT requirements. Additionally, comprehensive daily, weekly, and monthly quality assurance measures guarantee MRI studies of consistently high quality, providing a reliable basis for precise treatment planning. Beyond its crucial role in planning, the 1.5T MRI system is also used in collaboration with the Institute of Diagnostic Radiology, allowing convenient diagnostic examinations and follow-up imaging for patients treated in our clinic.

MR-guided treatment planning offers several significant advantages, notably the superior soft tissue contrast provided by MRI compared to computed tomography (CT). This enhanced contrast facilitates more precise and personalized delineation of target volumes and improves sparing of organs at risk (OARs), particularly in prostate cancer RT [1, 2]. Synthetic CT (sCT) has enabled MR-only workflows, eliminating the need for traditional CT scans in RT



1 MR-only treatment planning using 3D T2w SPACE and synthetic CT. Note the correct reconstruction of water density for the rectal balloon.

planning. These workflows use MRI alone, with AI algorithms generating the necessary sCT images required for dose calculation. Synthetic CT can streamline treatment planning and reduces patient exposure to additional imaging procedures while eliminating registration uncertainties (Fig. 1). One of the key areas where MRI has significantly improved RT precision is in the treatment of prostate cancer. Prostate tumors often have poor visibility on CT imaging due to insufficient soft tissue contrast, complicating accurate delineation of the target area [3]. This limitation is particularly critical in advanced RT techniques such as stereotactic body radiotherapy (SBRT), where high-dose, hypofractionated regimens demand exceptionally precise targeting. Employing a combination of MRI sequences – including 2D T2-weighted turbo spin echo (T2w TSE), diffusion-weighted imaging (DWI), and dynamic contrast-enhanced T1-weighted GRASP sequences – optimizes localization and delineation of intraprostatic tumors. This approach enables targeted dose escalation to the tumor while simultaneously reducing radiation exposure to adjacent OARs, thereby enhancing treatment efficacy and minimizing toxicity [3]. Notably, a large Phase III trial demonstrated that MR-guided high-dose boosting to intraprostatic lesions reduced biochemical treatment failure rates by more than half (hazard ratio 0.45, $p < 0.001$), highlighting the substantial clinical impact of MR-guided RT planning [1].

A major challenge in prostate RT is the reduction of genitourinary side effects. These effects can significantly impact a patient's quality of life. Erectile dysfunction (ED) is one of the most prevalent toxicities following RT for prostate cancer. It results from endovascular injury, direct neuronal damage, and radiation-induced fibrosis [4]. The neurovascular bundle (NVB), penile bulb (PB), corpora cavernosa (CC), and pudendal arteries (PA) are functionally critical structures, and studies have demonstrated clear dose-toxicity relationships for these tissues. For instance, a mean dose exceeding 20 Gy to the penile bulb or 36 Gy to the pudendal arteries has been associated with an increased risk of post-RT ED [5]. Recent studies have demonstrated the feasibility of MR-guided neurovascular-sparing prostate RT, with promising long-term functional outcomes. For example, Spratt et al. reported that 90% of patients remained sexually active five years after vessel-sparing radiotherapy using MR-based contouring [5]. However, widespread adoption of this approach has been limited by challenges such as MRI accessibility, contouring expertise, and time constraints. Conventional CT-based planning is insufficient for accurately identifying and contouring these delicate structures, due to the limited soft tissue contrast. High-resolution 3D TSE T2w SPACE allows for detailed delineation of anatomical structures for RT treatment planning. Moreover, deep learning MR-based auto-contouring solutions hold the potential to improve accessibility to vessel-sparing radiotherapy and focal dose boost.

With the increasing availability of RT-optimized MRI scanners, the optimal integration of MRI into MR-guided RT treatment protocols is becoming an ever-more important topic. In this article, we outline our experience in establishing an MRI workflow for RT treatment planning, leveraging the capabilities of MR in RT technology from Siemens Healthineers. We describe how dedicated protocols, patient positioning strategies, and deep-learning-supported contouring approaches can contribute to improved RT treatment precision. By sharing our insights, we aim to contribute to the ongoing development of MRI-based RT workflows and to highlight the potential of MR-guided treatment planning for enhancing oncological and functional outcomes in prostate cancer patients.

2 Imaging setup in RT treatment position for prostate cancer patients.

MR-imaging setup in treatment position

Patients receive MRI for RT planning in the RT treatment position to ensure optimal alignment with subsequent therapy sessions (Fig. 2). This approach enhances the accuracy of the target and of the OAR delineation, and improves the reproducibility for patient positioning during treatment. To realize the RT treatment position, a flat tabletop (INSIGHT, CQ Medical, Avondale, PA, USA) and MR-compatible positioning aids are employed. A Body 18 coil within an INSIGHT coil holder is positioned above the patient's pelvic region.

Pre-MRI patient preparation

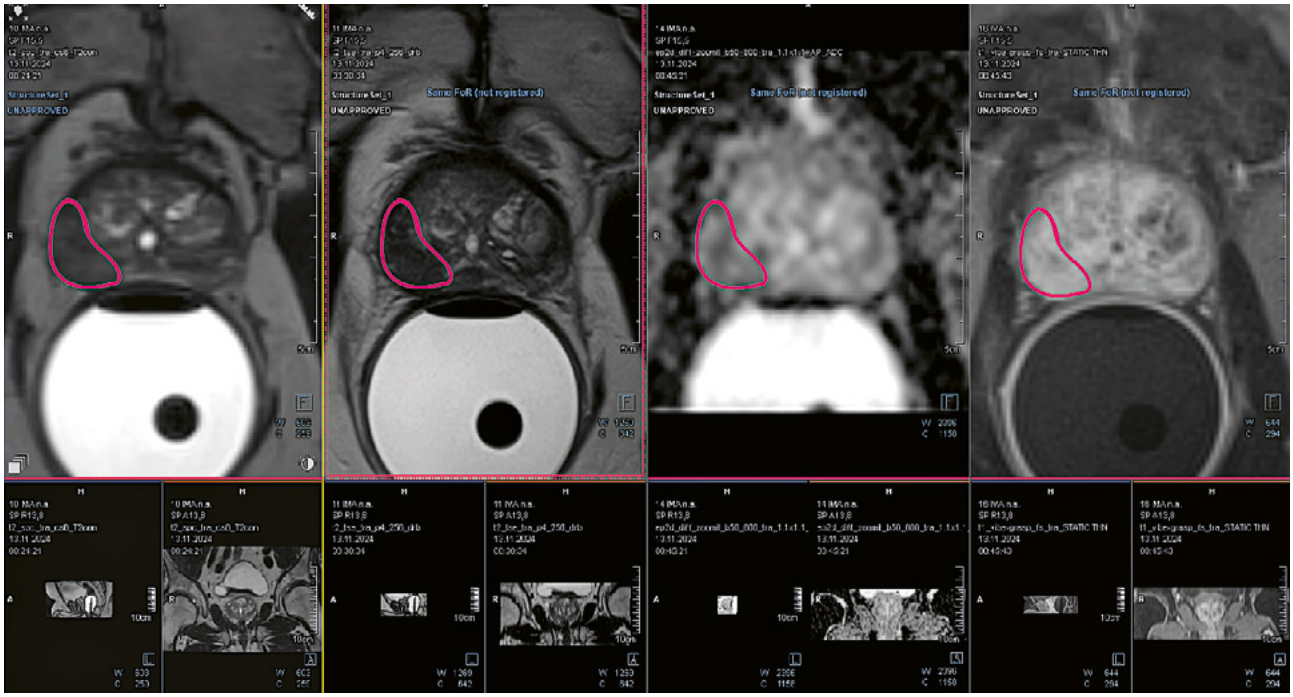
To standardize bladder and rectal conditions, all patients follow a structured preparation protocol prior to the MRI examination and all subsequent RT sessions. This includes:

- Bladder-filling protocol: Patients are instructed to drink a specified volume of water before the scan to ensure consistent bladder filling, as bladder volume can significantly impact prostate position and dosimetric planning.
- Rectal preparation: A rectal balloon (Balloon Rectal Tube, 10 mm/210 mm, Teleflex, Malaysia) is inserted before imaging and filled with 80 mL of water to standardize rectal geometry, reduce prostate motion, and improve treatment reproducibility [6, 7]. This step is particularly important for high-precision techniques such as SBRT, where small changes in prostate position can impact dose delivery and dose distribution [8, 9].
- Pharmacological preparation: To reduce bowel peristalsis and associated image artifacts, patients receive an intravenous injection of butylscopolamin unless contraindicated. Additionally, an intravenous contrast agent is administered to enhance the visualization of the intraprostatic tumor and lymph node metastases on T1w sequences.

MRI acquisition protocol

The primary MRI sequence for treatment planning is a 3D T2w SPACE sequence with Compressed Sensing (CS) acceleration, acquired with an isotropic voxel resolution of 1.0 × 1.0 × 1.0 mm^3 and a large field of view (FOV) to cover the pelvic region. The T2w SPACE forms the main sequence for treatment planning and is used for general OAR and target volume definition. We also use the T2w SPACE for neurovascular delineation, including the neurovascular bundles and internal pudendal arteries (see below).

Due to its superior in-plane resolution and soft tissue contrast, an additional 2D T2w TSE sequence with Deep Resolve Boost is employed for intraprostatic tumor delineation. DWI is performed using ZOOMit reduced-FOV single-shot echo-planar imaging (EPI) to help identify the intraprostatic tumor for focal dose escalation. A dynamic T1w GRASP VIBE sequence with fat suppression is used to assess dynamic contrast enhancement of intraprostatic lesions. Information from the 2D T2w TSE, the DWI, and the dynamic T1w GRASP is combined to delineate the intraprostatic tumor using the multimodal image viewing capabilities



3 Multiparametric contouring of the intraprostatic tumor using 3D T2w SPACE, T2w TSE DRB, ZOOMit EPI DWI, and dynamic T1-GRASP in *syngo*.via RT Image Suite.

of *syngo*.via RT Image Suite (Fig. 3). Finally, in patients with suspected or known lymph node metastases, a high-resolution, large-FOV 3D T1w VIBE with Dixon fat saturation is used. All protocols are transversal to ensure optimal compatibility with RT treatment planning systems.

This combination of RT imaging setup, dedicated patient preparation, and RT-optimized protocols aims to maximize the benefits of MRI in RT, particularly for specialized RT treatment modalities such as SBRT and vessel-sparing prostate radiotherapy.

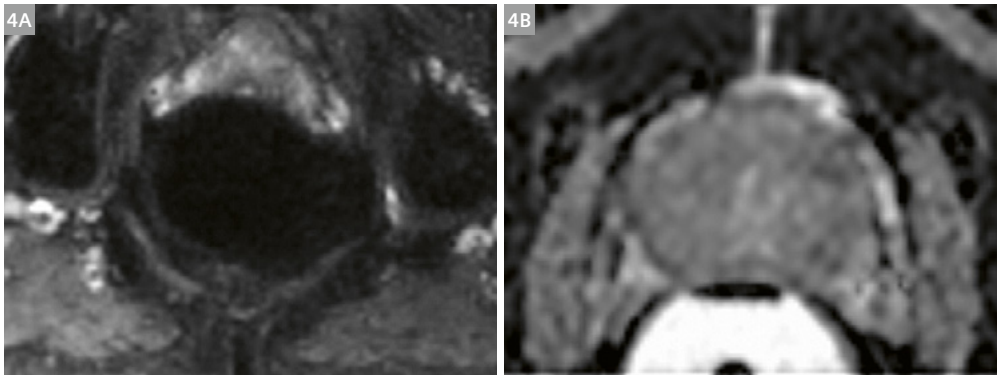
Name of protocol	sCTp1-Dixon-HR	t2_spc_tra_cs8_T2con	t2_tse_tra_p4_256_drb	t2_tse_sag_p4_256_drb	ep2d_diff_zoomit	t1_vibe-grasp_fs_tra_2.1s_3mm	t1_vibe_dixon_tra_p2_352_lymph_nodes
Acquisition type	3D	3D	2D	2D	2D	3D	3D
Orientation	Transverse	Transverse	Transverse	Sagittal	Transverse	Transverse	Transverse
Field of view (cm^2)	50.0 × 37.5	44.8 × 32.0	20 × 20	20 × 20	8.8 × 24.0	24.0 × 24.0	25.5 × 32.0
Acquisition matrix	320 × 240	448 × 320	256 × 256	256 × 256	42 × 114	224 × 224	280 × 352
Acquisition in-plane resolution (mm^2)	1.56 × 1.56	1.0 × 1.0	0.78 × 0.78	0.78 × 0.78	2.11 × 2.11	1.07 × 1.07	0.91 × 0.91
Slice thickness (mm)	2.0	1.0	3.0	3.0	3.0	3.0	2.0
Slice resolution (%)	66%	100%	/	/	/	79%	100%
Echo time (ms)	2.39 / 4.77	255	97	97	51	1.83	2.39 / 4.77
Repetition time (ms)	6.23	2200	7410	6060	3500	4.09	6.91
Flip angle (°)	15	120 / 90	160 / 90	160 / 90	90	12	10
Averages	5	1	4	4	1	1	3
Gradient nonlinearity distortion correction	3D	3D	3D	3D	3D	3D	3D
Shimming of B0 inhomogeneities	Patient-specific	Patient-specific	Patient-specific	Patient-specific	Patient-specific	Patient-specific	Patient-specific
Readout bandwidth (Hz)	1120	558	199	201	1828	500	470
Acceleration factor	4 (CAIPIRINHA)	8 (CS)	4 (GRAPPA)	4 (GRAPPA)	None	CS	2 (CAIPIRINHA)
Deep Resolve Boost	No	No	Yes	Yes	No	No	No
Acquisition time (min)	04:12	05:27	05:13	04:16	04:07	04:16	07:35
Contrast agent	None	None	None	None	None	Gadovist	Gadovist
RT planning indication	Synthetic CT	Main sequence for MR-only contouring, OAR delineation	Intraprostatic tumor delineation	Optional: Urogenital diaphragm (lower target volume boundary)	Intraprostatic tumor delineation	Intraprostatic tumor delineation	Optional: Nodal metastases delineation

Table 1: Sequence protocol parameters for prostate cancer treatment planning. CS: Compressed Sensing

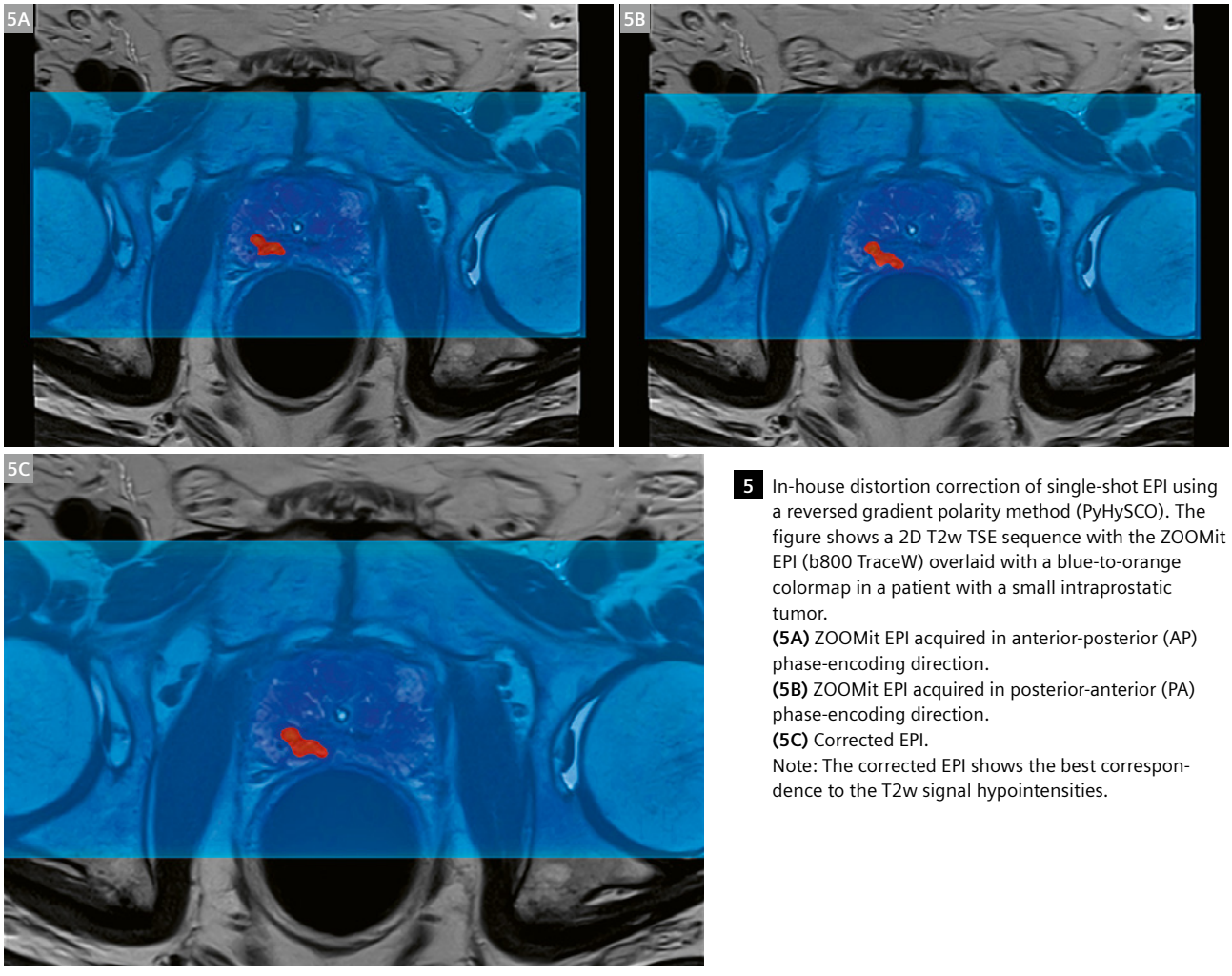
Optimizing MR imaging for RT planning: Lessons learned and practical improvements

Over the course of implementing MRI for RT treatment planning in prostate cancer, we identified several modifications to improve image quality and geometric accuracy. One significant adjustment was the optimization of the medium used for filling the rectal balloon. Initially, air was used as a filling material, following the conventional CT-based workflow, but we observed that this led to increased distortions, particularly in DWI. To mitigate this, we transitioned to filling the rectal balloon with water (Fig. 4). This change significantly improved signal homogeneity and reduced susceptibility artifacts, leading to more reliable diffusion images and better visualization of intraprostatic diffusion restrictions.

Improved single-shot EPI distortion correction was subsequently introduced via an in-house postprocessing



4 Air vs. water in the rectal balloon.
(4A) Air-filled rectal balloon;
(4B) water-filled rectal balloon.



5 In-house distortion correction of single-shot EPI using a reversed gradient polarity method (PyHySCO). The figure shows a 2D T2w TSE sequence with the ZOOMit EPI (b800 TraceW) overlaid with a blue-to-orange colormap in a patient with a small intraprostatic tumor.
(5A) ZOOMit EPI acquired in anterior-posterior (AP) phase-encoding direction.
(5B) ZOOMit EPI acquired in posterior-anterior (PA) phase-encoding direction.
(5C) Corrected EPI.
Note: The corrected EPI shows the best correspondence to the T2w signal hypointensities.

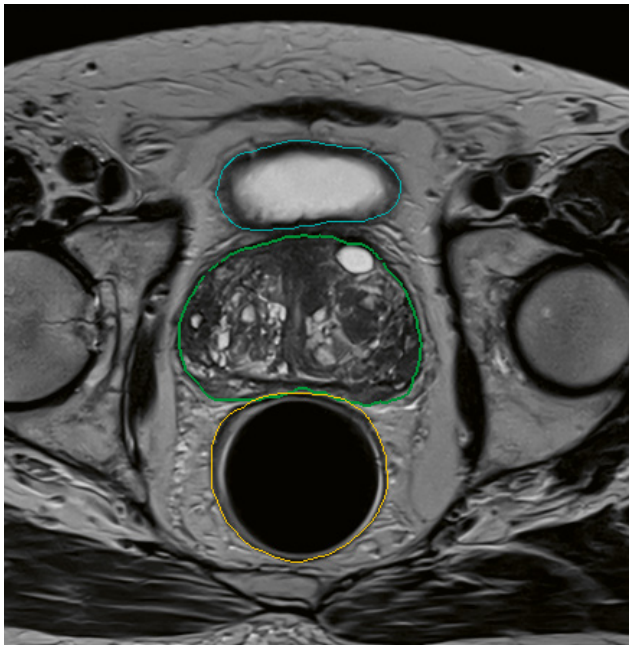
solution. Geometric distortions in EPI along the phase-encoding direction can complicate the precise localization of intraprostatic tumors for target volume definition. To mitigate these issues, we implemented a reversed gradient polarity correction method using the GPU-enabled susceptibility artifact distortion correction python library PyHySCO [10]. An in-house application was built that loads the two EPI series with opposite phase-encoding direction in DICOM format and outputs corrected series (Fig. 5).

Another important observation during the implementation of our MR-based planning protocol was the sequential order between fiducial marker implantation and planning MRI acquisition. It was observed that performing the MRI after marker placement could compromise intraprostatic tumor delineation. These early post-interventional scans often revealed localized hemorrhage around the fiducials, as well as artifacts on DWI. Such effects may mimic or obscure intraprostatic lesions, thus hampering accurate tumor delineation. To address this, the MR-guided prostate treatment planning workflow was changed to perform any fiducial marker implantation after planning MRI.

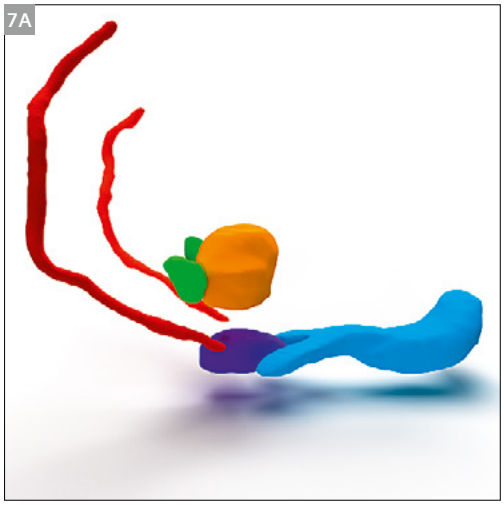
Introducing artificial intelligence for MRI-guided radiotherapy planning

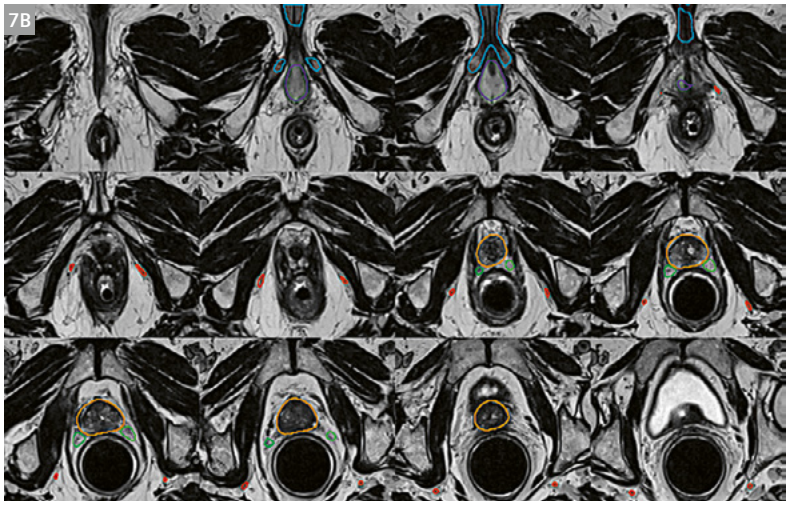
The integration of artificial intelligence (AI) into MRI-guided RT planning is transforming the way treatment is designed and optimized. At the Department of Radiation Oncology at Universitätsklinikum Erlangen, we have implemented deep learning approaches to enhance image analysis and support EBRT and brachytherapy planning [11]. We recently introduced MR-based autocontouring for OARs[1] in male pelvis patients via the *syngo*.via VC10A CUT version (Siemens Healthineers, Forchheim, Germany). In prostate cancer patients, we observed a significantly reduced manual workload, with MR-based OAR autocontouring being particularly valuable for MR-only workflows (Fig. 6).

An interesting novel application for AI in radiotherapy is the automated contouring of delicate neurovascular



6 MR-based OAR autocontouring for the male pelvis using *syngo*.via VC10A CUT[1] in clinical treatment planning.





7 Deep learning neurovascular OAR autocontouring on high-resolution T2w SPACE for a prostate cancer test case. **(7A)** 3D rendering of autosegmented neurovascular OARs. **(7B)** Transverse cross-sections. The nnU-net model was trained in-house on 40 manually delineated T2w SPACE datasets to autosegment the internal pudendal artery (red), the neurovascular bundle (green), the corpora cavernosa (blue), the prostate (orange), the penile bulb (violet), and the seminal vesicles (green).

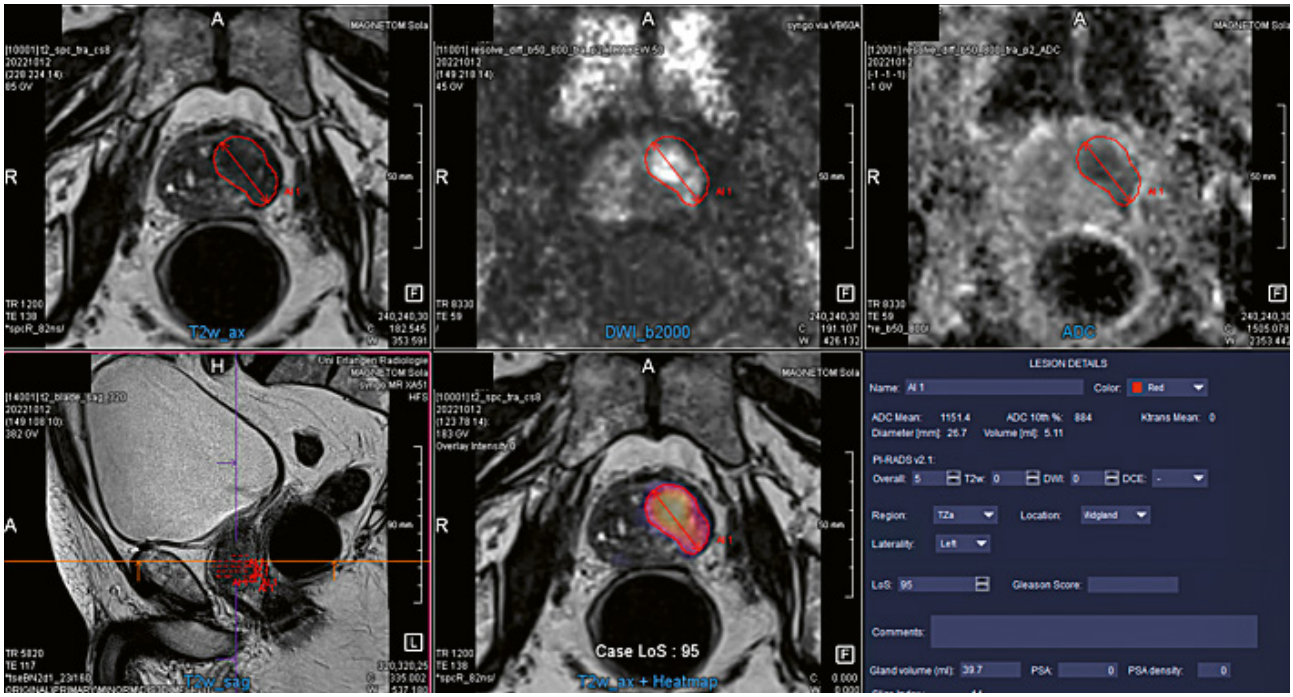
[1] *Work in progress. The application is currently under development and is not for sale in the U.S. and in other countries. Its future availability cannot be ensured.*

OARs that are visible thanks to the detailed image information provided by MRI. Traditional manual segmentation of high-resolution image datasets is time-consuming and prone to interobserver variability. Deep learning architectures, such as 3D U-Net [12], can assist in automatically delineating the OARs and target volumes. We developed and validated an in-house model for automatic segmentation of neurovascular OARs in high-resolution 3D T2w SPACE datasets based on the nnU-net pipeline [13], confirming its robustness and accuracy (Fig. 7). The model can autosegment neurovascular OARs including the internal pudendal arteries, penile bulb, and neurovascular bundles with high accuracy, and is currently being introduced into our clinical treatment workflow. Similar solutions will be interesting to integrate into commercial solutions to facilitate vessel-sparing radiotherapy in prostate cancer.

As well as supporting OAR delineation, AI could also play an important role in identifying dominant intraprostatic lesions (DILs) for focal dose escalation. Multiparametric MRI can enable personalized treatment planning for precisely targeting high-risk tumor regions with selective dose escalation. Techniques such as the simultaneous integrated boost (SIB) enable focused intensification of the radiation dose directly to these critical areas, improving biochemical cure rates in prostate cancer [1]. However, radiation oncologists frequently lack expert knowledge on interpreting multiparametric prostate images. Deep learning applications might serve as a robust decision-support tool throughout this process. We are currently evaluating the *syngo*.via Prostate AI Frontier[1] application for automatic segmentation of intraprostatic lesions for RT treatment planning. The Prostate AI Frontier application can detect and autosegment intraprostatic tumors by combining T2w, DWI, and contrast-enhanced T1w input series (Fig. 8). Clinical integration of similar autosegmentation solutions could increase precision and standardization in prostate cancer RT, while reducing manual planning time to facilitate single-day treatment planning and adaptive MR-guided protocols.

Conclusion

Integrating MRI into RT planning has significantly advanced prostate cancer treatment. Superior soft tissue contrast enables precise delineation of the prostate, accurate identification of dominant intraprostatic lesions, and clear differentiation of surrounding organs, resulting in highly personalized treatment strategies. At our center, we developed a combined MRI planning and RT treatment planning workflow, which includes standardized patient preparation, dedicated imaging in the treatment position, synthetic CT, and deep learning postprocessing. While implementing the comprehensive MR-guided planning protocol, we learned to optimize multiple aspects. This included changing the medium used for filling the rectal balloon, avoiding fiducial implantation before MRI, and implementing an in-house solution for reversed gradient polarity correction of single-shot EPI sequences. The recent



8 The *syngo*.via Prostate AI Frontier[1] application can autodetect and autosegment intraprostatic tumors on multiparametric MRI input data. AI applications could improve accessibility to MR-guided focal dose escalation in prostate cancer.

incorporation of MR-based pelvic OAR autocontouring has considerably reduced clinical workload and is particularly promising for MR-only workflows. Combining RT-optimized MRI with AI postprocessing applications could be crucial in facilitating advanced MR-guided treatment concepts such as focal dose boost and neurovascular sparing.

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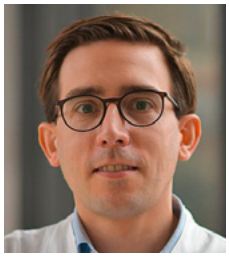


Florian Putz, M.D.

Contact

Florian Putz, M.D.
Senior Physician and Senior Researcher
Department of Radiation Oncology
Universitätsklinikum Erlangen
Universitätsstraße 27
91054 Erlangen
Germany
Tel.: +49 9131 8534080
florian.putz@uk-erlangen.de

Combining Cone Beam CT-Based Treatment Delivery on a C-Arm Linac with Offline MRI-Guided Adaptive Radiotherapy

Silvia Fabiano, Ph.D.; Klara Kefer; Michael Baumgartl; Gabrys Hubert, Ph.D.; Riccardo Dal Bello, Ph.D.; Michael Mayinger, M.D.; Sebastian M. Christ, M.D., Ph.D.; Lotte Wilke, Ph.D.; Matthias Guckenberger, M.D.; Stephanie Tanadini-Lang, Ph.D.

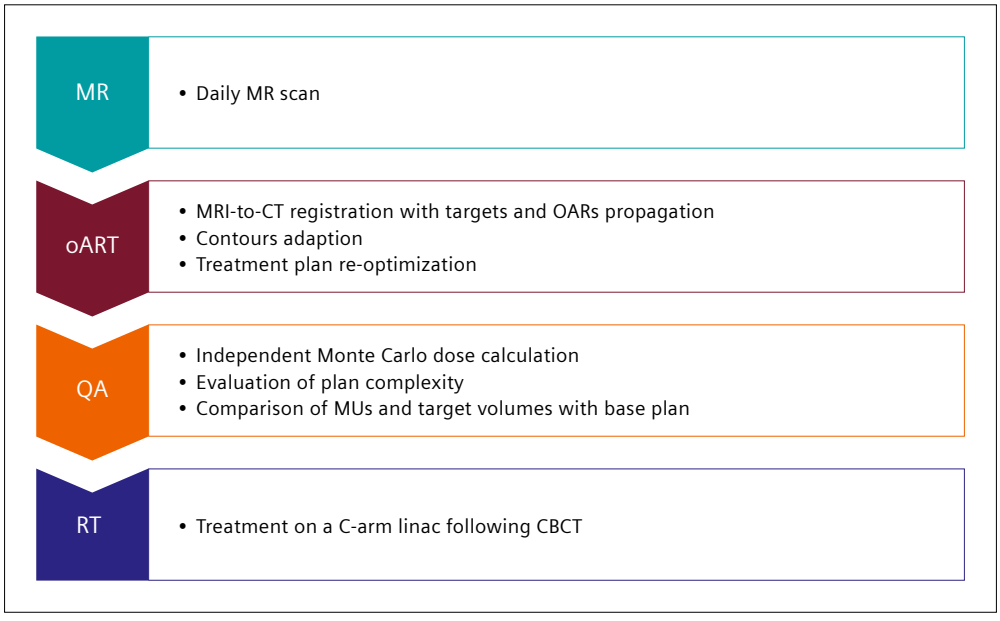
Department of Radiation Oncology, University Hospital Zurich (USZ), Switzerland

Introduction

Prostate cancer is the most common non-skin cancer in men and is often diagnosed at an early stage thanks to advancements in screening and imaging [1]. Treatment options have evolved significantly, with stereotactic body radiation therapy (SBRT) emerging as a highly effective, non-invasive approach [2, 3]. SBRT delivers high doses of radiation in a few sessions with remarkable precision, minimizing damage to surrounding organs such as the bladder and the rectum [4].

Magnetic resonance (MR)-informed adaptive radiotherapy further enhances treatment accuracy by using real-time MR imaging to track and adapt intrafractional anatomical changes, such as prostate motion and variations in adjacent tissues. This combination of technologies reduces side effects and improves clinical outcomes, representing a cutting-edge solution for prostate cancer management.

However, the widespread adoption of hybrid MR-linear accelerators remains limited due to the high costs of construction, purchase, and maintenance [5–7]. Moreover, the substantial time and resource demands of each treatment session reduce patient throughput [8]. As a more accessible alternative, this study proposes adaptive radiotherapy on a cone beam computed tomography (CBCT)-guided linear accelerator, using MR images acquired in the treatment position, immediately before treatment, for contouring and plan adaptation (Fig. 1).



1 MR-guided adaptive radiotherapy in a CBCT-guided C-arm linac workflow.

Materials and methods

Base-plan generation

The treatment planning process begins with the acquisition of a planning CT scan. In addition, T1-weighted and T2-weighted MR imaging is performed on the department's 1.5T MAGNETOM Sola scanner (Siemens Healthineers, Erlangen, Germany). The imaging data are then transferred to the Eclipse treatment planning system (v.16.1; Varian Medical Systems, Palo Alto, CA, USA) and are rigidly registered. Following the delineation of target volumes and organs at risk (OARs) on the planning CT based on the MR images, a base plan for SBRT is created. This plan is generated according to a checklist to ensure compliance with internal quality standards. Any necessary auxiliary structures for plan optimization are generated using an ESAPI script that was developed in-house. Hence, dose calculation is performed using the Acuros XB v.16.1.0 algorithm (Varian Medical Systems, Palo Alto, CA, USA). The plan is then reviewed by a physicist and approved by a physician.

At our institution, patient-specific quality assurance (PSQA) includes an independent Monte Carlo dose calculation and an evaluation of the plan's complexity. Depending on the complexity, portal dosimetry may be performed prior to the first treatment.

As the planning system does not support online adaptive treatments, the base plan is then prepared for online adaptation through the following steps:

- Detailed notes are made on the auxiliary structures used in the optimizer and on any dose compromises made due to critical OARs.
- Optimization objectives are saved in a patient-specific template.
- Two copies of the CT scan are created: one containing target contours to be rigidly copied onto the adaptation MR images, and another for deformable structures (e.g., gastrointestinal structures).

Daily MR-guided adaptive radiotherapy on a CBCT-guided linear accelerator

On the day of treatment, T2-weighted MR imaging is acquired in the treatment position using the department's 1.5T MAGNETOM Sola scanner. This MRI is then registered to the original planning CT scan. Target contours from the original plan are rigidly transferred to the new MR imaging, while OAR contours are mapped using deformable registration. The physician then adapts the target contours on the new MRI and, if necessary, adjusts any OARs within a 2 cm margin of the tumor. The adapted structure set is subsequently assigned to the original planning CT scan, and a planning target volume (PTV) is generated.

Next, a physicist uses the ESAPI script to automatically generate all auxiliary structures required for plan optimization, following the planning notes. The base plan with the adapted structure set is then re-optimized on the original planning CT scan using the saved optimization objectives. If dosimetric goals and constraints are not met, the optimization objectives are adjusted iteratively until an acceptable plan is achieved. Once optimized, the adapted plan undergoes a final dosimetric review and is approved by the physician.

To ensure accurate and safe treatment delivery, patient-specific quality assurance is performed as it was for the base plan. Additionally, the ESAPI script automatically verifies plan normalization and conducts a comparative analysis of key parameters – including dose per fraction, target volumes (with an internal threshold of 20%), and monitor units (with an internal threshold of 20%) – against the base plan.

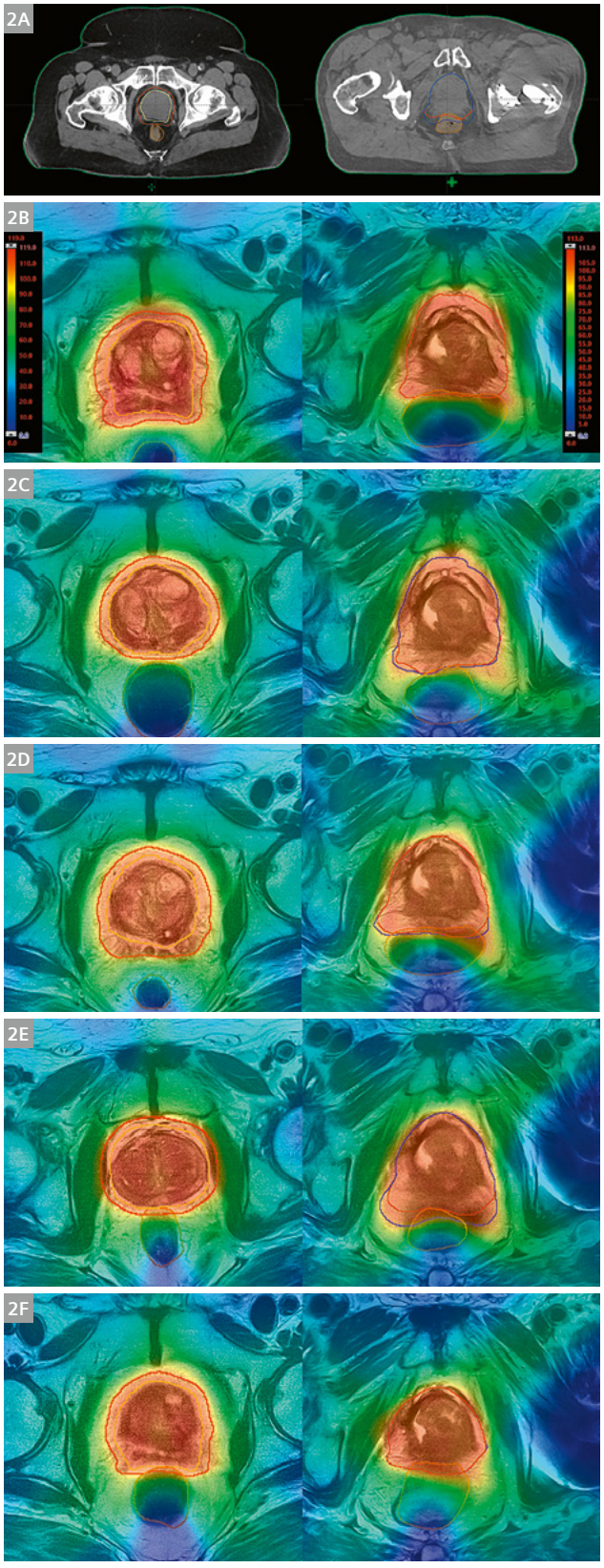
Finally, prior to radiation delivery, a verification CBCT scan is acquired to aid patient positioning on either a Varian Edge or TrueBeam linear accelerator (Varian Medical Systems, Palo Alto, CA, USA).

Clinical cases

We have used this new workflow for treating patients with pelvic lesions that are expected to benefit from online adaptive radiotherapy that takes account of variations in bladder and rectum filling. Here, we present two clinical cases of prostate cancer.

Patient 1 is a 70-year-old male with a medical history of seropositive rheumatoid arthritis, hypertensive heart disease with paroxysmal atrial fibrillation, Type 2 diabetes mellitus, and psoriasis vulgaris. He was diagnosed at our institution with prostate adenocarcinoma (pT2c cN0 cM0, Gleason Score 7a, "unfavorable intermediate risk") and underwent weekly primary stereotactic radiotherapy for one month. The total prescribed dose was 40.0 Gy to the clinical target volume (CTV) and 37.5 Gy to the PTV in 5 fractions. No significant acute radiation-induced toxicities were observed. Planned follow-up includes prostate-specific antigen (PSA) monitoring and multidisciplinary care.

Patient 2 is an 89-year-old male with a history of localized prostate adenocarcinoma (cT2c cN0 cM0) under active surveillance since 2010. His medical history includes multiple prostate interventions, bladder tamponade, and comorbidities including diverticulosis, erectile dysfunction, and chronic kidney changes. He presented at our institution with a PSA increase to 53 µg/L, and prostate-specific membrane antigen (PSMA) PET/CT confirmation of localized disease. He underwent primary SBRT with 5 × 7/7.25 Gy every other day to avoid androgen deprivation therapy. At six-month follow-up, PSA had decreased to 30.1 µg/L.



2 Planning CT scans for Case 1 (left) and Case 2 (right), showing target volumes and main OAR contours **(2A)**. Adapted contours and dose distributions for fractions 1 to 5 **(2B–2F)**.

Results

Figure 2A shows the planning CT scans for cases 1 and 2, respectively, with the target volumes and main OARs highlighted. All treatment fractions were adapted (Figures 2B–2F). Tables 1A and 1B summarize the institutional clinical goals for cases 1 and 2, respectively. In both cases, adaptation made it possible to achieve plans comparable to the base plan. Without adaptation, target coverage could have been compromised, and OARs might have received a higher dose. On average, for Case 2, the coverage of the PTV_high would have decreased by 54%, while for Case 1, the rectum would have received a 9% higher dose.

PSQA was passed for all fractions, with an average relative change in PTV/PTV_low volume of 1.1% and 19.1%, and in monitor units (MU) of 4.5% and 0.1%, compared to the base plan for cases 1 and 2, respectively. Independent Monte Carlo dose calculations yielded an average passing rate of 99.1% and 99.3% for the two cases.

The median total session time was 128 minutes for Case 1, and 116 minutes for Case 2 (Fig. 3). Notably, patients remained on the treatment table only during image acquisition and radiation delivery. Figure 3 also shows the median times for the individual workflow phases. It can be seen that planning is currently the most time-intensive phase owing to the multiple optimizations that are typically required to meet the OAR dose constraints.

Discussion

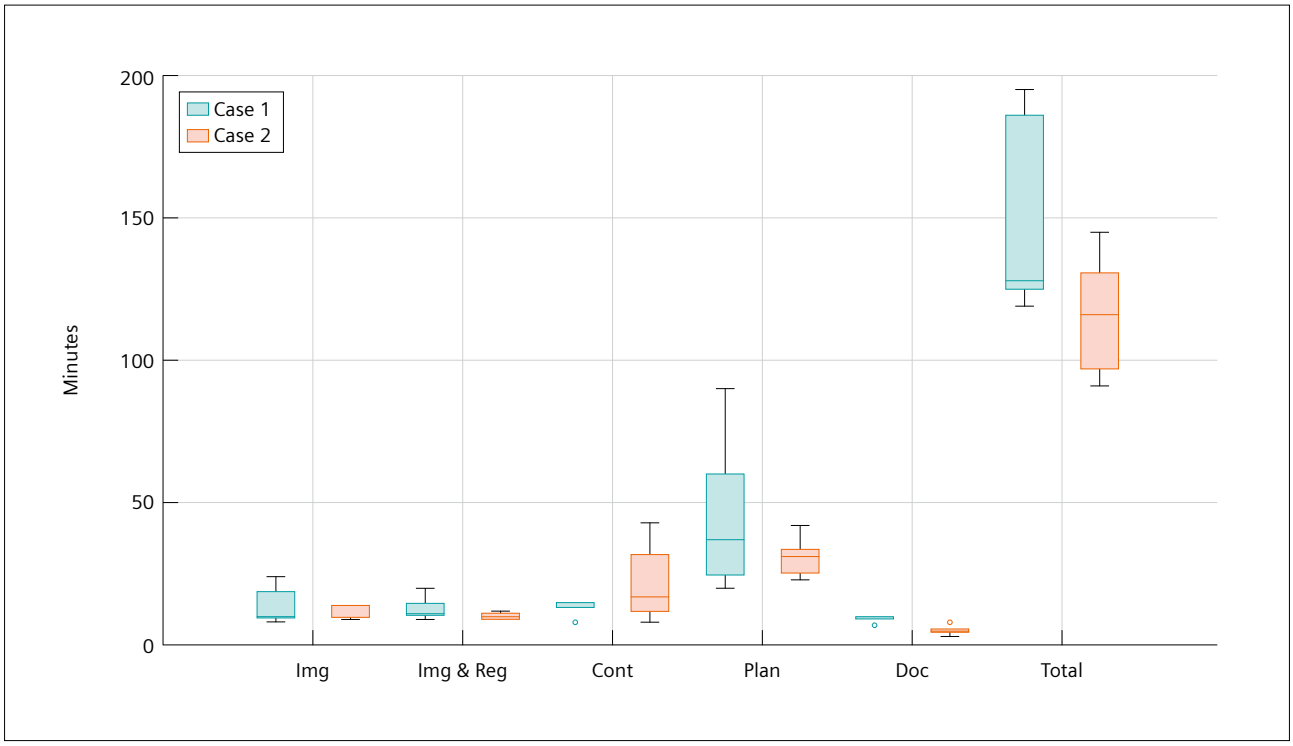
We presented our experience with adaptive radiotherapy (ART) using a CBCT-guided linac with offline MR guidance, detailing the workflow and clinical integration of this approach.

Unlike MR-linac-based adaptive radiotherapy, this approach lacks real-time imaging during beam delivery, as cine MRI is not available for tumor tracking. Additionally, the reported average session times exceed those documented for adaptive radiotherapy [9–11]. However, this method may be more readily implemented in standard radiotherapy departments, offering greater flexibility and leveraging higher-quality MR images for plan adaptation. Furthermore, it has the potential to enhance accessibility and optimize resource use.

In general, ART is particularly promising for managing pelvic cancers, as it enables adaptation to intrafractional anatomical changes, such as variations in bladder and rectal filling. In the future, we plan to conduct a clinical trial to validate the feasibility and efficacy of this approach in patients with pelvic lymph node metastases. This study will incorporate an AirShuttle system (CQ Medical, Avondale, PA, USA) for transferring patients between imaging and treatment, potentially improving workflow efficiency by eliminating the need for patient repositioning [12].

A	Case 1			
		Plan		
Structure	**Clinical goal**	**Base**	**Recalculated**	**Adapted**
CTV	D 95% ≥ 40 Gy	40.28	39.86	40.45
PTV	D 95% ≥ 37.5 Gy	37.5	35.94	37.74
Bladder	D 5 cc < 38 Gy	39.67	37.00	39.54
Bowel	D 1 cc < 25 Gy	1.23	1.95	1.75
Rectum	D 0.5 cc < 38 Gy	40.02	42.79	39.41
B	**Case 2**			
		Plan		
Structure	**Clinical goal**	**Base**	**Recalculated**	**Adapted**
PTV_high	D 95% ≥ 36.25 Gy	36.25	16.51	36.25
PTV_low	D 95% ≥ 33.25 Gy	35.66	14.88	35.26
Bladder	D 5 cc < 38 Gy	37.43	34.24	37.38
Bowel	D 1 cc < 25 Gy	1.80	1.75	3.94
Rectum	D 0.5 cc < 38 Gy	37.67	37.68	37.72

Table 1: Clinical goals for Case 1 **(A)** and Case 2 **(B)**. Dose statistics for the adapted plans are averaged across all fractions.



3 Median duration of the five phases of an adaptive session: imaging (Img), image import and registration (Imp & Reg), contouring (Cont), planning (Plan), and documentation (Doc). "Total" represents the time from MRI acquisition to the completion of radiation treatment.

Conclusion

The approach proposed in this study for ART presents a promising alternative to hybrid systems, offering easier integration into standard radiotherapy settings. It has the potential to improve resource use and increase patient throughput while leveraging high-quality MR imaging. Although adaptation times could still be refined, the new workflow may enhance patient comfort by reducing the time spent on the treatment table.

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Contact

Silvia Fabiano, Ph.D.
Department of Radiation Oncology
University Hospital Zurich (USZ)
Rämistrasse 100
8091 Zürich
Switzerland
Tel.: +41 43 253 20 67
silvia.fabiano@usz.ch

Enhancing Precision in Radiation Therapy by Integrating MRI into Treatment Planning

Sushil Beriwal, M.D., MBA, FASTRO, FABS, FICRO, FACRO[1]; Deepak Khuntia, M.D., FASTRO[2]

[1]Vice President, Multidisciplinary Oncology, Medical Affairs at Varian, a Siemens Healthineers Company, Washington, DC, USA
[2]Senior Vice President and Chief Medical Officer, Medical Affairs at Varian, a Siemens Healthineers Company, Palo Alto, CA, USA

Imaging is an integral part of radiation planning. It provides information about the target volume and the adjacent organs at risk (OARs), which is critical at multiple points in the radiation therapy (RT) workflow. Historically, RT planning used plain X-rays, but this was largely replaced by computed tomography (CT) in the 1990s. Today, CT imaging is still the major modality for treatment planning and dose calculation. However, magnetic resonance imaging (MRI) provides unique advantages in certain clinical situations, thanks to its superior soft tissue contrast and provision of additional functional information. MRI is nowadays used for planning both external beam RT (EBRT) and brachytherapy. It is commonly used for RT planning in the prostate, brain, nasopharynx, liver, pancreas, rectum, cervix, and spine. The following overview provides some case-based examples to highlight the role of MRI in radiation dose planning and delivery. The challenges and solutions (Table 1) are also discussed.

MRI helps oncologists accurately contour the tumor and surrounding OARs. The common sequences used in RT planning are as follows:

- **T1-weighted MRI** to define anatomical structures
- **T2-weighted MRI** to highlight tumors and edema
- **Diffusion-weighted imaging (DWI) and perfusion MRI** to provide functional insights into tumor biology

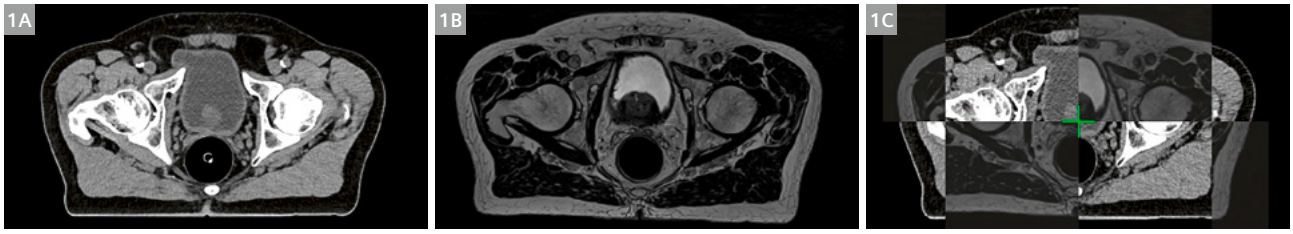
Workflow

The most common workflow involves performing both a CT and an MRI scan of the patient in the planning position. The two images are then fused for contouring and planning. Depending on the clinical situation, either rigid or deformation registration is used for image fusion. While MRI provides excellent soft tissue contrast for contouring the target and/or the OARs, CT imaging is still required for electron density information to enable accurate dose calculation.

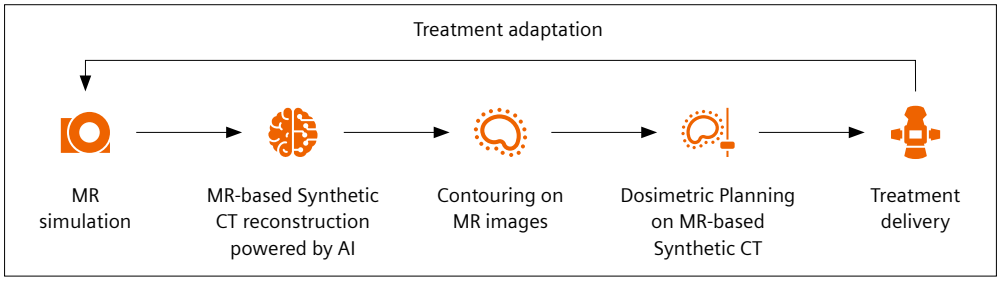
Challenge	Solution
Geometric distortions in MRI	MRI-CT fusion
	Distortion correction algorithm with in-plane resolution of 1–2 mm
Lack of electron density information for dose calculation	MRI combined with CT imaging for accurate dose planning
	Deep learning algorithm to create MR-based synthetic CT imaging
Motion artifacts	Motion management techniques, such as 4D MRI

Table 1: Challenges and solutions of MRI in RT.

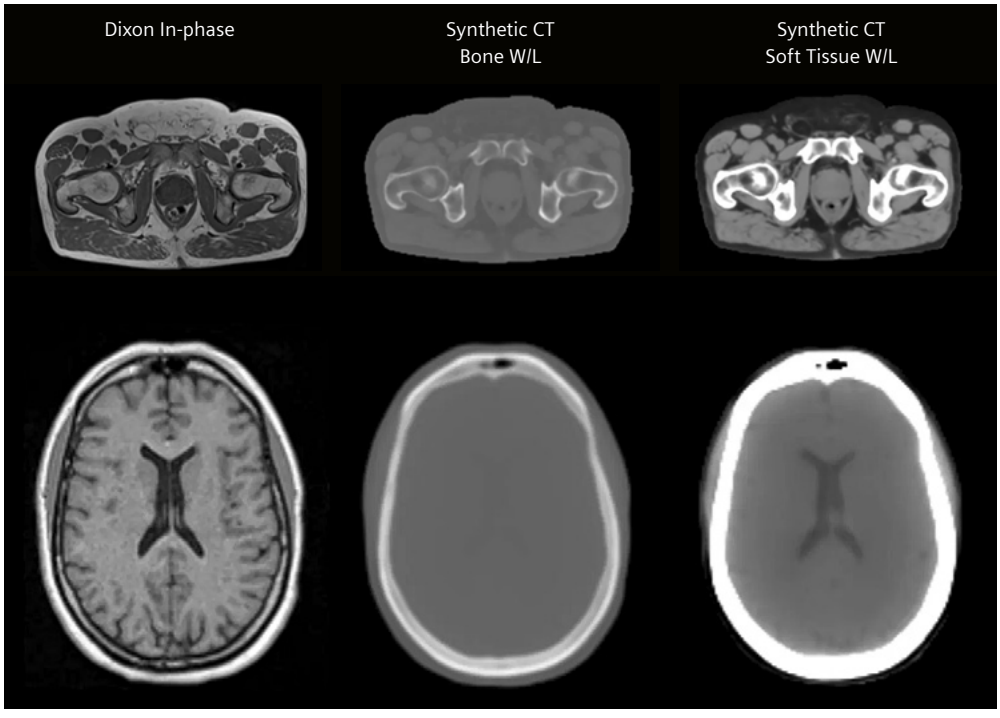
However, fusing CT and MRI scans can make the workflow more complicated and may introduce uncertainties to the planning process. MR-based synthetic CT imaging offers the possibility of combining dosimetric planning with the superior soft tissue contrast of MRI for OAR and target delineation. An MR-only workflow eliminates the need for CT-to-MRI registration, reducing systematic registration errors and unnecessary ionizing radiation from the CT scan. Synthetic CT imaging has been developed and evaluated in support of MR-only treatment planning in a variety of anatomical sites, including the brain and pelvis. The key sequence for MR-based synthetic CT reconstruction is the T1-weighted VIBE-Dixon sequence. It takes 3 to 5 minutes to acquire these images. A deep learning algorithm is used to create synthetic CT imaging with an in-plane resolution of 1.0 × 1.0 mm (brain) and 2.0 × 2.0 mm (pelvis). The result has excellent geometric and HU fidelity for dose calculation in the brain and pelvis.



1 **(1A)** CT scan and **(1B)** MRI of the pelvis with **(1C)** deformation fusion of the prostate. Variations in bladder and rectum filling can be seen in the two scans.



2 MR-only workflow with synthetic CT imaging for dose calculation and daily cone beam CT (CBCT) match.

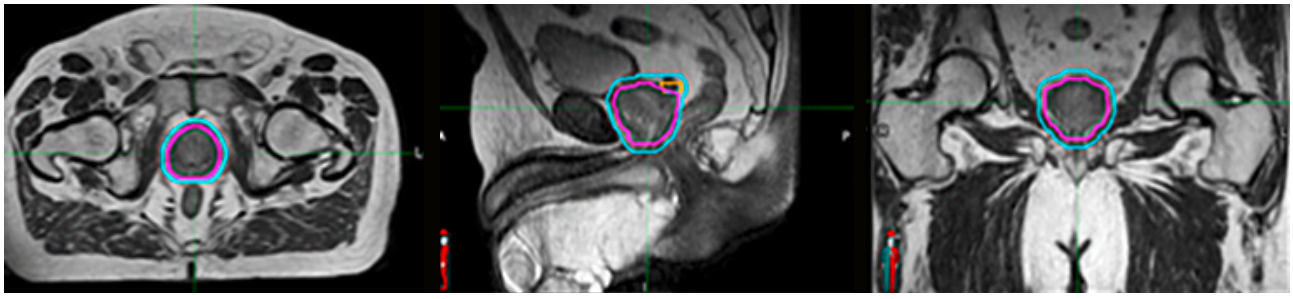


3 Dixon in-phase MRI with synthetic CT scan.

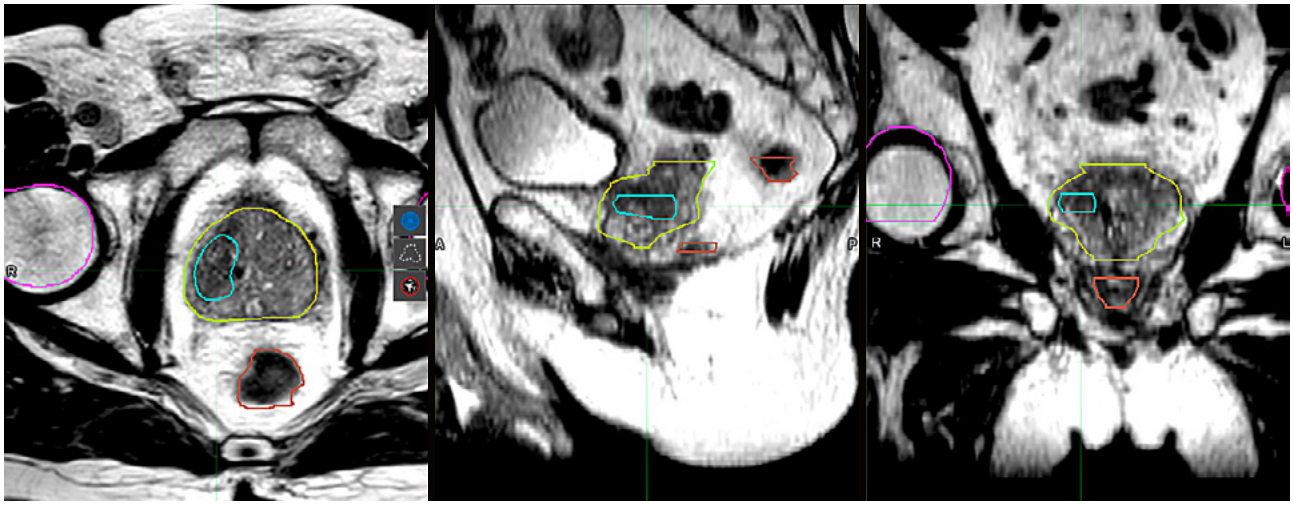
Clinical examples

Prostate cancer

Prostate cancer is one of the most common cancers where MRI is used for RT planning. The delineation of the prostate is better, especially at the base and apex, which leads to a 20%–30% reduction in target volume compared to CT imaging. This is important, as prostate EBRT has moved to hypofractionation (20 fractions) or ultrafractionation (5 fractions), and accurate volume delineations add to the precision of RT delivery and expose less healthy tissue to radiation. MRI also allows to deliver isotoxic microboost to dominant lesions, which can be contoured on MRI using a combination of T2-weighted and diffusion-weighted images. This has been shown to reduce local recurrence without significantly increasing morbidity.



4 MRI of the pelvis showing target contouring of the prostate (dark pink), proximal seminal vesicles (light orange), and planning target volume (blue).

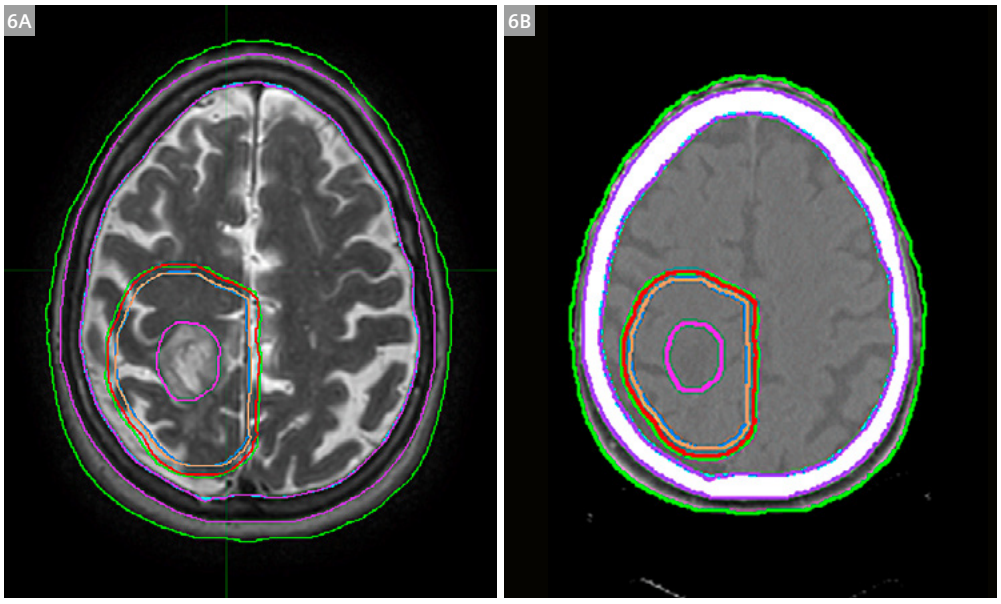


5 MRI of the pelvis with contouring of the prostate (green) and the dominant lesion for microboost (blue).

Brain

MRI is the gold standard for both primary brain tumors and metastases. Contrast-enhanced T1 sequences and T2-weighted FLAIR sequences are routinely used for contouring in primary brain tumors. MRI also helps to better define OARs such as the optic chiasm, nerves, pituitary, brainstem, and hippocampus. Hippocampal-sparing RT for brain metastases has been shown to reduce cognitive decline.

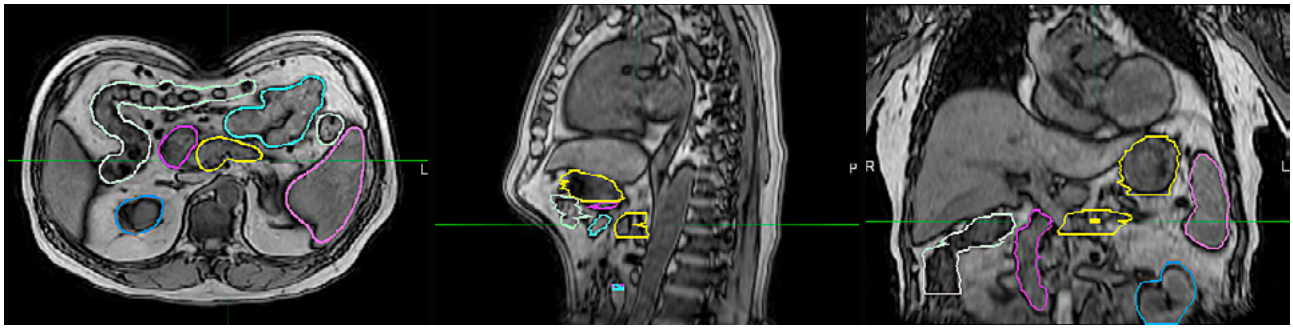
Stereotactic radiosurgery is one of the most common techniques used in brain metastases. For Linac-based radiosurgery, fusion of MRI (3D MPRAGE) and CT scans is currently required for contouring, planning, and treatment. The outcomes are very good, with local control > 80%, but this workflow can sometimes lead to delays of one to two weeks between the MRI scan and treatment. Data shows that a delay of more than one week between MRI and radiosurgery can lead to changes in volume in a significant number of patients. The MR-only workflow can potentially allow us to compress the time between simulation and treatment, and therefore treat these patients on the same day.



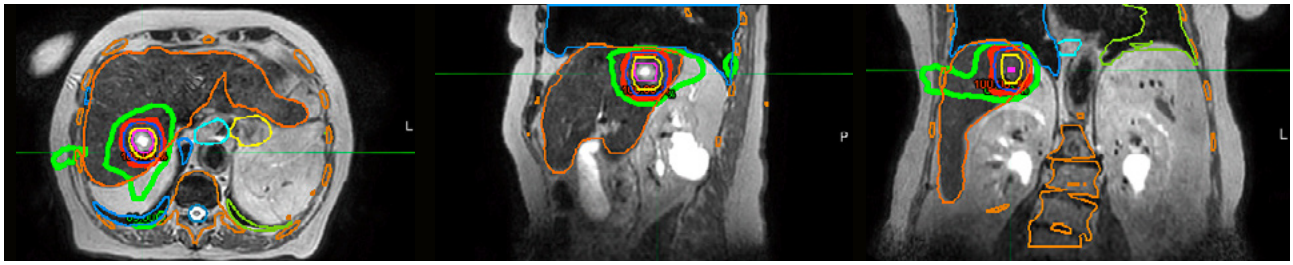
6 **(6A)** T2-weighted MRI showing the gross tumor volume (GTV) in pink with the clinical target volume (blue) and the planning target volume (red), compared to **(6B)** CT scan of the brain showing an inconspicuous GTV (pink).

Pancreas and liver

MRI is better suited to delineating liver and pancreatic lesions, and is routinely fused with planning CT imaging to help contour the target volume. Four-dimensional MRI can further help this workflow to better define targets and OARs by accounting for positional changes caused by breathing.



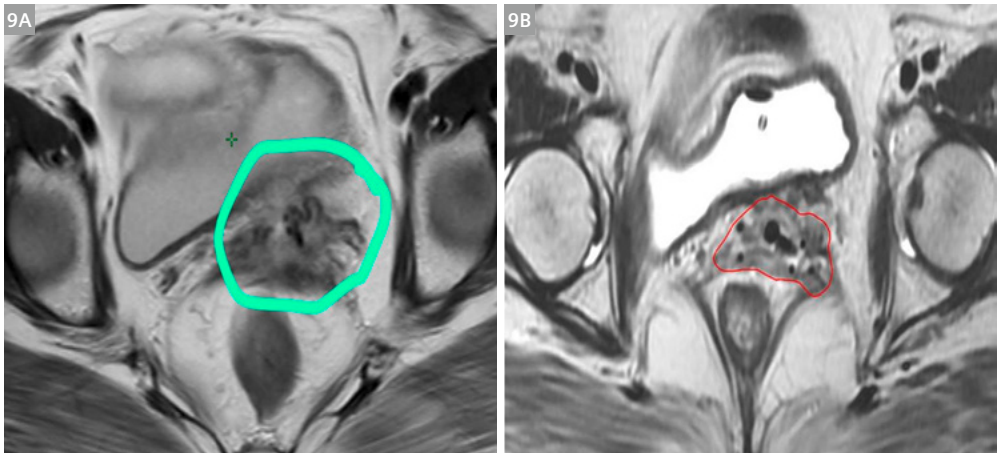
7 MRI of the abdomen showing the pancreatic gross target volume (yellow), and the duodenum (pink), small bowel (green), and stomach (blue).



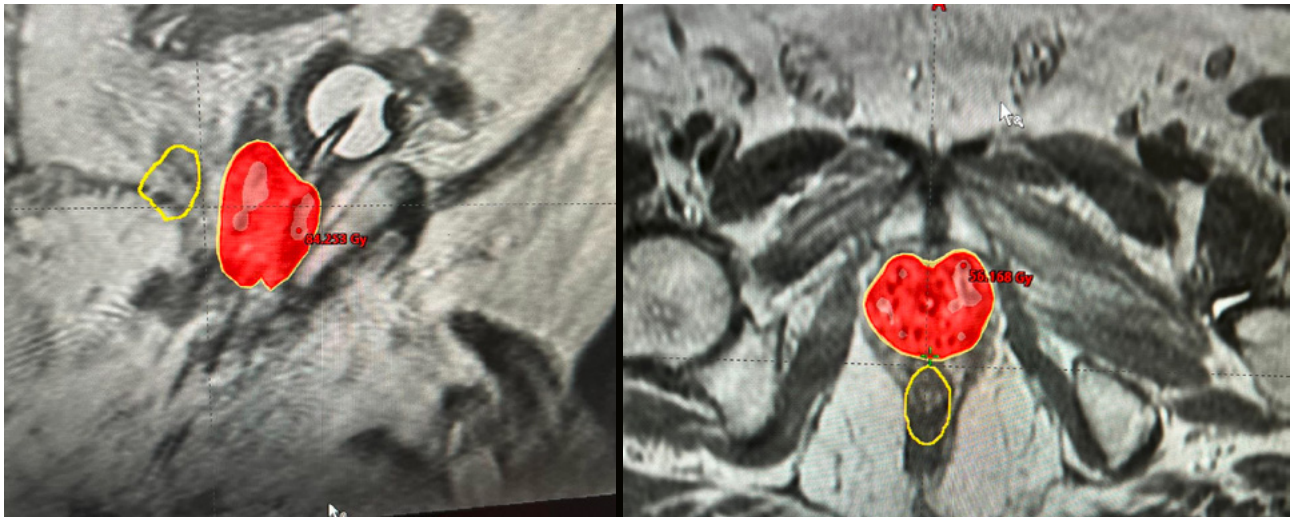
8 Liver metastases (pink: metastases, and green: 50% isodose line) with prescription dose covering the target.

Brachytherapy

MRI is now commonly used for gynecological and prostate brachytherapy. The EMBRACE studies have shown that MR-based adaptive brachytherapy for cervical cancer helps improve local control and reduce morbidities. The target volume is smaller compared to CT imaging, and residual disease is visible, which can help with focal dose escalation. With modern MR-based planning, local control is almost 90% for locally advanced cervical cancer. Similarly, MRI is used for prostate brachytherapy, both for a boost after EBRT and/or as salvage for radiorecurrent disease. The visibility of lesions on MRI helps to boost or better treat the radiorecurrent area.



9 **(9A)** Prebrachytherapy MRI showing eccentric tumor in the cervix, with a hybrid applicator (Aarhus Applicator Set) with straight and oblique needles to cover **(9B)** the high-risk clinical target volume (red).

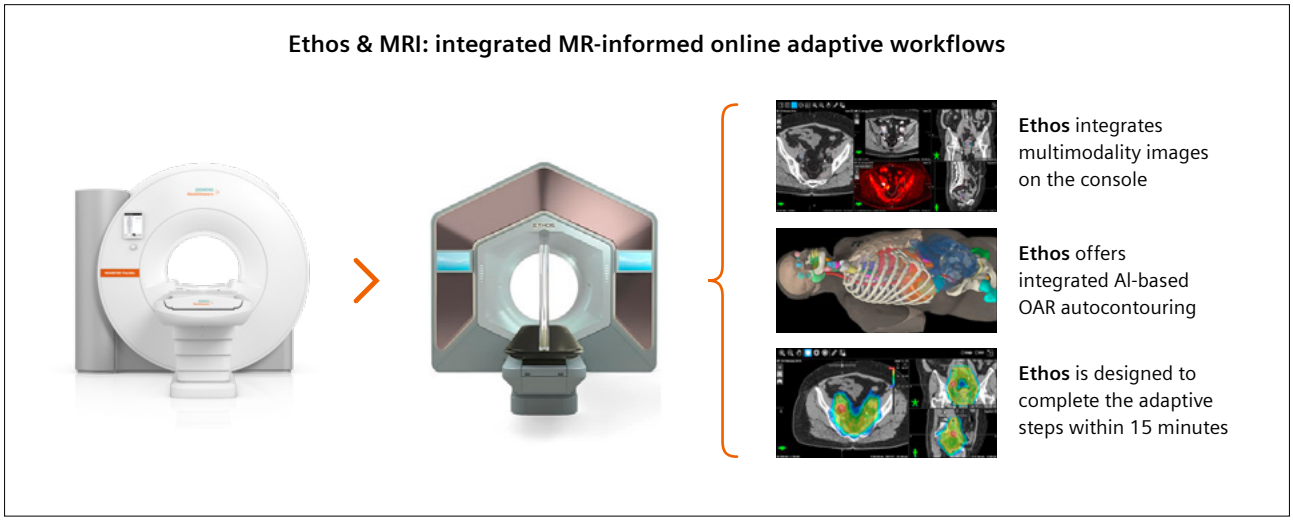


10 MRI of the prostate, with a high-dose-rate brachytherapy boost of 15 Gy covering the target (yellow and solid red) and sparing the rectum (yellow).

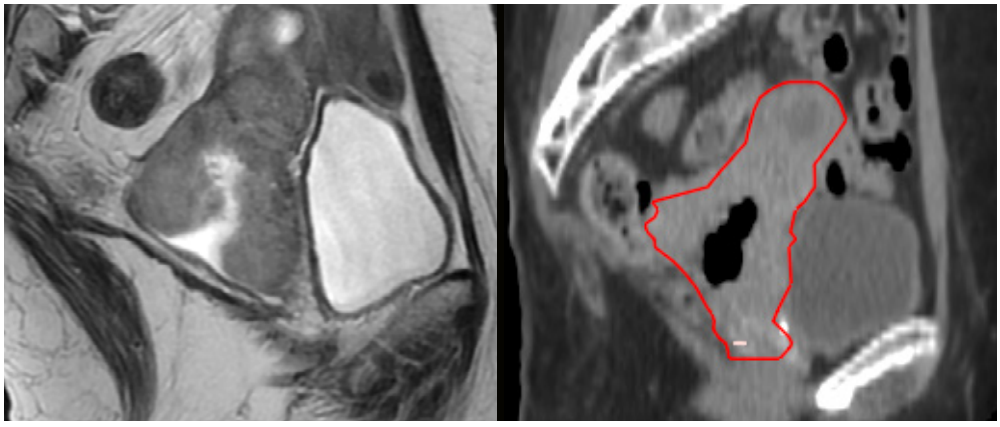
Adaptive radiation therapy

In adaptive RT, the treatment is adapted in response to anatomical changes during the course of RT. Adaptation while the patient is still on the treatment couch is called online adaptive RT(oART). If the adaptation is done in between fractions, it is called offline adaptive RT.

Ethos (Varian, a Siemens Healthineers Company, Palo Alto, CA, USA) is an online adaptive technology. Recent integration of state-of-the-art HyperSight imaging (Varian, a Siemens Healthineers Company, Palo Alto, CA, USA) has opened up significant scope to include MRI in the workflow (Fig. 11). Since HyperSight has excellent soft tissue contrast and can be used for dose calculation, it could enhance online adaptation through an efficient MRI-CBCT workflow. Weekly MRI using fusion with HyperSight CBCT can be used to adjust the contouring in diseases like brain tumors, cervical cancer, and rectal cancer, as significant changes can occur during the course of radiation. This makes it possible to combine the efficiency of Ethos for oART with MR-based volumes for adaptation. The same concept can also be used for offline adaptive RT using TrueBeam. During the course of RT in certain cancers such as cervical cancer, tumor volumes can regress by as much as 60%–80% during EBRT. Integrating weekly MRI scans can help us treat to reduced margins and thus improve therapeutic ratios.



11 Dedicated MRI for RT. Generate and MR image for potential treatment adaption and send to Ethos. This Workflow is applicable to all RT Pro Editions (1.5T MAGNETOM Sola, 3T MAGNETOM Vida, and 0.55T MAGNETOM Free.Max RT).



12 The difference between MRI and CT imaging in cervical cancer, and how MRI helps with contouring.

Conclusion

The role that MRI plays in radiation oncology will continue to grow as we move toward precision and personalized care. It helps to define targets and OARs for treatment planning, boosts volume definition, and enables early assessment for response and online adaptive RT. Ongoing studies are conducting MRI scans throughout the course of RT to enable adaptive EBRT for CBCT-based linear accelerators, to establish the impact on patient outcomes. Incorporating MRI into adaptive workflows for disease sites where we expect to see changes in the target volume (anatomical and/or functional) during RT can potentially help us improve therapeutic ratios, either by reducing the margins or changing the prescription dose. An MR-only workflow also obviates the need for a CT scan, even in adaptive workflows. Rapidly expanding AI-based MRI autosegmentation will also help with efficiency and with incorporating this technology into practice.

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Contact

Sushil Beriwal, M.D., MBA, FASTRO, FABS, FICRO, FACRO
Varian, a Siemens Healthineers Company
801 Pennsylvania Avenue
Washington, DC
USA
Sushil.beriwal@varian.com

Deepak Khuntia, M.D., FASTRO
Varian, a Siemens Healthineers Company
3100 Hansen Way
Palo Alto, CA
USA
Deepak.khuntia@varian.com

Clinical Implementation of 0.55T MRI Simulation for Stereotactic Radiotherapy Using the MAGNETOM Free.Max RT Edition

Joshua Kim, Anthony Doemer, Adina Fratila, Robert Rusnac, Mira Shah, M. Salim Siddiqui, Benjamin Movsas, Kundan Thind

Department of Radiation Oncology, Henry Ford Health, Detroit, MI, USA

Stereotactic radiotherapy (SRT) is a treatment strategy that aims to maximize the biological effectiveness of treatment by delivering a high dose in a few (1–5) fractions. SRT is used in the intracranial treatment of malignant tumors such as brain metastases, of benign tumors such as vestibular schwannomas and acoustic neuromas, and of functional diseases such as trigeminal neuralgia. In order to minimize dose to healthy brain and other nearby radiosensitive organs at risk (OARs), margins of only 0–1 mm around the contoured gross target volume (GTV) are used to define the planning target volume (PTV), and a more heterogeneous dose is allowed within the target in order to achieve rapid dose falloff at the edges. Consequently, very high precision is required for the delineation of the target and OARs, and for patient setup in order to ensure accurate treatment delivery. For contouring, it is essential to have high-quality images that provide high spatial resolution over the full brain and superior soft tissue contrast to be able to distinguish the soft tissue structures within the brain. For this reason, MRI has been the standard for target volume and OAR contouring for SRT. It has been used as an adjunct to CT imaging, with the MR images rigidly registered to the treatment planning CT and used for contouring while the CT image set is used for dose calculation and patient setup at the machine.

While MRI is essential for the contouring of targets and OARs, care must be taken in the selection of imaging sequences used for this task. High-resolution 3D imaging sequences best meet the needs of SRT because they provide high isotropic spatial resolution and are less susceptible to distortions arising from B_0 inhomogeneity [1]. High isotropic resolution is important for avoiding inaccurately contouring the extent of the tumor due to partial volume effect from the larger slice thicknesses and to an added slice gap typically seen in 2D image acquisition sequences [2, 3]. Higher field strengths (1.5–3T) have typically been used for MR simulation. These have allowed for images with a high signal-to-noise ratio (SNR) that is adequate for the needs of SRT while minimizing the scan time for patients. With the recent introduction of the 0.55T MAGNETOM Free.Max RT Edition (Siemens Shenzhen Magnetic Resonance Ltd., Shenzhen, China) for MR simulation, we aimed to establish whether lower field simulation can provide adequate SNR for patients within a reasonable time frame.

Patient scanning and workflow

All volunteers and patients were scanned as part of a study – approved by the Institutional Review Board (IRB) – that focused on workflow and scanning protocol optimization for the MAGNETOM Free.Max RT Edition. For patient scanning, MR simulation was performed immediately following CT simulation, which was facilitated by the MRI scanner's location adjacent to the CT simulation room. To maximize SNR on the 0.55T system, patients were scanned using the standard Head/Neck coil from Siemens Healthineers, with the head immobilized using standard techniques (e.g., thermoplastic mask interface, headphones, padding as needed). A key objective was patient tolerance and minimizing motion artifacts. Therefore, our goal was to keep the scan times of individual clinically necessary sequences to between 6 and 8 minutes, and the total protocol time to under 30 minutes.

Sequence optimization

Clinical MR scans required by physicians for SRT at our institution consist of pre- and post-contrast 3D T1-weighted acquisitions, a T2-weighted acquisition, and a T2 fluid-attenuated inversion recovery (T2 FLAIR) acquisition. Sequence optimization was performed through volunteer and initial patient scanning.

T1-weighted imaging

High-resolution 3D imaging covering the whole brain is needed for contouring lesions and OARs such as the optic nerves [4, 5]. Gradient echo sequences like T1-MPRAGE are commonly used at higher field strengths. On the 0.55T MAGNETOM Free.Max RT Edition, initial testing showed

that the SNR for T1w MPRAGE was insufficient for SRT contouring needs without extending the scan time beyond 10 minutes or increasing voxel size unacceptably. We evaluated alternative 3D sequences: T1 FLASH (gradient echo) and T1 SPACE (turbo spin echo, TSE). Both provided sufficient SNR. However, the T1 SPACE images exhibited excessive smoothing, which was perceived as an undesirable texture and attributed to the high compressed sensing (CS) factor required to achieve acceptable scan times. Reducing the CS factor resulted in prohibitively long scans. The 3D T1 FLASH sequence provided a good balance of improved SNR over MPRAGE at 0.55T, and clinically acceptable scan times (under 7 minutes). While gray-white matter contrast was lower than typical high-field MPRAGE, this was not deemed a concern for radiotherapy contouring purposes.

T2-weighted imaging

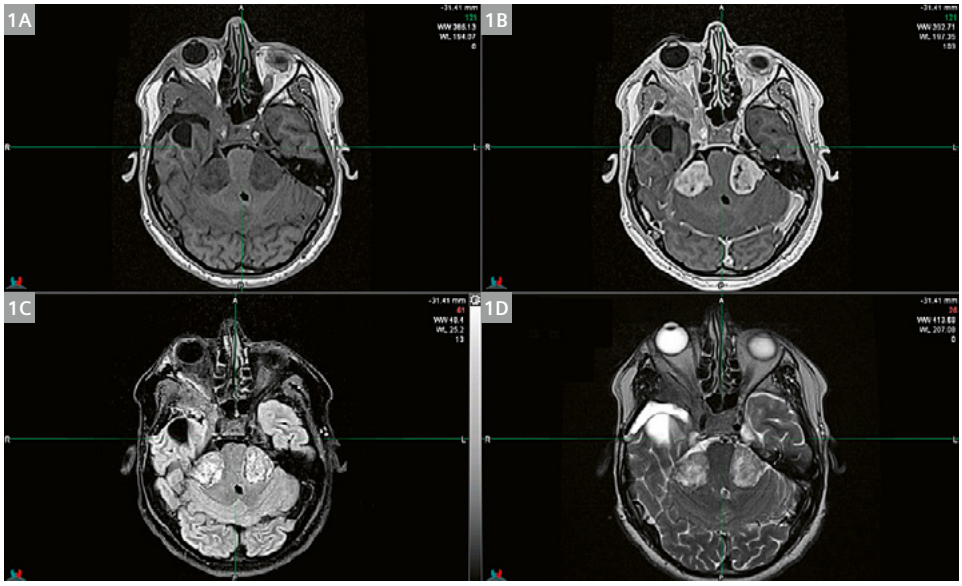
This is used for delineating excision cavities, nonenhancing lesions, and OARs like the cochlea [5, 6]. A 2D TSE sequence provided adequate image quality for physicians' needs. A slice thickness of 4 mm was used, but activating the RT planning add-on allowed for a -50% slice gap, yielding an effective slice spacing of 2 mm for planning.

T2 FLAIR imaging

This is used for contouring vasogenic edema, infiltrating tumor, and defining OAR boundaries like the brainstem [7, 8]. A 3D SPACE sequence was optimized. Sufficient image quality was achieved after adjusting the CS factor to 2.5. The resulting scan time was approximately 9 minutes, which was longer than other sequences but deemed acceptable within the overall protocol time.

Final imaging protocol and contrast administration

For patient scans, the precontrast T1 FLASH and T2 TSE sequences are acquired first. Gadolinium-based contrast agent is then administered. The T2 FLAIR sequence is acquired immediately after injection, allowing time for contrast uptake during this scan. Approximately 10–15 minutes after contrast injection (following contrast-agent manufacturer recommendations), the postcontrast 3D T1 FLASH scan is acquired. Figure 1 displays example images acquired using this protocol for a patient with bilateral vestibular schwannomas and a right-sided meningioma abutting the right optic nerve.



1 **(1A)** Pre-contrast T1 FLASH, **(1B)** post-contrast T1 FLASH, **(1C)** T2 FLAIR, **(1D)** T2 TSE.

	TR (ms)	TE (ms)	α (°)	Acquisition matrix* (mm²)	FOV (mm²)	Slice thickness (mm)	TA (min)
3D T1 FLASH	9.36	3.44	120	180 × 224	198 × 246	1	6:57
Axial T2	11710	115	120	240 × 240	230 × 230	4**	6:38
T2 FLAIR	5000	237	150	256 × 256	256 × 256	2	9:05

Table 1: Imaging protocol
* Interpolation used to provide double the acquisition matrix resolution.
** -50% slice gap in RT mode used for an equivalent slice thickness of 2 mm.

Results

In total, 46 patients requiring SRT planning have been successfully scanned using the optimized brain protocol on the 0.55T MAGNETOM Free.Max RT Edition at our institution. The resulting images consistently provided SNR and spatial resolution deemed sufficient by the treating radiation oncologists for the critical contouring needs of SRT. While individual sequence scan times required adjustments and optimization compared to typical high-field protocols, the total routine clinical protocol scanning time was reliably completed in less than 30 minutes.

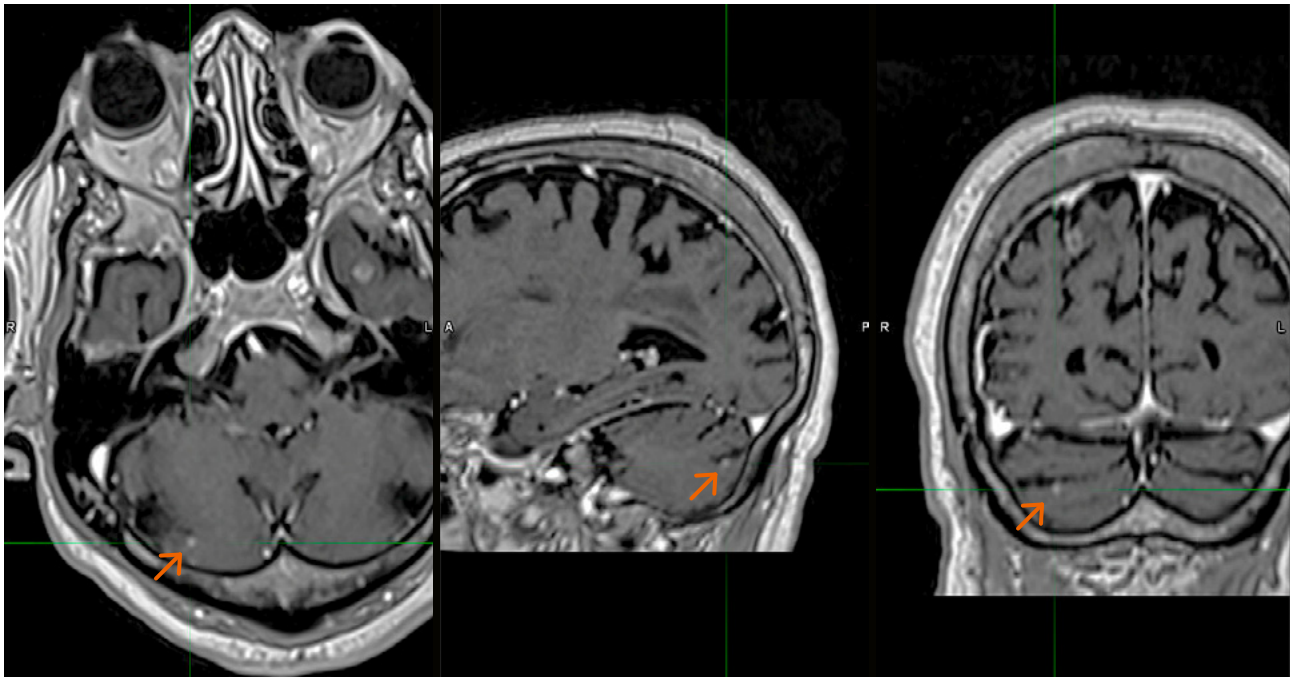
The image quality achieved proved clinically impactful: In one patient scanned for multiple known targets, an additional metastatic lesion measuring less than 0.03 cc, which had not been clearly identified on prior diagnostic scans, was visualized on the postcontrast 3D T1 FLASH sequence (Fig. 2). This finding allowed for the inclusion of this lesion in the SRT treatment plan.

Discussion

This study demonstrates that the 0.55T MAGNETOM Free.Max RT Edition can produce MRI datasets suitable for the demanding requirements of SRT planning. Through careful sequence selection and optimization, particularly using 3D T1 FLASH and optimized 3D T2 FLAIR SPACE sequences, adequate SNR and spatial resolution were achieved for precise target and OAR delineation.

While individual sequence scan times on the 0.55T system are moderately longer than those typically achieved on 1.5T or 3T scanners for similar resolution, the optimization process resulted in a total clinical protocol time of less than 30 minutes, which is well-tolerated by patients and integrates efficiently into the clinical radiotherapy workflow. The successful identification of a very small, previously uncertain metastatic lesion (Fig. 2) underscores that the image quality is not only adequate but clinically robust for identifying small targets that are critical in SRT.

The viability of using a 0.55T system for MR simulation in SRT has significant implications. It potentially broadens access to high-quality MR simulation for radiotherapy centers that may not have access to high-field MR systems due to the cost or siting constraints associated with higher field strengths. Furthermore, the specific design characteristics of the MAGNETOM Free.Max RT Edition (e.g., its 80 cm bore) offer benefits for patient comfort and setup, although this was not formally assessed in this study. This work shows that despite the inherently lower SNR of low-field MRI, optimization strategies can yield clinically excellent results for advanced applications like SRT.



2 Metastatic lesion (arrow) identified in postcontrast 3D T1 image.

Conclusion

The 0.55T MAGNETOM Free.Max RT Edition, when used with an optimized imaging protocol that includes 3D T1 FLASH and 3D T2 FLAIR SPACE sequences, provides image quality sufficient for target and OAR delineation in stereotactic radiotherapy planning. Total protocol times are clinically acceptable, demonstrating that this low-field MR system is a viable and valuable option for MR simulation in radiotherapy.

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Contact

Joshua Kim, Ph.D.
Director of Imaging Physics
Department of Radiation Oncology
Henry Ford Cancer Institute
2799 W. Grand Blvd
Detroit, MI 48202
USA
Tel.: +1 313.916.2180
jkim8@hfhs.org

MAGNETOM Free.Max Simulator: First Impressions

Aaron M. Allen, M.D.; Hila Rosenfeld, R.T.T.; Nina Shenkman, R.T.T.; Firas Mansour, MR Application Specialist; Sion Koren, Ph.D.

Department of Radiation Oncology, Helmsley Cancer Center, Shaare Zedek Hospital, Jerusalem, Israel

Modern radiotherapy (RT) relies on accurate tumor volume delineation. Utilizing the best imaging has become the standard of care for contouring and simulation. One tool that has entered the standard of care is multiparametric MR imaging (MRI) for routine RT planning. Today, nearly every case of definitive central nervous system (CNS) tumors or prostate cancer uses MRI for RT planning.

Of the clinics that use MRI for planning, many still rely on diagnostic MRI obtained either prior to CT simulation or in parallel to simulation, and then fuse the images for the purposes of contouring MR-based anatomy. However, in recent years, the use of MRI simulators with a dedicated RT setup, workflow, and positioning devices has proven superior to the use of fused diagnostic images [1]. There are a number of reasons for this, including the acquisition

1 Patient simulated on MAGNETOM Free.Max with a custom MRI-compatible thermoplastic mask and a head coil.

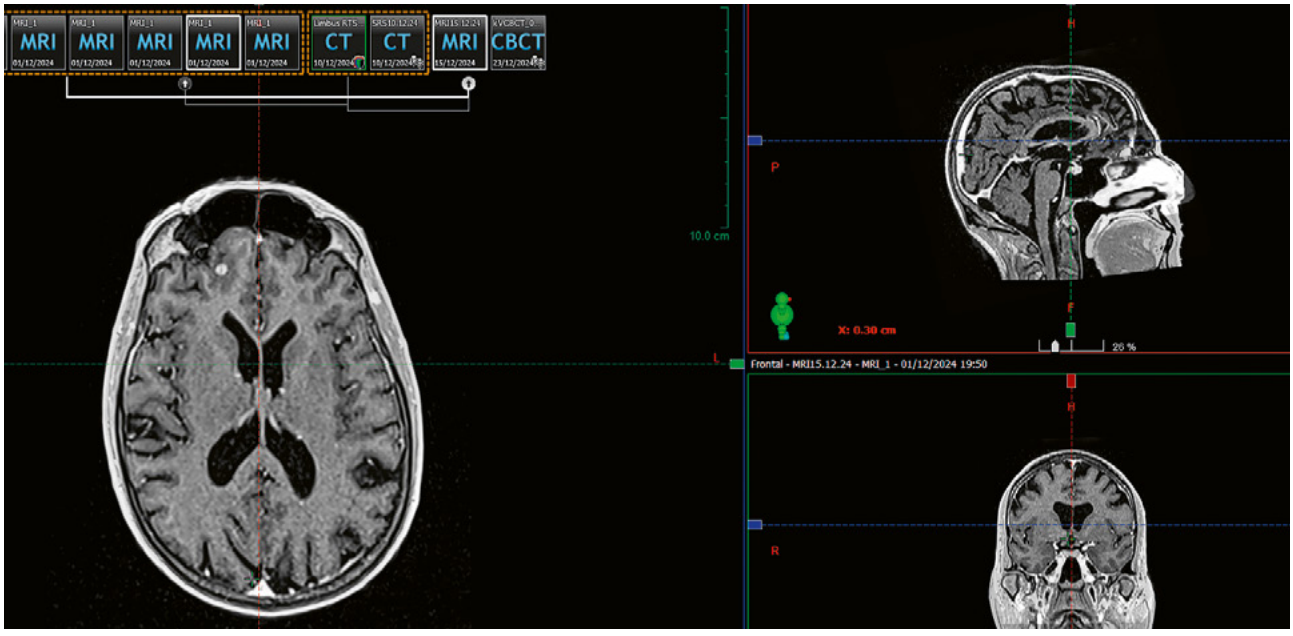
of images with an RT-standard flat tabletop and the ability to scan the patient with RT positioning devices such as thermoplastic masks, wing boards, and abdominal compression. In addition, the choice of imaging sequences for RT simulation purposes is often different to those needed for diagnostic imaging. Finally, synthetic CT produced by MRI simulators can obviate the need for CT simulation, saving the patient and the department additional time and procedures.

In 2023, our institution decided to acquire an MRI simulator and we were tasked with choosing the best vendor and solution to meet our clinical and departmental needs. We reviewed the options in the market and the various vendors. We chose to acquire a novel product from Siemens Healthineers: the 0.55T MAGNETOM Free.Max RT Edition (Siemens Healthineers, Erlangen, Germany). Several factors led to this decision. First, the smaller footprint and helium-free magnet without the need for a quench pipe matched the space and design of our department and made installation and start of clinical work much easier and quicker. Second, the 80 cm large bore would allow us to scan all RT patients (even breast cancer patients) in the same position as they would be in for treatment on our linacs. Finally, we were impressed with the examples of image quality shown on MAGNETOM Free.Max diagnostic systems and were convinced it would be a significant addition to our RT planning environment. Our institution has multiple higher field MRI systems for diagnostic purposes, and the lower cost of the MAGNETOM Free.Max system would enable us to fully dedicate this system to RT planning without the need to share it with diagnostic radiology.

In September 2024, we completed installation and commissioning of the MAGNETOM Free.Max RT Edition in our department and began clinical use. This was the first installation worldwide. Our institutional plan was to begin using it with CNS patients (with brain metastases) and prostate patients, who would also undergo diagnostic imaging, and then compare the MAGNETOM Free.Max images with the diagnostic images, as well as the time and the use of RT immobilization devices and coils. Below, we detail some of the clinical examples and results from these early patients.

Central nervous system patients

Patients were simulated with a thermoplastic mask (Klarity Medical, Heath, OH, USA) and connected to the custom head rest. The scan was performed with a specialized head coil (Fig. 1). The patients chosen for the initial planning scans were patients with brain metastases set to undergo stereotactic radiosurgery. Again, nearly all of these patients underwent a diagnostic scan to detect the disease; however, the utility of MRI simulation in these patients was the ability to obtain recent MR images within one to two days of treatment in the same orientation and immobilization as the CT simulation.



2 Sample of an axial T1 post-gadolinium scan obtained on the MAGNETOM Free.Max system and loaded into the Eclipse treatment planning software (Varian, a Siemens Healthineers Company, Palo Alto, CA, USA).

The CNS patients had a single sequence: a T1 3D gradient echo sequence in the axial plane with injection of contrast medium prior to scanning. The average acquisition time of this scan is 12 minutes. The following parameters were used (Table 1).

One of the patients treated is shown in Figure 2. This patient had non-small cell lung cancer and was sent to the department for stereotactic radiosurgery.

CNS sequence parameters	
FOV read	245 mm
FOV phase	80%
TR	9.44 ms
TE	3.50 ms
Matrix	224
Voxel size	0.5 × 0.5 × 1 mm
Number of excitations	3
Phase encoding direction	L>R
Bandwidth	130 Hz/Px
Scan time	11 min

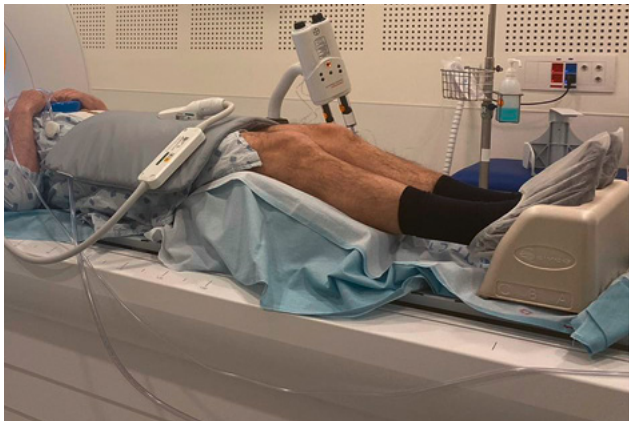
Table 1: CNS sequence parameters.

Genitourinary patients

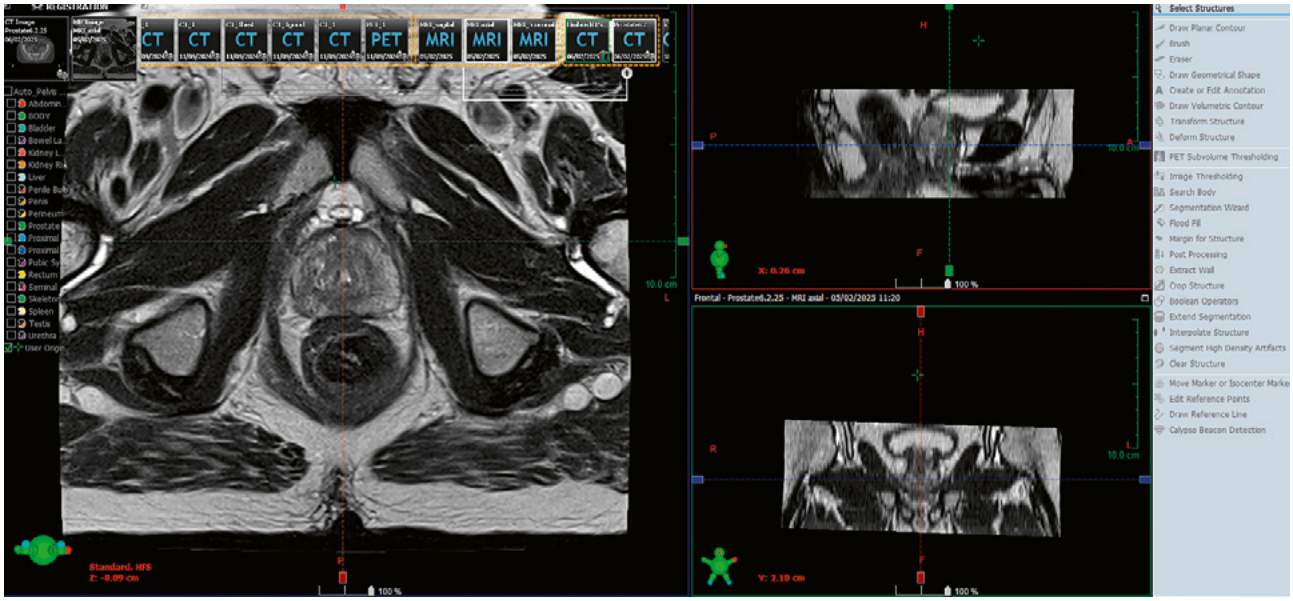
Patients with prostate cancer also underwent diagnostic MRI at diagnosis. After the decision to treat with RT, patients selected for stereotactic radiotherapy underwent gold seed placement and/or spacer insertion under ultrasound guidance. The patients then underwent CT simulation as well as MRI simulation.

For MRI simulation, patients were placed supine with knee rests and ankle immobilization as shown in Figure 3. Patients were scanned with T2-weighed imaging in three planes (axial, sagittal, and coronal). The entire procedure took an average of 20–25 minutes.

A representative case is shown in Figure 4.



3 Patient setup for prostate cancer. Patient supine with knee and ankle support, and pelvic coil.



4 Example of a patient with prostate cancer simulated on MAGNETOM Free.Max with a T2 axial scan, loaded into the Eclipse treatment planning software (Varian, a Siemens Healthineers Company, Palo Alto, CA, USA).

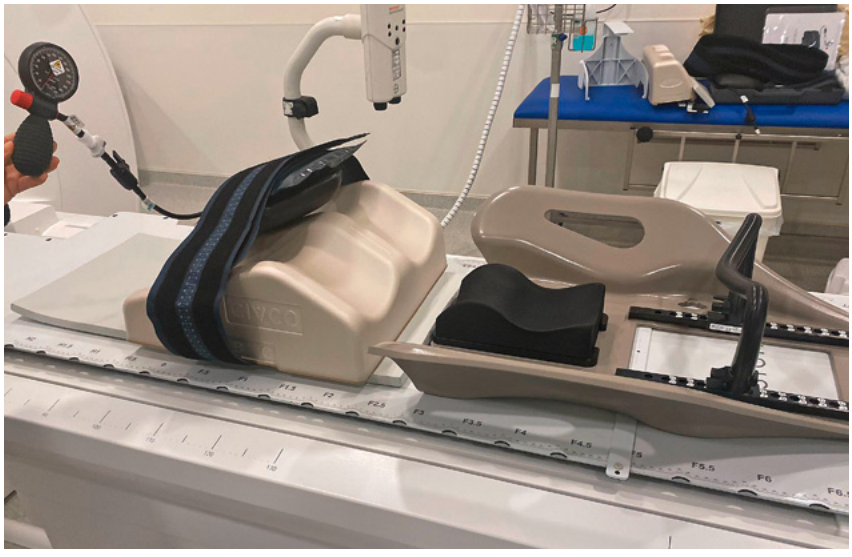
Sequence	Axial T2 TSE	Coronal T2 TSE	Sagittal T2 TSE	T1 VIBE Dixon
TR	3100 ms	3100 ms	6200 ms	9.74 ms
TE	83 ms	83 ms	83 ms	2.6 ms
Field of view	220 mm	220 mm	220 mm	400 mm
Slice thickness	3 mm	3 mm	28 mm	3 mm
Gap	0	0	0	20%
Averages/NEX	7	8	7	1
Phase encoding direction	R>L	R>L	A>P	A>P
Phase oversampling	200	200	160	0 Slice oversampling 11%
Base resolution	256	256	256	192
Voxel size	0.4 × 0.4 × 3 mm	0.4 × 0.4 × 3 mm	0.4 × 0.4 × 3 mm	1 × 1 × 3 mm
Bandwidth	155 Hz/Px	155 Hz/Px	155 Hz/Px	330 Hz/Px
Scan time	5 min	5 min	5:50 min	18 sec

Table 2: Sequence parameters.

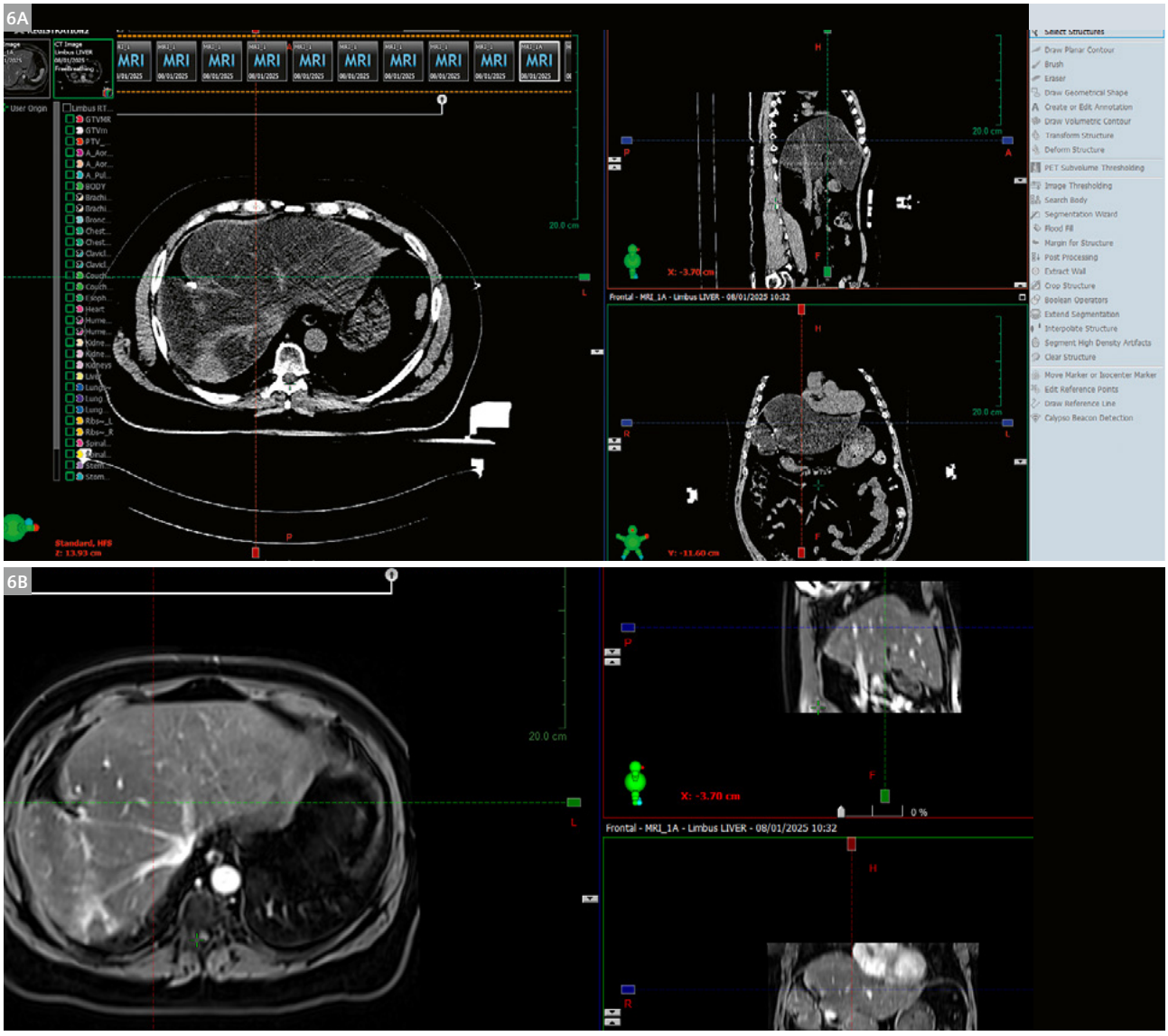
Liver

Many patients scheduled for liver-directed RT did not (unlike the brain metastases or prostate cancer patients) have a diagnostic MRI prior to RT planning. This was especially true for patients with colorectal liver metastases, who are traditionally imaged with CT and PET/CT imaging. For these patients, it was the availability of MRI within the department that prompted the additional simulation. For these patients, images were generated supine with arms raised and immobilized with a WingSTEP device (IT-V, Innsbruck, Austria). Again, the large bore of the MRI simulator enabled this positioning comfortably for all patients. In addition, since our departmental standard for stereotactic radiotherapy to the liver includes abdominal compression, we also used an abdominal compression device when scanning liver patients. An example of the setup is shown in Figure 5.

For liver patients, we used T1 VIBE Dixon sequences and T2 STIR with and without contrast media injection. These studies took an average of 30 minutes of scanning time.



5 Setup design for simulation of abdominal (liver) patient. This includes the WingSTEP device and an abdominal compression belt.



6 Example of a patient with colon cancer metastases to the liver simulated on MAGNETOM Free.Max, with **(6A)** CT images, and **(6B)** T1 VIBE Dixon postcontrast loaded into the Eclipse treatment planning software (Varian, a Siemens Healthineers Company, Palo Alto, CA, USA).

A representative image of a patient with colorectal liver metastases can be seen in Figure 6. In these cases, the definition of the lesion was much improved compared to CT simulation and PET/CT fusion.

Contact

Professor Aaron Allen
Chairman
Department of Radiation Oncology
Shaare Zedek Medical Center
PO Box 3235
Jerusalem 9103102
Israel
Tel.: 972-2-6649851
aaronal@szmc.org.il

In summary, the 0.55T MAGNETOM Free.Max RT Edition provides a novel tool to assist in RT planning. This article describes the first patients worldwide scanned with this system. The early results are promising, but much work will be needed to improve the protocols and procedures, and to determine the overall clinical effect.

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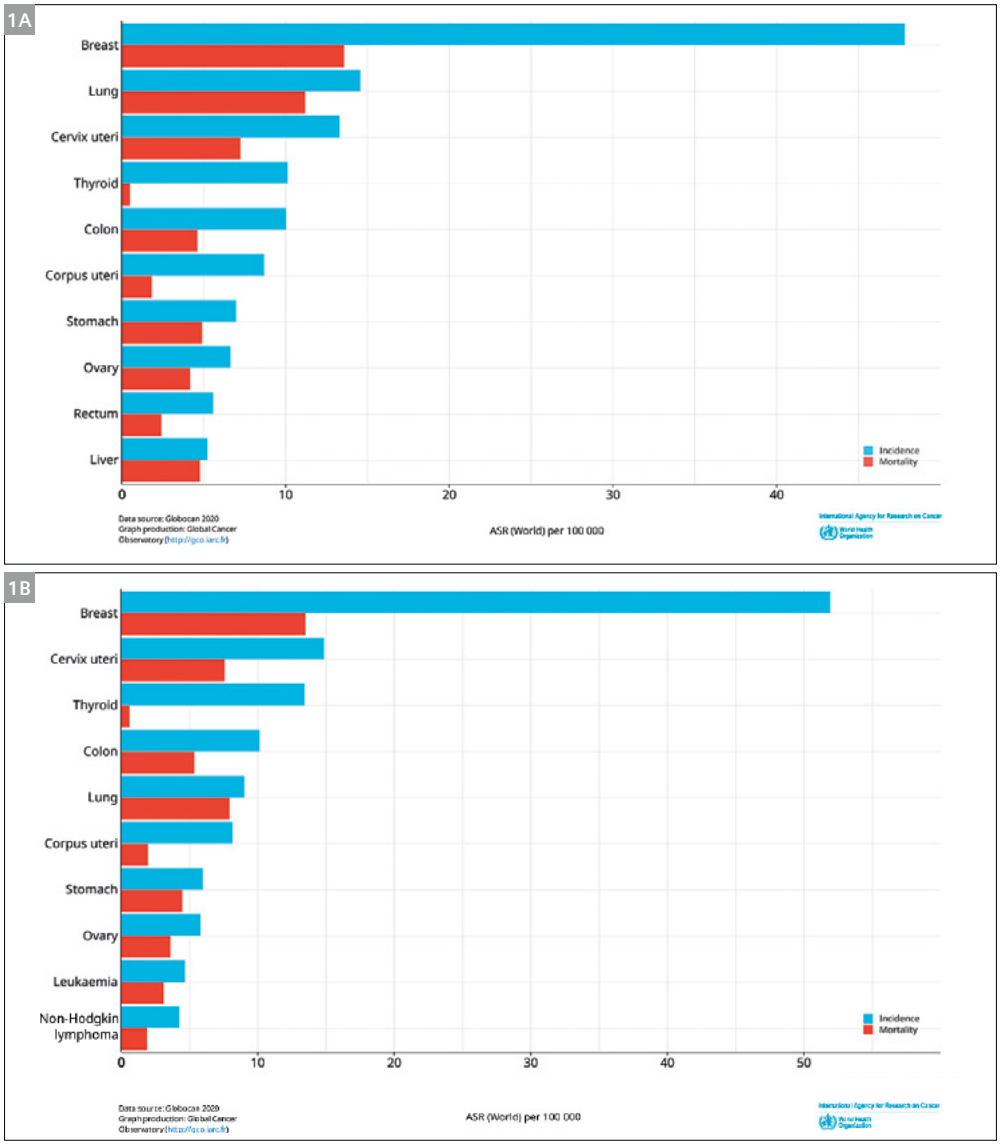
MRI-Guided Adaptive Brachytherapy in Cervical Cancer

Ricardo Ruggeri, M.Sc. Medical Physicist

Technical Director, Department Head, and Director of the Medical Physics Residency at the Centro Oncológico Integral of Leben Salud, Patagonia, Argentina

Introduction

Cervical cancer is a significant public and private health challenge in Latin America, where it ranks second in incidence and mortality among female cancers. Globally, it is the third most common cancer in women, with a significant burden in middle- and low-income countries [1]. The high incidence in the Latin America region highlights the need for advanced treatment strategies, such as image-guided adaptive brachytherapy (IGABT).



1 **(1A)** Estimated age-standardized incidence and mortality rates (World) in 2020, worldwide, females, all ages (excl. NMSC). **(1B)** Estimated age-standardized incidence and mortality rates (World) in 2020, Latin America and the Caribbean, females, all ages (excl. NMSC).

In Argentine Patagonia, the increasing demand for cancer treatments has posed logistical and clinical challenges. To ensure that 100% of patients have access to IGABT with the highest quality standards, the Centro Oncológico Integral (COI) at Leben Salud has developed a model for optimizing technological, IT, and human resources. This has enabled us to provide effective treatment that is aligned with the principles of the EMBRACE II protocol [2] and ensures high-precision brachytherapy for all our patients.

Currently, COI manages four to five cases per day, two days a week (Wednesdays and Fridays). This high demand led us to develop an efficient clinical process, where each stage of treatment is carefully planned. The key to ensuring the availability and quality of IGABT is the optimized management of resources, which has enabled maximum efficiency in the use of the MRI scanner, image planning, availability of the medical and technical team, and integration of digital tools for planning and patient follow-up.

Designing a structured workflow was fundamental to this process. The precise definition of schedules for image acquisition and treatment has enabled the efficient use of MRI time, avoiding delays and enabling optimal treatment for each patient. Furthermore, the use of advanced platforms such as *syngo*.via RT Image Suite (Siemens Healthineers, Forchheim, Germany) has allowed seamless integration of MR images into medical contouring, facilitating simultaneous visualization of sequences and automatic extrapolation of structures. This means that each patient receives an individualized and optimized plan in every IGABT session.

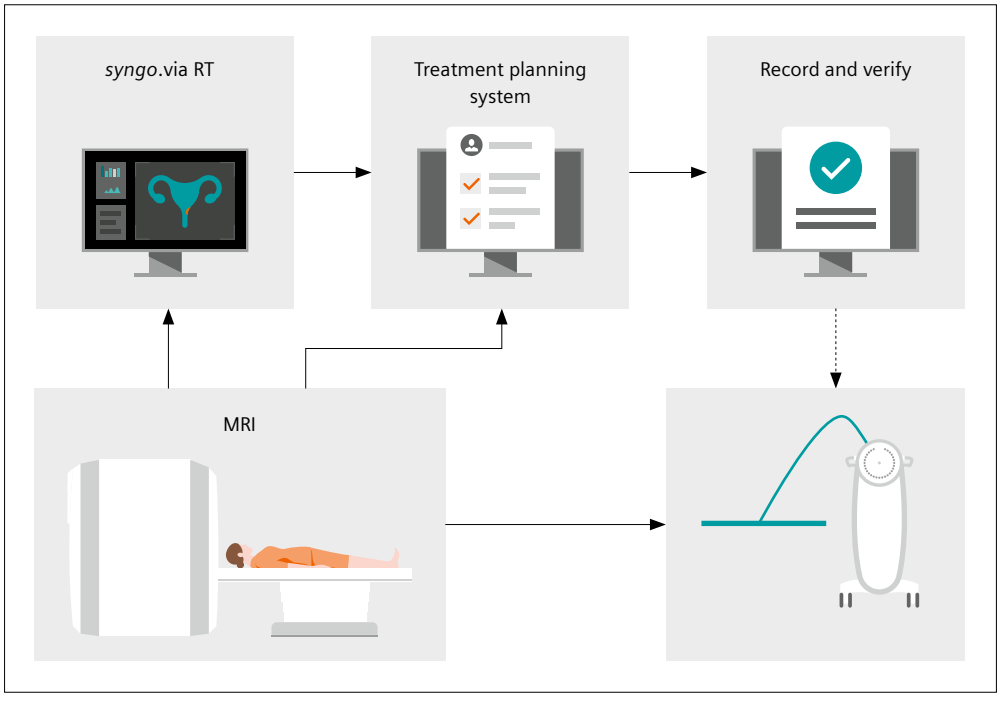
COI has therefore successfully implemented a model that not only meets the high demand for treatment, but also ensures that every patient receives treatment based on international best practices, with daily planning and personalized adaptation in all brachytherapy sessions.

This article details our experience of implementing the technology, the processes designed for resource optimization, and the clinical impact of IGABT in treating cervical cancer.

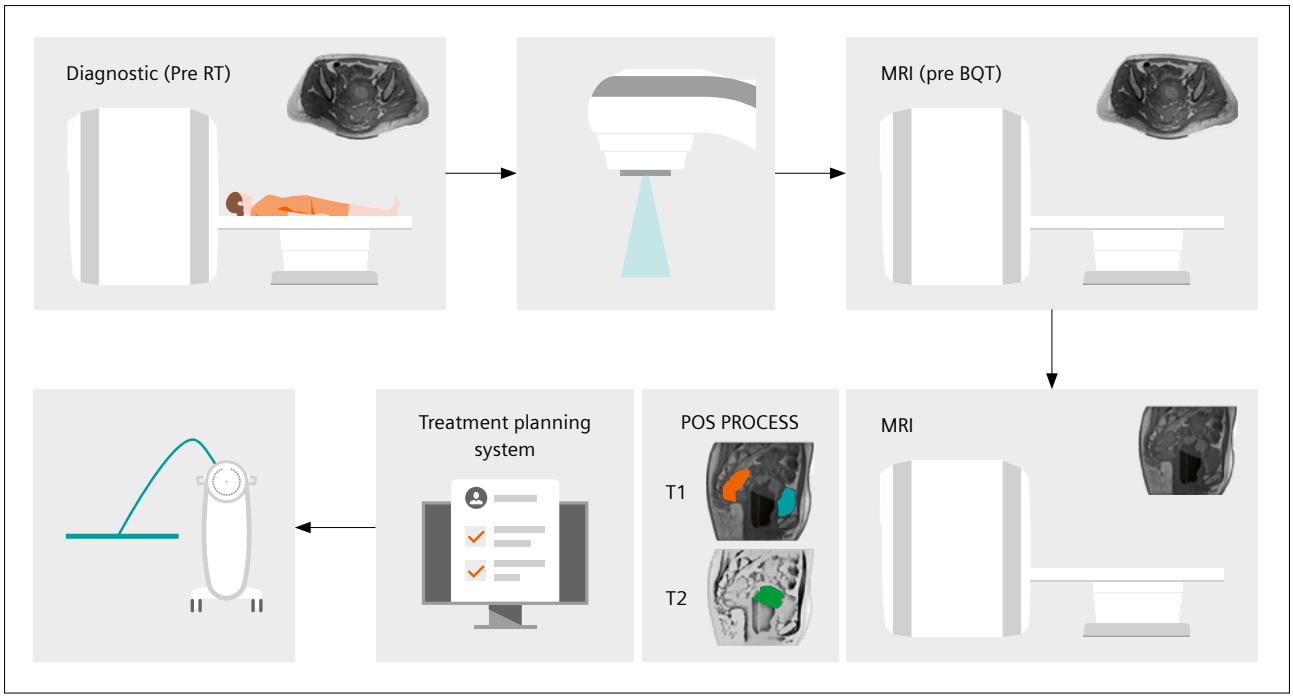
Materials and methods

COI uses an IGABT protocol that follows the guidelines established by EMBRACE II. We optimize each phase of the treatment to achieve precision, safety, and efficiency. Below are the key steps of this process:

1. Image acquisition and pre-brachytherapy planning
Before starting brachytherapy, external radiotherapy is performed with a dose of 46 Gy in daily fractions, followed by a detailed evaluation using pre-brachytherapy magnetic resonance imaging (MRI). This imaging is crucial for evaluating tumor response and determining the IGABT strategy.



2 Simplified MRI brachytherapy workflow with either *syngo*.via RT postprocessing software or a direct connection to the treatment planning system.



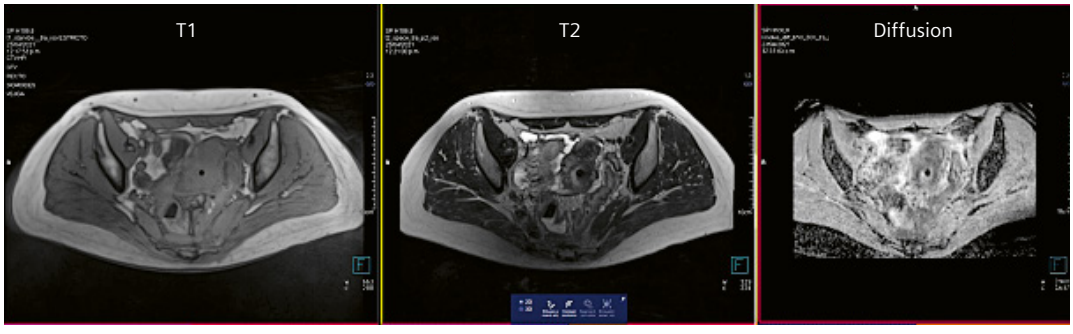
3 IGABT workflow using *syngo*.via RT post-processing software. RT = radiotherapy; BQT = brachytherapy; POS PROCESS = post-processing.

For image acquisition, the 3T MAGNETOM Skyra system (Siemens Healthineers, Erlangen, Germany) is used.
The following sequences are applied to ensure complete characterization of the lesion:

- T1-weighted: For the precise delineation of organs at risk (bladder, rectum, and sigmoid colon).
- T2-weighted: To precisely define the high-risk clinical target volume (CTV-HR).
- Diffusion-weighted imaging and ADC maps: To identify the macroscopic GTV.

2. Use of *syngo*.via RT Image Suite for contouring
Once the MR images have been acquired, they are integrated into the *syngo*.via RT Image Suite platform. This tool enables simultaneous visualization of all sequences, facilitating precise contouring of relevant anatomical structures.

- The radiation oncologist contours each structure on the sequence where it is best visualized.
- The software automatically extrapolates the contours to the other sequences, allowing real-time optimization of anatomical segmentation.
- The T1-weighted sequence, with all contoured structures, is then exported to the brachytherapy planning system.



4 Examples of T1, T2, and diffusion-weighted sequences used for contouring of OARs, CTVs, and GTVs, respectively.

3. IGABT implementation with daily planning
IGABT is performed in three sessions with 8 Gy administered per session, ensuring optimal personalization of the treatment. The following happens in each session:

- A new MRI scan is performed with the same sequences used in the prebrachytherapy phase.
- New contouring of anatomical structures is performed in *syngo*.via RT Image Suite.
- A new dose plan is generated, adjusting the distribution according to the anatomical evolution of the tumor and organs at risk.
- The plan is exported to the brachytherapy treatment system, ensuring maximum precision in dose delivery.

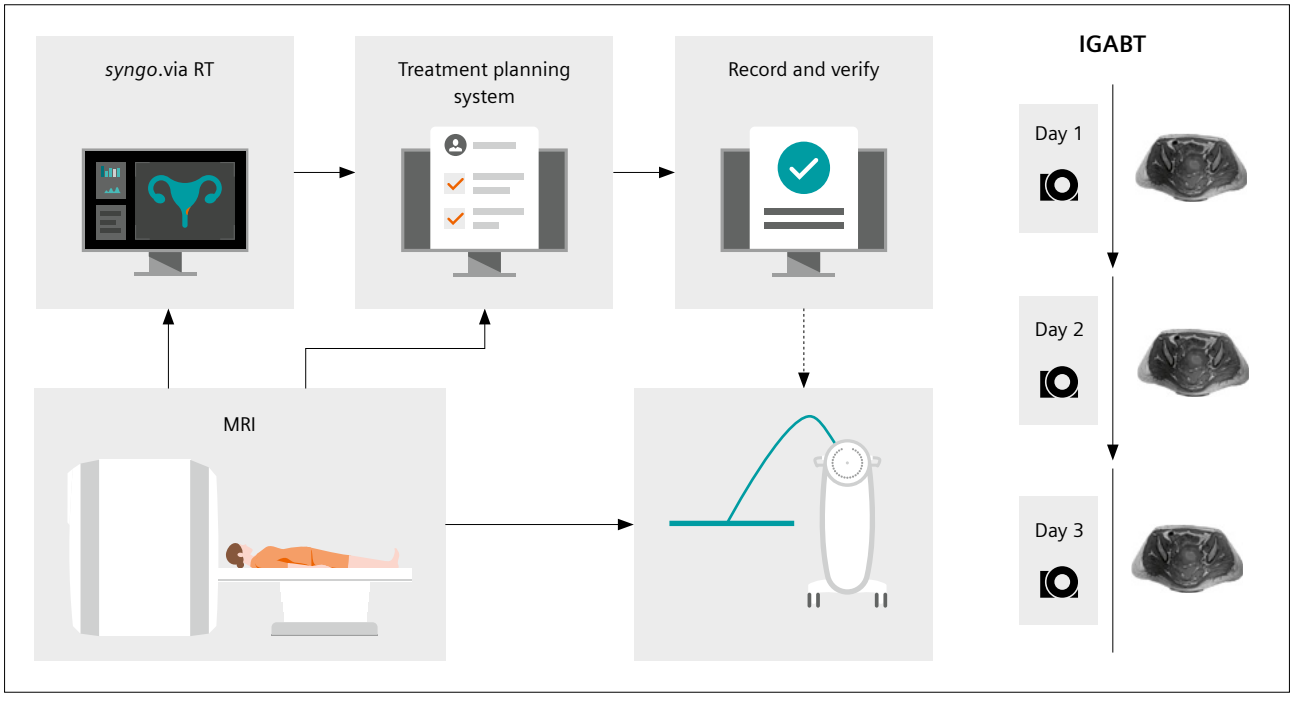
4. Post-brachytherapy follow-up
After treatment completion, patients continue with a rigorous follow-up, which includes the following:

- Post-brachytherapy MRI evaluation to analyze tumor response and detect possible adverse effects.
- Periodic medical check-ups to assess clinical progress.
- Symptom questionnaires based on the Common Terminology Criteria for Adverse Events (CTCAE), with electronic patient report outcome tools allowing detailed monitoring and better management of toxicity.

5. Workflow optimization and resource management
With *syngo*.via RT Image Suite, we have been able to optimize our human resources to increase our service productivity: While the second patient undergoes image acquisition in the 3T MRI scanner, the first patient is already being planned, so the treatment planning system can be used exclusively for dosimetry.

Traditionally, contouring was done in the planning system, which created a bottleneck because the physicist could not plan while the physician was contouring and vice versa. The improved workflow enables us to manage two brachytherapy treatment processes simultaneously, with minimal time lag between them, which eliminates downtime and optimizes IT and human resources without overloading them.

Additionally, an MRI-compatible patient transport system was designed in-house to ensure safe transfer to the scanner without affecting the position of the brachytherapy applicator. This system has drastically reduced procedure times, improving both patient safety and comfort.



5 Daily image acquisition steps for IGABT implementation.

6 A hands-on system for mobilization of brachytherapy patients. The system is used to transfer patients who have an applicator in place. It allows up to three patients to enter the workflow simultaneously.

Discussion

Implementing IGABT using the 3T MAGNETOM Skyra system and *syngo*.via RT Image Suite has substantially optimized brachytherapy treatments at COI. The combination of these tools has made dose delivery more precise, reduced toxicity, and enabled an efficient workflow. As a result, we can treat a high volume of patients without compromising quality.

1. Impact on dosimetric precision and toxicity reduction
Using MRI in every IGABT session has been crucial for accurately defining the tumor and organs at risk. Traditionally, brachytherapy based on a single 3D scan had limitations when it came to assessing tumor evolution and adapting dose distribution. Our protocol involves the following:

- A T1w sequence is used to precisely define organs at risk (bladder, rectum, and sigmoid colon).
- A T2w sequence is used to delineate the CTV-HR.
- Diffusion-weighted imaging (DWI) and ADC maps facilitate identification of the macroscopic GTV.

A study of 60 patients demonstrated that planning based on a single 3D scan does not allow treatment adaptation to anatomical changes occurring between sessions. The findings showed the following:

- 40% of cases required planning adjustments after MRI evaluation.
- 66% of cases presented dosimetric variations within 3% in CTV-HR, reflecting the stability of the adaptive method.
- In non-adaptive treatments, 28% of cases showed underdosing in CTV-HR, which could affect therapeutic outcomes.
- Up to 36% of cases showed overdosing in the bladder, 23% in the rectum, and 26% in the sigmoid colon, increasing the risk of toxicity.

Additionally, the study identified that applicator changes between sessions (only possible with IGABT) were necessary in 25% of patients. These changes avoid suboptimal treatment geometry.

2. Workflow optimization and service efficiency
One of the greatest achievements has been the ability to treat multiple patients in parallel without causing clinical delays or reducing treatment quality. This was made possible by:

- *syngo*.via RT Image Suite, which allows contouring to be performed while the next patient undergoes image acquisition.
- Decentralization of contouring and dosimetric planning, which prevents bottlenecks in the planning system.
- Development of an MRI-compatible patient transport system, which allows patients to be transferred to the scanner without moving the brachytherapy applicator, ensuring safety and speed.

3. Clinical benefits and future perspectives

As well as allowing us to meet regional demand, our IGABT model has also improved treatment quality compared to conventional methods. The key clinical benefits include:

- Greater personalization of treatment, with dynamic adjustments in each session.
- Increased patient safety and comfort thanks to the structured design of the workflow.
- Better monitoring of tumor response, enabling real-time assessment of progression using high-quality imaging.

For the future, we aim to continue optimizing the process as follows:

- Incorporate artificial intelligence to automate contouring, reduce planning times and improve reproducibility.
- Develop machine learning-based predictive models that can anticipate tumor response and enable real-time treatment adaptation.

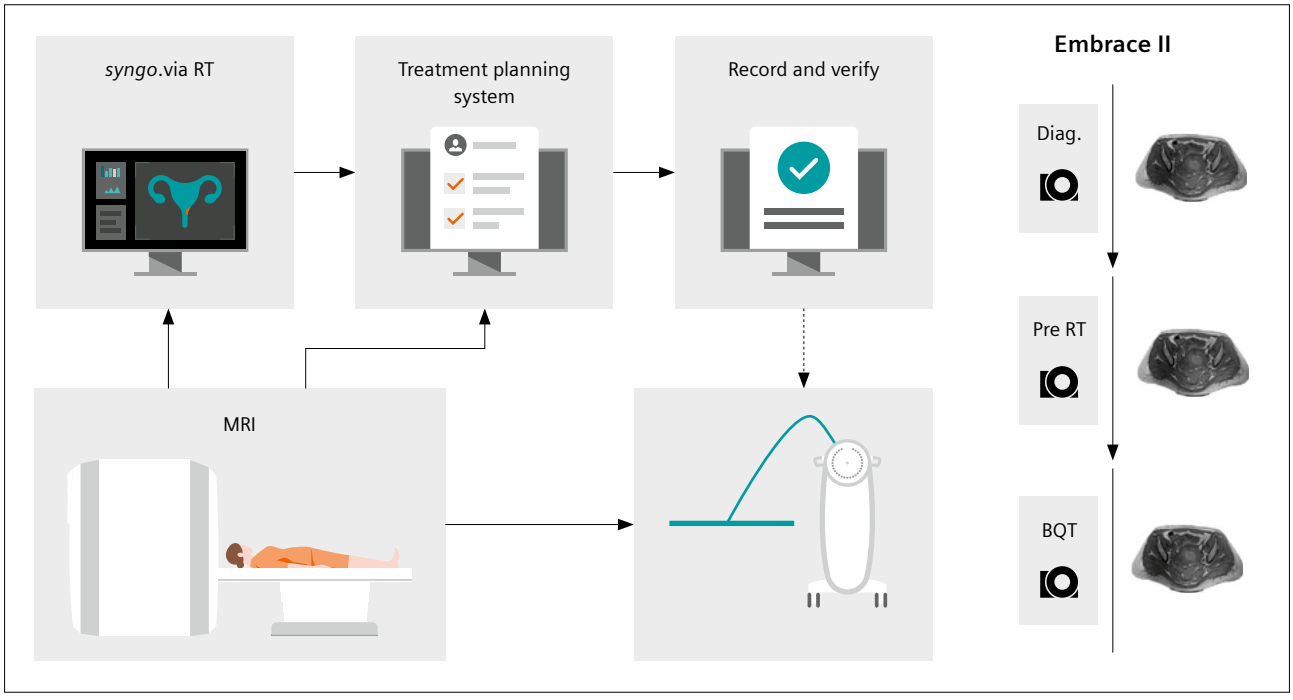
Conclusion

The development and implementation of IGABT with the 3T MAGNETOM Skyra scanner at COI has enabled a qualitative leap in the personalization of cervical cancer treatment. The approach has not only improved dosimetric precision and reduced toxicity in organs at risk; it has also optimized the use of clinical and technological resources, thereby creating an efficient and sustainable model.

1. Advances in personalized treatment

Adaptive planning in each session has proven to be a key factor in improving clinical outcomes. The ability to adjust dose distribution according to anatomical changes has allowed us to:

- Optimize coverage of CTV-HR, ensuring compliance with dose criteria established in EMBRACE II.
- Significantly reduce variability in dose administration, minimizing underdosing in tumors and overdosing in organs at risk.
- Implement dynamic applicator change strategies when clinically required, which prevents suboptimal treatment configurations.



7 Image acquisition steps for the IGABT process to harmonize with the Embrace II protocol. RT = radiotherapy; BQT = brachytherapy.

2. Impact on patient safety and quality of life
Incorporating MRI into each session has enabled better evaluation of tumor relationships with surrounding anatomical structures. This has resulted in:

- Lower toxicity in the bladder, rectum, and sigmoid colon due to more precise dose control.
- Fewer adverse effects associated with conventional brachytherapy, such as ulcerations and telangiectasias in high-dose areas.
- Greater confidence in treatment planning and administration, by reducing the uncertainty associated with a single 3D scan.

3. Optimization of workflow and system efficiency
Standardizing the IGABT process has enabled us to treat a higher volume of patients without compromising treatment quality. The main achievements include:

- Better utilization of MRI time, thanks to synchronization between image acquisition and planning.
- Efficient use of *syngo*.via RT Image Suite, which has decentralized the contouring process and allowed simultaneous planning of multiple patients.
- Reduction of idle times and increased productivity of the multidisciplinary team, allowing up to 30 patients per month to be treated without affecting waiting times or quality of care.

4. Outlook and improvements
The success of the IGABT implementation at COI opens up new opportunities to further optimize cervical cancer treatment. Future areas of work include:

- Automating contouring using artificial intelligence to reduce planning times and standardize results.
- Developing predictive models based on machine learning to anticipate tumor evolution and adjust therapeutic strategies in real time.
- Integrating telemedicine and digital monitoring tools to improve treatment traceability and long-term response evaluation.

Final comments
Implementing IGABT with MRI in each brachytherapy session has transformed the approach to cervical cancer treatment at COI. The model has proven effective in optimizing dosimetry, reducing toxicity, and improving patients' quality of life. Additionally, it has established an efficient workflow that improves accessibility to treatment without compromising quality.

We therefore recommend expanding the model to other oncology centers looking to enhance the precision and effectiveness of gynecological brachytherapy by aligning with the international standards established in EMBRACE II.

Acknowledgments

We are very grateful to the multidisciplinary team at COI for their dedication to the implementation of these advancements, and to the team at Siemens Healthineers for their collaboration on integrating the MRI system into brachytherapy treatment.

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Contact

Ricardo Ruggeri, M.Sc.
Technical Director and
Head of Medical Physics Department
Centro Oncológico Integral (COI),
a member of the Leben Salud group
Industriales Neuquinos 2800
Neuquén, Patagonia
Argentina
rruggeri@lebensalud.com

Whole-Body Evaluation of the Bone using PD-Weighted VIBE Sequences with Deep Learning Reconstruction and Applications in Oncology

Will McGuire[1], Marie Fennessy[1], Elisabeth Weiland[2], Dominik Nickel[2], Anwar R. Padhani[1]

[1]Paul Strickland Scanner Centre, Mount Vernon Hospital, Northwood, Middlesex, UK
[2]Siemens Healthineers, Erlangen, Germany

In the last decade, whole-body MRI (WB-MRI) has been established as a standard diagnostic and treatment-monitoring tool for cancer patients with bone disease [1, 2]. Bone metastases are a common finding in late-stage cancer patients and can be associated with poorer prognosis, treatment resistance, and tumor-related adverse skeletal events, such as fractures, spinal cord compression, and the need for bone radiotherapy.

Standard WB-MRI protocols, as prescribed in the Metastasis Reporting and Data System (MET-RADS) and the Myeloma Response Assessment and Diagnosis System (MY-RADS) [3, 4], focus exclusively on the evaluation of bone marrow involvement, largely because of the inability to visualize the mineralized bone. Thus, WB-MRI has always had the limitation of requiring computed tomography (CT) scans to confidently evaluate the bone structure for surgical interventions and radiation therapy planning.

In recent years, there has been increasing interest in the development of CT-like images using MRI. Acquiring CT-like images simultaneously with conventional WB-MRI could have several benefits, including negating additional CT appointments, eliminating ionizing radiation doses, and minimizing spatial registration errors. Indeed, the creation of synthetic CT-like images for radiotherapy planning purposes is already possible using the *syngo*.via RT Image Suite. However, these images cannot provide the level of bone matrix detail needed for the radiological diagnosis of bone pathology.

Multiple investigators have reported bone MRI using a variety of VIBE and ZTE/UTE approaches [5, 6]. Structures with no signal return show black against a uniformly gray soft tissue background—known as "black-bone" imaging. When the image contrast is inverted, the bone appears white, like that in CT.

Recently, we reported that Deep Resolve Boost (DRB) reconstruction could cut whole-body diffusion-weighted imaging (WB-DWI) sequences by almost 50% without corresponding declines in image quality [7]. Building on our experience, we developed and clinically implemented a proton density (PD)-weighted VIBE sequence[1] using DRB to demonstrate its added value for bone imaging in WB-MRI examinations.

[1]*Work in progress. The application is currently under development and is not for sale in the U.S. and in other countries. Its future availability cannot be ensured.*

Black-bone contrast with VIBE

We iteratively developed 2 mm slice thickness StarVIBE and Cartesian VIBE sequences with a PD-weighted, 3° black-bone flip angle. A low flip angle was chosen to reduce the soft tissue contrast as much as possible, mimicking bone-window CT, while maintaining a workable SNR.

Images were acquired in-phase to reduce the appearance of the chemical shift artifact of non-bone structures. Receive bandwidth can be increased to reduce pixel shifts further as desired. Regardless of parameter selection, air and other non-signal-generating anatomical structures (e.g., bowel air, metal implants, surgical clips) appear as high signal on inverted images and can be distracting to radiologists.

StarVIBE is robust against motion artifacts due to the radial *k*-space sampling method, and produces good-quality CT-like images. This technique relies on setting an optimal number of radial views that are sufficient to fill the *k*-space for the selected matrix. The acquisition time (TA) increases with the number of radial views and slices, which limits the practicality of applying this method across the whole body.

SNR was noted to be extremely poor with conventional VIBE sequences, owing to the selected flip angle. We applied Deep Resolve Sharp and Boost-enhanced VIBE (DL-VIBE)[1], provided by Siemens Healthineers as a research application, to improve image quality. DL-VIBE can be acquired either with breath-hold for imaging of the mobile skeleton (e.g., ribs, sternum) or under free breathing for higher resolution. We used DL-VIBE as the preferred approach because it provides adequate bone details for diagnosis within an acceptable total acquisition time. The key parameters for StarVIBE and DL-VIBE are shown in Table 1.

Whole-body applications

Vertex-to-thigh body coverage can be achieved in less than 5 minutes using breath-hold DL-VIBE. Paired with the reported time savings of DRB WB-DWI [7], it may be possible to integrate this sequence within 60-minute appointment times.

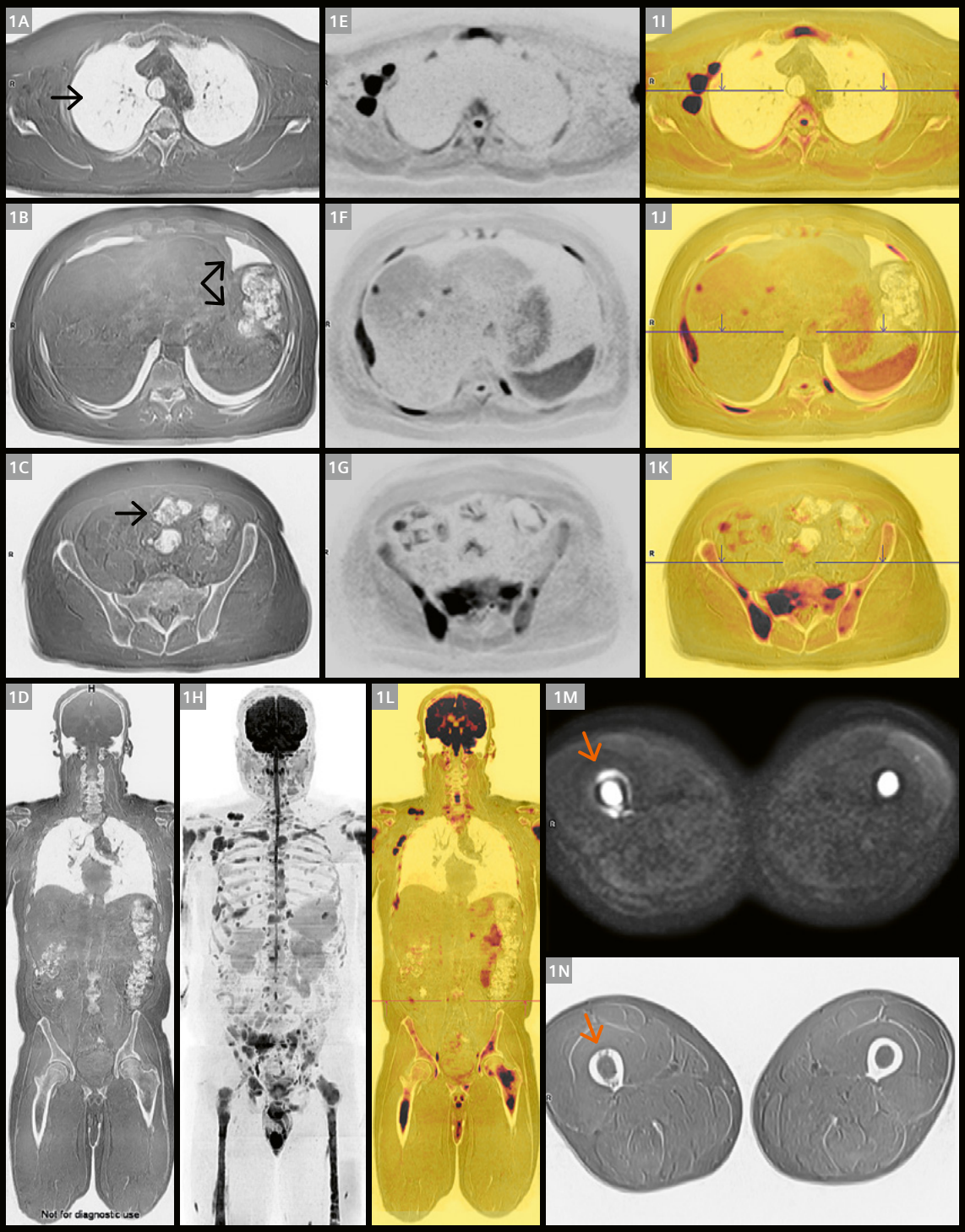
Composing stack-of-slice groups can result in stepping artifacts along continuous bone structures, unless 3D distortion correction is applied. This correction results in signal voids in several of the first and last slices of a group. Therefore, it is important to ensure that sufficient overlap is applied. Nevertheless, we have noted that a 2 mm slice thickness facilitates good quality multi-planar reformatting (MPR), which is useful for whole-body and long-bone evaluations as illustrated in the cases.

The CT-like images can be fused with b = 900 s/mm^2 DWI sequences to produce images with a similar appearance to PET/CT. Fusion imaging increases the conspicuity of hypercellular deposits and clearly communicates the positions of abnormalities in the skeleton. From PET/CT and SPECT/CT, we know that the CT component adds to the specificity of diagnoses by reducing false-positive findings [8]. We are investigating if the CT-like VIBE MRI provides similar benefits for WB-MRI examinations.

Sequence	Slices	TE (ms)	TR (ms)	Flip angle (degrees)	Field-of-view (mm) / matrix	*k*-space trajectory	Acceleration factor	Partial Fourier	Acquisition time per slab (min:sec)	Technical notes
StarVIBE	176 @ 2 mm	4.77	6.61	3	400 / 256	Stack-of-stars; 320 radial views	N/A	Slice 5/8	06:00	Stellate artifact from the radial trajectory
Breath-hold DL-VIBE	176 @ 2 mm	4.77	6.4	3	400 / 224	Cartesian	3 (PE) 2 (3D)	Phase 6/8 Slice 6/8	00:17	Good image quality, sharpness limited by breath-hold capacity
Free-breathing DL-VIBE	176 @ 2 mm	4.77	6.54	3	400 / 384	Cartesian	2 (PE) 2 (3D)	Disabled	02:04 (2 averages) 01:03 (1 average)	Resolution is comparable to CT. 2 averages optimal for elevated BMI

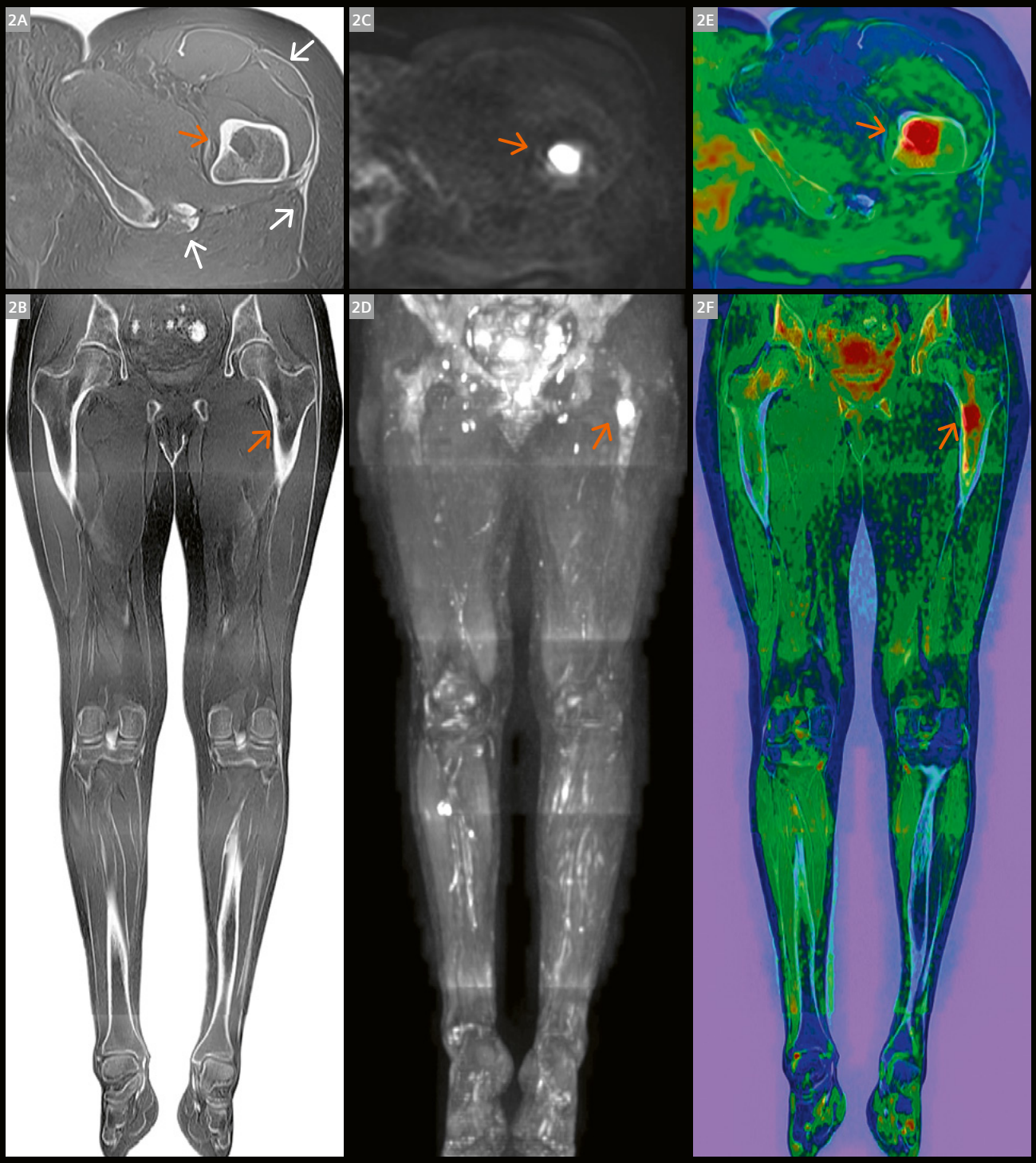
Table 1: Key parameters for StarVIBE and DL-VIBE on a 1.5T MAGNETOM Sola.

Case 1



1 A 54-year-old male patient with multiple myeloma post autologous transplant. Multiple hypercellular bone lesions are seen throughout the skeleton and in the right axillary lymph nodes. Breath-hold DL-VIBE **(1A–1C, 1D)** and inverted b900 **(1E–1G, 1H)** were acquired across a whole-body range in the axial plane. Fused DL-VIBE/inverted b900 **(1I–1K, 1L)** enable precise registration of bone marrow disease in relation to the cortical bone. Coronal MPR of DL-VIBE **(1D)** demonstrates good-quality composed images with no artifactual stepping of continuous bone structures. Note the artifactual brightness of non-signal-returning lung and bowel gas (black arrows). Extra-osseous, paramedullary disease (orange arrows) was observed on b900 **(1M)** with DL-VIBE **(1N)** demonstrating an intact bony cortex.

Case 2



2 A 59-year-old female patient with metastatic melanoma. Higher resolution free-breathing DL-VIBE **(2A)**, b900 **(2C)**, and fused DL-VIBE/b900 **(2E)** using an alternative color look-up table. Coronal MPRs and non-inverted MIP projection are shown **(2B, 2D, 2F)**. Note the artifactual bright low-signal-returning tendons and muscle fascia (white arrows). A percellular lytic lesion is seen in the left femur (orange arrows). With DL-VIBE, it was possible to confidently determine that the overlying cortical bone is intact.

Conclusion

Deep learning reconstructions, specifically Deep Resolve Boost, can markedly shorten the acquisition times of PD-weighted VIBE sequences to produce CT-like images. It is possible to undertake this on a whole-body basis and we have successfully integrated it into our routine WB-MRI protocols that comply with MET-RADS and MY-RADS.

Visit magnetomworld.siemens-healthineers.com/hot-topics/quantitative-whole-body-mri to download black-bone protocols for 1.5T.

Contact

Will McGuire, MSc MRSO (MRSC™)
Principal MRI Radiographer
Paul Strickland Scanner Centre
Northwood, UK
will.mcguire@stricklandscanner.org.uk

Professor Anwar R. Padhani,
MBBS MRCP FRCR
Consultant Radiologist and Professor of Cancer Imaging
Paul Strickland Scanner Centre
Northwood, UK
anwar.padhani@stricklandscanner.org.uk

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MRI meets Radiation Therapy: Flexibility, Precision, and a World of Workflow Possibilities

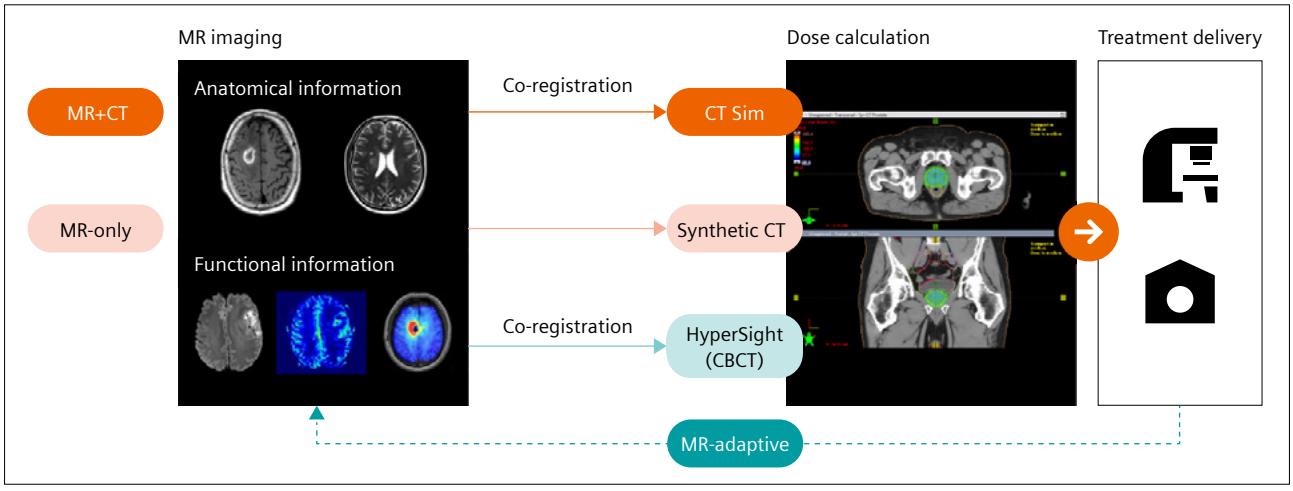
Siti Masitho, Ph.D.; Arun A. Joseph, Ph.D.

Siemens Healthineers, Forchheim, Germany

The emergence of magnetic resonance imaging (MRI) as the new standard in radiation therapy (RT) planning marks a transformative shift in oncology. Compared to the traditional computed tomography (CT)-based workflows, MRI offers unparalleled soft tissue contrast, enabling more accurate tumor delineation and precise identification of organs at risk (OARs). Its advanced functional imaging capabilities, e.g., diffusion-weighted imaging (DWI) and perfusion imaging, provide deeper insights into tumor biology, which allows for truly personalized treatment strategies. MRI is especially beneficial for anatomical sites rich with soft tissues, such as the brain, prostate, abdomen, and the head and neck.

The integration of MRI into RT workflows has led to a growing consensus among clinicians and RT experts regarding its value in enhancing treatment precision. Key requirements for effective MRI utilization in RT include standardized imaging protocols that address factors such as patient positioning, sequence optimization, and geometric accuracy [1]. Ensuring image precision is critical and requires robust distortion correction techniques and quality assurance protocols. Additionally, RT professionals require specialized training to interpret MRI data accurately and integrate it seamlessly into contouring, dose calculation, and adaptive planning processes.

The MAGNETOM Vida RT Pro Edition (3T), MAGNETOM Sola RT Pro Edition (1.5T), MAGNETOM Flow RT Pro Edition (1.5T), and MAGNETOM Free.Max RT Pro Edition (0.55T) are dedicated MRI scanners for RT which address the requirements for integration into RT workflows. Other than fulfilling the key requirements by providing dedicated RT protocols, setup for reproducible patient positioning, simplified imaging protocols (myExam RT Assist), and dedicated QA protocols, the MRI-for-RT solutions also enable advanced functions such as 4D MRI, MR-based synthetic CT, AI-powered Deep Resolve technology, and many more. These capabilities open up many ways of integrating MRI to maximize patient benefits in RT (Fig. 1).



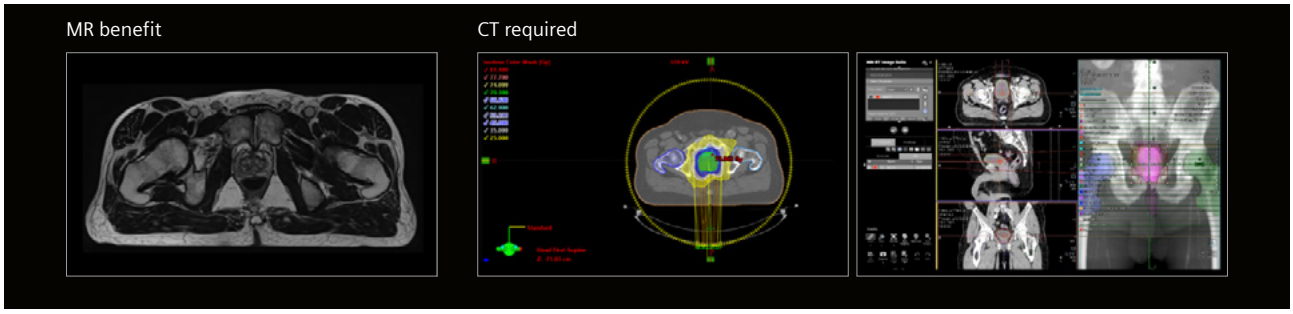
1 Flexible integration of dedicated MRI into various radiation therapy workflows.
Brain images (top left) courtesy of MVZ InnMed Oberaudorf, Oberaudorf, Germany; MRI contrast images (right) courtesy of Spitalul Clinic Sanador, Bucharest, Romania; diffusion/perfusion-weighted images (bottom left) courtesy of Hospital Ruber Internacional, Madrid, Spain; MR spectroscopy image (bottom left) courtesy of Emory University, Atlanta, GA, USA.

Combined MRI+CT workflow

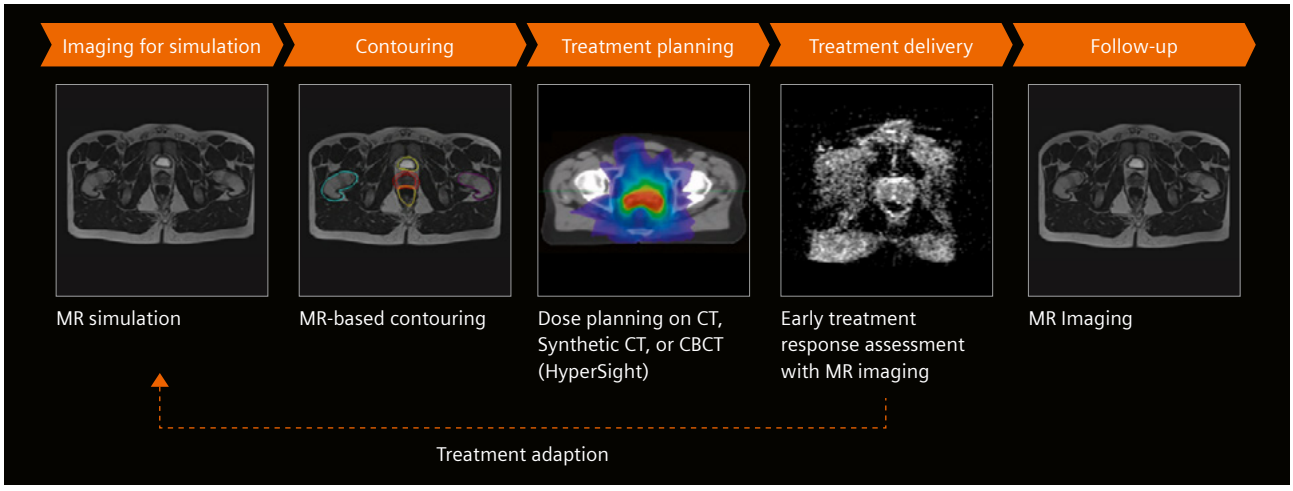
The most typical MR-informed workflow is a combined MRI and CT workflow in RT. This workflow leverages the strengths of both imaging modalities to enhance treatment accuracy and patient outcomes. While CT remains essential for dose calculation due to its electron density information, MRI provides superior soft tissue contrast for better visualization of the tumor and OARs [2]. In this workflow, MRI is typically used for target and OAR contouring, while CT serves as the primary dataset for treatment planning and dose optimization. Accurate image registration between MRI and CT is crucial, requiring not only optimized registration techniques but also minimized anatomical variations. A dedicated RT setup for MRI acquisition enables patient positioning in the RT position, with the possibility of enabling fixation of an immobilization mask. Studies have shown that acquiring MR images in the diagnostic position may lead to an MRI-CT registration inaccuracy of up to 2 mm [3], while treatments like stereotactic radiosurgery allow a margin of just 1–2 mm between the clinical target volume (CTV) and the planning target volume (PTV) [4]. Acquiring MRI in the RT position is therefore recommended to reduce registration inaccuracies [5].

MR-only workflow

An MR-only workflow using synthetic CT (sCT) represents a significant advancement in RT planning, eliminating the need for separate CT scans while maintaining the accuracy required for dose calculations. In this approach, MRI serves as the only imaging modality. As well as providing superior soft tissue contrast for delineation, its advanced algorithms can generate synthetic CT images from MRI data, estimating electron density information (Fig. 3). This workflow reduces registration inaccuracies associated with MR-CT registration, reduces the number of imaging sessions while maintaining precision in RT planning, minimizes patient exposure to additional radiation, and may improve overall



2 A combined MRI+CT workflow. MRI is used for target and organ-at-risk contouring, while CT is still required to provide Hounsfield unit values for dose calculation and to create a digitally reconstructed radiograph (DRR) for patient positioning at the treatment machine. *CT image (middle) courtesy of Universitätsklinikum Erlangen, Strahlenklinik, Erlangen, Germany. VMAT plan (right) generated internally by Varian, a Siemens Healthineers Company (Palo Alto, CA, USA), for demonstration purposes; not clinically used.*



3 MR-only radiation therapy workflow. Treatment adaption can be done by additional MRI acquisition throughout the course of therapy. *MR-based synthetic CT image courtesy of Brigham and Women's Hospital, Dana-Farber Cancer Institute, Harvard Medical School, Boston, MA, USA.*

workflow efficiency. A deep learning-based synthetic CT algorithm is available starting from software version VB60A, assuring geometric fidelity and HU accuracy for the brain and the pelvis region [6]. One limitation of this workflow relates to generating synthetic CT of patients with implants that were not included in the algorithm's training and validation. Despite the limitations, continuous advancements in the technology are progressively addressing these challenges, making MR-only workflows increasingly viable in clinical practice.

MR-informed adaptive workflow

Changes in tumor size, as well as the inhomogeneous tumor response, require treatment adaptions between fractions so as to potentially increase treatment effectivity and reduce toxicity. Salkeld et al. [7] found that 78% of patients required a change in management when there was a delay longer than seven days between imaging and radiosurgery. An MR-informed adaptive workflow in RT leverages additional MR imaging to continuously optimize treatment delivery based on anatomical and physiological changes. This workflow enables clinicians to adapt treatment plans right before the treatment delivery to account for tumor shrinkage, changing patient anatomy, and tumor response. After delineation on the new MR imaging, the planning image is typically deformably registered to the new MR image. Then, for the adaption, the current dose is calculated and optimized on the planning image.

For the dose adaption, a CT, sCT, or cone beam CT (CBCT) image can be used as a planning image. High-resolution CBCT, such as that provided by HyperSight (Varian, a Siemens Healthineers Company, Palo Alto, CA, USA), provides high-quality, large field-of-view, and accurate HU values for dose calculation (Fig. 3).

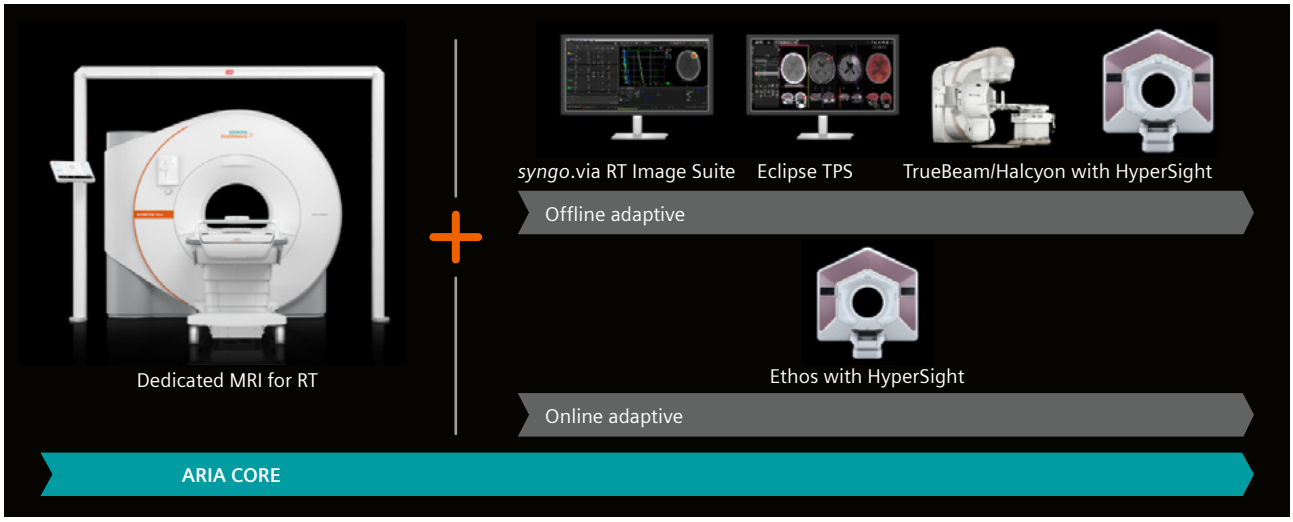
Using a standalone MRI system and a standalone linac combines the full capability of the MRI scanner and the accuracy of a linac. Having separate systems allows more flexible access to each, as well as flexible combinations between the MRI scanner and any linac. This decoupling of systems allows for shorter on-couch time at the linac without imaging, which therefore maintains a high patient throughput. Additionally, the full benefits of MRI can be harnessed to deliver high image quality and functional information.

Synergy with other systems

Whether for a combined MRI+CT workflow, an MR-only workflow, or adaptive RT, the MRI systems can be flexibly integrated into any clinical setup and existing ecosystem – consisting of the treatment planning software, linacs, and oncology information systems of any vendor – enabling clinicians to leverage high-quality MRI data without disrupting established protocols.

As we continue to drive innovation and integration, the synergy between dedicated MRI and our comprehensive product portfolio will further empower a wide range of RT workflows. Excellent visualization of soft tissue, image accuracy, and precision provided by our MRI scanners serve as the foundation for more precise contouring. This enables smaller delineations of CTVs, potentially reducing long-term toxicity [8]. Additionally, the AI-powered MR-based autocontouring solution, e.g. with *syngo*.via RT Image Suite (starting from software version VC10), can enhance the efficiency and accuracy of OAR delineation, saving valuable time in patient treatment.

The dedicated RT protocol optimizes MR images for RT, ensuring high-resolution imaging with automatic



4 Examples of our synergy. Combination of MRI with dedicated software such as ARIA CORE, *syngo*.via RT image Suite, the Eclipse treatment planning system, and advanced linacs (TrueBeam and Halcyon for offline adaptive RT, or Ethos for intelligent online adaptive RT).

distortion correction. Without distortion correction, tumor locations may be inaccurately contoured [1], whereas its application has been associated with improved local control in brain stereotactic RT [9]. Dedicated RT setups also ensure patient positioning reproducibility, improving MR-CT registration accuracy in a combined MRI+CT workflow, and ensuring accurate synthetic CT generation for MR-only workflows with *syngo*.via RT image Suite. The Eclipse treatment planning system (Varian, a Siemens Healthineers Company, Palo Alto, CA, USA) automates and streamlines the creation of a high-quality treatment plan, where the plan quality is directly influenced by the imaging and delineation precision. Furthermore, integration with advanced linacs such as TrueBeam and Halcyon from Varian enables highly precise MR-informed RT treatment delivery. When combined with Varian's Ethos radiotherapy system, our solution supports intelligent online adaptive therapy within one cohesive ecosystem, enhancing patient outcomes while maintaining clinical efficiency (Fig. 4).

Adaptive treatment relies on increased access to repeated MRI. An MRI system with a quench-pipe-free design (e.g., the 0.55T MAGNETOM Free.Max RT Edition and the 1.5T MAGNETOM Flow RT Pro Edition) allows installation within a bunker, closer to the linac. This proximity enhances MR-informed adaptive workflows by enabling easier and faster access to MR imaging for treatment adaption. Reduced distance between imaging and treatment can also help minimize time to treatment. Additionally, a shuttle system may improve efficiency by streamlining patient transfer and reducing the risk of anatomical changes between imaging and treatment.

Lastly, for advanced in-room imaging, HyperSight provides high resolution CBCT, ensuring precise patient positioning and offering clinicians the option to adapt the treatment plan on the CBCT data. HyperSight is an optional feature on the TrueBeam, Halcyon, and Ethos systems, further enhancing imaging capabilities.

Throughout the entire patient treatment, the ARIA CORE Oncology Information System (Varian, a Siemens Healthineers Company, Palo Alto, CA, USA) manages scheduling and centralizes crucial patient documentation, ensuring seamless coordination across the MR-informed RT workflow.

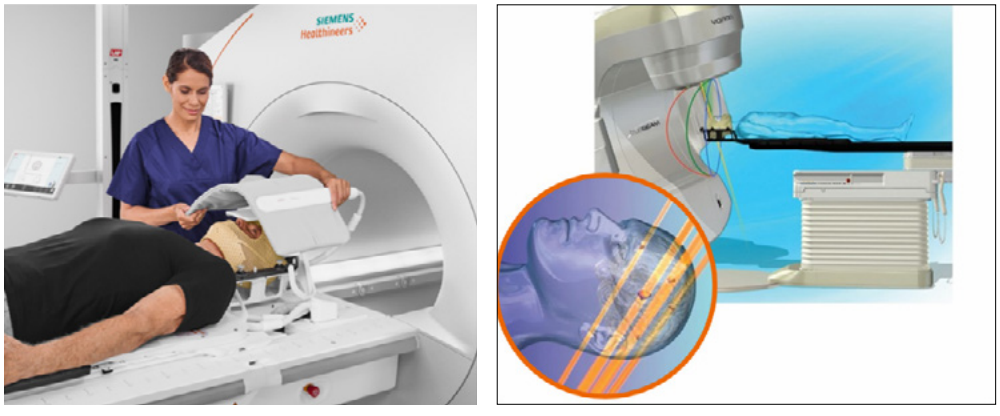
Examples of MRI integration into RT workflows

MRI-informed workflow for brain stereotactic radiosurgery

High accuracy and precision are essential in brain stereotactic radiosurgery (SRS), which typically delivers a high dose with a steep gradient. In intracranial SRS, single-fraction doses can reach up to 24 Gy, with a clinical target volume/planning target volume margin of less than 1 mm [4]. Additionally, the treatment of small brain metastases requires dedicated and optimized MRI sequences for precise localization and definition.

High-resolution, isotropic T1-weighted and T2-weighted images enable superior visualization of even the smallest brain metastasis. Beyond anatomical imaging, functional imaging such as diffusion-weighted imaging and chemical exchange saturation transfer provide deeper insights into tumor biology, aiding in early treatment response assessment.

To further optimize MRI for RT, a dedicated RT protocol ensures that MR-related distortions are automatically minimized. Additionally, a dedicated RT overlay ensures precise



5 Dedicated MR imaging protocol with the Encompass SRS MR Immobilization System, enabling HyperArc treatment for brain stereotactic radiosurgery on TrueBeam and Edge systems.

patient immobilization and fixation of the stereotactic immobilization mask, contributing to accurate image alignment and treatment planning. The AI-powered MR-based autocontouring solution enables clinicians to contour OARs more confidently and efficiently, improving treatment accuracy.

HyperArc (Varian, a Siemens Healthineers Company, Palo Alto, CA, USA) is a guided workflow within the Eclipse treatment planning system, specifically designed to streamline SRS treatment planning. It simplifies the process by enabling automated and efficient plan creation. By integrating an Encompass SRS MR Immobilization System (QFix Systems, Avondale, PA, USA), equipped with HyperArc markers, the system allows automated and efficient creation of an SRS treatment plan within Eclipse. This automated planning feature provides predetermined arc trajectories for TrueBeam and Edge systems, guaranteeing collision-free gantry and couch rotations (Fig. 5). Finally, treatment delivery remains fully automated and collision-free, eliminating the need for the therapist to enter the room. This not only accelerates treatment delivery but also enhances the patient experience by providing a fast and efficient SRS treatment.

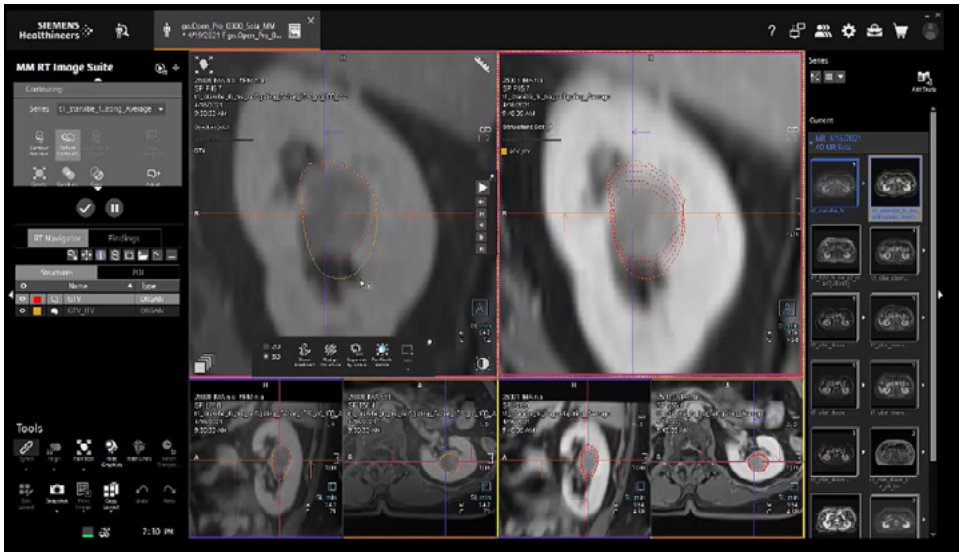
MRI-informed liver stereotactic body RT with 4D MRI

Managing breathing motion is a critical aspect of RT, particularly when treating tumors in the areas where breathing motion can cause significant tumor movement, such as in thoracic and abdominal regions. Proper motion management ensures precise treatment planning and delivery. Without it, tumor motion can lead to underdosing the tumor and overdosing surrounding healthy tissues, reducing treatment effectiveness and increasing toxicity. Understanding the tumor's motion trajectory is essential for accurate targeting.

Liver tumor delineation on CT is particularly challenging due to poor soft tissue contrast and the rapid elimination of contrast agent. This is where 4D MRI provides a significant advantage. However, MRI acquisitions take longer than CT imaging, making them more susceptible to motion artifacts. Unmanaged motion can result in unusable images and require repeated scans, increasing overall scan time. Without proper motion management, MRI-based tumor delineation can be inaccurate, which can compromise dose planning precision and ultimately affect treatment outcomes.

Delineating liver tumors based on CT can be very challenging because of the inherently poor soft tissue contrast, which will lead to improper delineation of the tumor and reduced accuracy in dose planning. 4D MRI – RT Respiratory Self-Gating, based on a StarVIBE acquisition, addresses these challenges by binning images into different respiratory phases. This allows for precise target delineation at each phase of the breathing cycle. This method eliminates the need for external respiratory devices or surrogates, offering a streamlined workflow for MR-based RT planning of moving targets. Due to its superior soft tissue contrast and enhanced tumor and OAR visualization compared to 4D CT [10], 4D MRI is particularly advantageous for liver stereotactic body RT (SBRT). By accounting for respiratory motion, clinicians can reduce unnecessary irradiation of healthy liver tissue, potentially lowering radiation-induced liver disease and improving long-term patient outcomes [11].

The RT Respiratory Self-Gating Workflow in *syngo*.via RT Image Suite further enhances efficiency by allowing clinicians to contour the tumor in one respiratory phase and automatically propagate those contours across all phases to generate the internal target volume (ITV). Figure 6 shows an example of the functionality.



6 The 4D MRI – RT Respiratory Self-Gating Workflow in *syngo*.via RT Image Suite, enabling contouring in all respiratory phases (red) and creating the ITV (orange).

Additionally, the tumor curve display provides a clear visualization of tumor trajectory, assisting clinicians in motion-adaptive treatment planning. 4D MRI capabilities, together with a standalone linac, can fulfill motion management needs, while preserving full MRI capabilities and optimizing patient throughput.

Conclusion

The ability of MRI to support a wide range of radiotherapy workflows enhances treatment precision, reduces planning margins, and minimizes toxicity to healthy tissues. As technology continues to evolve, MRI is not just complementing RT workflows; it is redefining them, offering a new solution for precision, adaptability, and patient-centered care. In the end, collaboration between multidisciplinary teams – radiologists, radiation oncologists, and physicists – is essential to establish best practices for MRI in RT.

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Contact

Siti Masitho, Ph.D.
Siemens Healthineers AG
SHS VAR CTH M RTM
Siemensstr. 1
91301 Forchheim
Germany
Tel.: +491733495170
siti.masitho@siemens-healthineers.com

Positioned for Precision: Optimizing MR Imaging from the Table Up

Arun Joseph[1]; Lucas Thompson[1]; Luke Federspiel[2]; Lisa Vandenberg[2]

[1]Siemens Healthineers, Forchheim, Germany
[2]CQ Medical, Orange City, IA, USA, and Avondale, PA, USA

Transforming MR workflows in radiation therapy

Improving MR imaging workflows in radiation therapy starts with seamless integration of patient positioning solutions that drive precision and efficiency. In this article, clinicians share real-world examples of how they are using CQ Medical's MRSeries and Symphony systems (CQ Medical, Avondale, PA, USA) to streamline treatment planning and enhance outcomes. These solutions are designed for optimal performance with MRI systems from Siemens Healthineers.

Real world impact: Precise positioning for high-quality imaging

Stephen Hedley, M.Sc.; Serena West, B.Sc.

Northern Centre for Cancer Care, Newcastle upon Tyne Hospitals NHS Foundation Trust, Newcastle, UK

At the Northern Centre for Cancer Care in Newcastle upon Tyne, UK, clinicians Stephen Hadley and Serena West have demonstrated the clinical benefits of the Universal Couchtop MR Overlay (UCT, CQ Medical, Avondale, PA, USA) in enhancing MR workflows.

"We have used the UCT with our 1.5T MAGNETOM Sola (Siemens Healthineers, Erlangen, Germany) since its release in 2022, deploying the overlay daily for a wide range of anatomical sites. Our center serves over 2.1 million people and treats more than 6,000 patients per year. More than 35% of our patients receive radical intent external beam radiotherapy and have MRI as part of their standard of care. Therefore, maximizing efficiency whilst offering the best quality care is imperative, and the UCT overlay system allows us to achieve this for every patient.

As well as being used daily for radiotherapy patient scans, our MAGNETOM Sola is also routinely used for clinical trials and routine diagnostic scans. We, therefore, greatly appreciate the fact that a single operator can easily place and remove the overlay, securely docking it into the MAGNETOM Sola's couch. We use the overlay and associated coil bridges for seven clinical sites: prostate, including stereotactic ablative body radiotherapy (SABR) and MR-only; gynecological external beam therapy (EBRT); head and neck, including SABR; rectum; anus; liver SABR; and spine SABR. The versatility and flexibility of positioning available using the included coil bridge allows us to achieve high-quality anatomical scans of all these sites using a single Body 18 receive coil and the posterior spine coil.

The compatibility of the UCT with the Body Pro-Lok ONEBridge abdominal compression bridge allows for slick setup of patients requiring respiratory motion management both for CT and MR imaging, such as liver SABR patients.

Overall, the UCT with its lightweight design, versatile coil placement options, and compatibility with the Body Pro-Lok ONEBridge system provides high-quality MR imaging for a wide range of patients, whilst maintaining high patient throughput and satisfaction."

1 The 1.5T MAGNETOM Sola with coil and positioning setup.

Clinical insights: Lithotomy patient transfer optimized for MR-guided radiotherapy

Jay Shelton, M.D.[1,2]; Zhiqian "Henry" Yu, Ph.D., DABR[3]; Holly Clark, RN, BSN, CNOR[3]

[1]Emory University Department of Radiation Oncology, Winship Cancer Institute, Atlanta, GA, USA
[2]Edward Loughlin Department of Radiation Oncology, Grady Cancer Center for Excellence, Atlanta, GA, USA
[3]Department of Radiation Oncology, MD Anderson Cancer Center, Houston, TX, USA

Jay Shelton, M.D., notes that prostate and gynecological brachytherapy workflows are becoming increasingly complex and delicate. The Symphony lithotomy solution plays an integral role in supporting and enabling the addition of MRI into these procedures. This solution maintains patient position and increases comfort and compliance throughout insertion, image acquisition, and treatment, ultimately helping to improve outcomes.

MD Anderson implemented a Symphony solution with imaging equipment from Siemens Healthineers to enhance the efficiency and precision of its gynecological brachytherapy workflows.

One major challenge in obtaining multiple imaging modalities for gynecological and genitourinary patients is keeping patients and brachytherapy applicators in the same position during transportation. In many clinics, the CT, MRI, and treatment rooms are not in the same area or even on the same floor, so the patient must be transported quite far. Keeping patients and applicators in the exact same position throughout the imaging and treatment process is crucial. A few millimeters of change in applicator location within the patient could alter the expected delivery dose to an unacceptable amount. Keeping the patients on the same tabletop from the time of implant until after radiation delivery is the best solution.

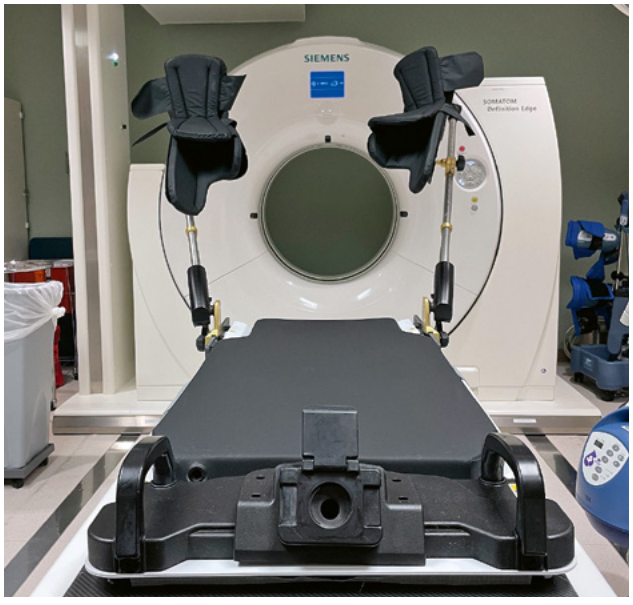
The MD Anderson workflow uses MR-conditional solutions including three AirShuttle devices, two AirDrive Caddie solutions, and one AirDrive Trolley, ensuring smooth transfers with minimal staff effort. This streamlined process reduces the risk of applicator displacement, improves staff efficiency, and enhances patient comfort.

The AirShuttle is positioned on the couchtop of the CT system (SOMATOM Edge; Siemens Healthineers, Forchheim, Germany). The patient was then set up on the AirShuttle and the implant procedure was started. To have the patient in lithotomy position, the AirShuttle contains side rails that allow stirrups to be easily attached.

Once the procedure is complete, the integrated AirDrive Trolley blower is used to inflate the AirShuttle and transfer onto the trolley. The patient is then rolled to the MRI suite, which is four floors above the brachytherapy suite. Since every part of the Symphony system is MR-conditional, the trolley can be rolled directly into the MRI scanner (a 3T MAGNETOM Vida; Siemens Healthineers, Erlangen, Germany) room, and the AirShuttle with the patient can slide from the trolley to the MR tabletop.

Once the MRI is done, the patient is slid back onto the trolley, rolled back to the brachytherapy suite, and treated.

In this workflow, the patient is never separated from the AirShuttle. This ensures minimum applicator displacement during transport. Fusing the CT and MR images and



2 Lithotomy position for initial CT image acquisition on a SOMATOM Definition Edge.

3 Transport to MR suite and transfer to MRI scanner (3T MAGNETOM Vida).

verifying relative locations of the applicator and patient anatomy validates this. Prior to using Symphony, the team would transfer the patient using sheets, which required more staff and effort. Additionally, they had to be extremely careful that the applicator position did not change during the shift. With the Symphony system, it is easy to slide the patient from one surface to another with two staff. The MRI suite does not accommodate normal stretchers. The team previously used a normal stretcher, so had to move the patient and the MR scanner tabletop to a separate room for patient transfers. Upon completion of the scan, this process was repeated. This was cumbersome and risked causing long wait times.

As brachytherapy implants become more complex with a mixed use of solid applicators and needles, maintaining patient position is of the utmost importance. With increased access to MRI scanners in radiation oncology departments, all patients are likely to receive an MRI for every brachytherapy fraction in the future. A big focus of recent brachytherapy research has been replacing CT with MRI as the primary imaging modality. This will lead to implants being done directly in the MR suite, requiring all devices used to be MR-conditional. To be future-proof, clinics should therefore only purchase brachytherapy equipment that is MR-conditional. Finally, for clinics with large patient volumes, duplicate patient transport devices are extremely helpful, increasing patient throughput and redundancy. In summary MRI is already a critical component of brachytherapy today and is expected to become a leading imaging modality as clinical adoption and supporting evidence continue to grow. With a focus on applicators and treatment planning, patient transport is often overlooked. Having a low friction transfer device to keep patients in a fixed position while also easily transferrable from one couchtop to another makes the entire workflow much smoother and can benefit all clinics.

4 MR image acquisition with a 3T MAGNETOM Vida.

Update on combining CT-based online adaptive radiotherapy with offline MR guidance: The modular adaptive radiotherapy system (MARS)

Fabian Weykamp, M.D.

Department of Radiation Oncology, Heidelberg University Hospital, and Clinical Cooperation Unit Radiation Oncology, German Cancer Research Center (DKFZ), Heidelberg, Germany
Heidelberg Institute of Radiation Oncology (HIRO), Heidelberg, Germany
Clinical Cooperation Unit Radiation Oncology, German Cancer Research Center (DKFZ), Heidelberg, Germany

Building on previous work integrating MR imaging into adaptive radiotherapy while maintaining consistent patient positioning, Fabian Weykamp, M.D., and his team at the German Cancer Research Center (DKFZ) in Heidelberg have refined their workflow using the Symphony Alta AirShuttle and AirDrive Trolley from CQ Medical.

At DKFZ, the Symphony patient transport system (AirShuttle) is used to facilitate continuity of positioning across imaging and treatment. The system connects the planning CT scanner, the Ethos adaptive radiotherapy system (Varian, a Siemens Healthineers Company, Palo Alto, CA, USA), and a 3T MAGNETOM Vida MRI scanner, allowing the patient to remain on a single transfer surface throughout the imaging and treatment workflow. This approach supports consistent positioning between MR acquisition and treatment, which can assist in spatial alignment.

5 Patient positioning after the MRI scan.

6 Shuttling the patient from the MRI scanner to the Ethos system.

7 Patient positioning on the Ethos system.

Incorporating MRI into the offline adaptive treatment planning workflow has allowed DKFZ to expand its use of advanced imaging techniques, including functional imaging such as diffusion-weighted imaging (DWI), while maintaining patient positioning from imaging to treatment. Insights on the clinical utility and outcomes of this approach continue to evolve through practical experience. Leveraging this shuttle-based approach further enables the use of existing MRI and treatment room setups – even when not co-located – without significant modifications to facility layout. It also supports more flexible scheduling of MRI sessions and treatment appointments, potentially improving overall patient throughput.

For more details, please see:
Weykamp F, Schlemmer H-P, Jäkel O, Debus J. Combining CT-Based Online Adaptive Radiotherapy with Offline MR Guidance: The Modular Adaptive Radiotherapy System (MARS). MReadings: MR in RT. 2024;(10):13–19.
Available from:
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Collaboration in Practice

CQ Medical works closely with imaging and treatment technology leaders, including Siemens Healthineers, to address real clinical challenges. Through these collaborations, solutions are developed with input from users – prioritizing safety, precision, and workflow compatibility. The goal is to support clinicians in delivering more efficient and informed care.
Explore how these tools are being used in clinical practice:
↗ www.CQmedical.com.

Contact

Luke Federspiel
Vice President of Strategic Alliances
CQ Medical
1401 8th Street SE
Orange City, Iowa 51041
USA
Tel.: +1 712.737.8688
luke.federspiel@cqmedical.com

Meet Siemens Healthineers

Siemens Healthineers: Our brand name embodies the pioneering spirit and engineering expertise that is unique in the healthcare industry. The people working for Siemens Healthineers are totally committed to the company they work for, and are passionate about their technology.

We have long supported the adoption of MRI in radiation therapy by offering dedicated products, while *MReadings: MR in RT* shares the insights and experiences of MAGNETOM users, further highlighting the clinical value of MRI in this field.

Complementing these efforts is a remarkable global team dedicated to advancing the use of MRI in radiation therapy. Representing different regions around the world, these passionate individuals serve as ambassadors for MRI in RT. They bring expertise, enthusiasm, and personalized support directly to you – helping clinicians explore and implement MRI in their radiation therapy workflows.

In this edition, we are pleased to introduce this exceptional team of professionals – the faces of MRI in radiation therapy – who are driving change and making a difference, one partnership at a time. Dr. Nashiely Pineda Alonso serves as the representative for Europe, Middle East and Africa; Viktor Li covers China, Hong Kong, and Taiwan; Terumasa Takemaru is responsible for the Asia Pacific region, including Japan and India; and Lucas Thompson represents North- and Latin America.

Nashiely S. Pineda Alonso, Ph.D.

Born in Puebla, Mexico, Nashiely pursued a career in France in electronic engineering specializing in signal and image processing. After completing her engineering degree, she joined General Electric Healthcare in Buc, near Paris (2000–2003), working with the digital mammography development team. Concurrently, she completed a Master's degree in Medical Imaging at Université Paris XI (2000–2002), where she discovered her passion for magnetic resonance (MR). Subsequently, she was awarded a CIFRE doctoral scholarship from the French government, co-funded by Siemens Healthcare. Her Ph.D. research (2003–2006) focused on the study and classification of glial tumors using magnetic resonance spectroscopy (MRS), conducted at the Université de Nantes and the Neuroradiology Department of Laennec Hospital in Nantes, France.

Following her doctorate, she pursued a postdoctoral position at Emory University in Atlanta, Georgia, USA (2006–2008). There, working under the supervision of Prof. Diego Martin and Prof. Xiaoping Hu, she developed a precise, effective, and non-invasive MRS method capable of quantifying iron and fat in just 15 seconds. This innovation is highly beneficial for diagnosing liver and blood conditions, offering superior accuracy and rapid results and, crucially, allowing patients to avoid invasive biopsies. The method, called HISTO (2008), is patented and has since been incorporated into magnetic resonance product innovations from Siemens Healthineers. Since 2008, Nashiely has been an integral part of Siemens Healthineers, where she has held diverse roles spanning customer support in research and scientific collaboration, clinical applications, marketing, sales, and business development. Currently, she serves as the Sales Director for MR in RT for the EMEA region.

How did you first come into contact with MRI?
When I was 15 years old, I saw an MRI scan of my little sister's brain. This was back in the 1990s, and these were the first MRI systems available in Mexico. I realized the importance of a diagnostic image in finding the right cure. My sister had a brain tumor that was first diagnosed as acute childhood migraine. And from that moment, I decided I wanted to know more about MRI and contribute to the improvement of healthcare diagnostics.

What do you find most fascinating about MRI in RT?
MRI offers a broader spectrum of contrast options than any other RT simulation technology. This superior contrast enables clearer definition of tumors and organs at risk, leading to more precise therapy and, consequently, improved cure rates and reduced patient toxicity.

Furthermore, the technological advancements allow an MR-only approach. This is because it is possible to derive Hounsfield units from MRI for dose calculations on the treatment planning systems (TPS) using a single calibration curve, independent of modalities, with AI-based algorithms maximizing MR-only workflow efficiency. The synthetic CT (sCT) obtained makes it possible to streamline workflows for target definition, patient marking, and beam placement using digitally reconstructed radiographs (DRR) derived from sCT. This eliminates the need for CT/MRI registration, avoiding potential errors and unnecessary ionizing radiation. It also reduces the number of scans and improves patient comfort. The MR-only approach eliminates CT simulation, potentially freeing up CT scanners for other patients.

What do you find most motivating about your job?
Knowing that our work and efforts at Siemens Healthineers help to improve cancer treatment and save lives.

How do you perceive the impact of MRI in RT?
I'm in contact with many professionals in the EMEA region who work in MRI in RT, and our interactions consistently highlight its profoundly positive impact on patient outcomes. Beyond this, the ongoing exploration of MRI's capabilities in RT fuels research, empowering these groups to make substantial contributions to healthcare knowledge worldwide.

What would you do if you could spend a month doing whatever you wanted?
I enjoy supporting my community, and by that I mean the place where I live, the school my son attends, the company I work for, the country I come from. So I'd dedicate that month to fully supporting humanitarian activities, employee resource groups, or volunteering in the associations to which I already contribute in my free time.

Viktor Li (Li Mao)

Viktor Li graduated with a Bachelor's of Medicine in 2011 and went on to earn a master's of medicine in 2014, majoring in medical imaging and diagnostic radiology. He began his career the same year, joining Philips as an MR clinical application specialist. Still at Philips, he later became an MR application manager before taking on the role of application leader for the oncology market. In 2023, he moved to Bayer as a medical science liaison manager for radiology. In 2024, Viktor joined Siemens Healthineers as product manager of MR-sim within the CTH team in China. Li has written and edited several books on MRI, including on MRI-guided radiotherapy.

How did you first come into contact with MRI?
I majored in medical imaging as a doctor of radiology, so I came into contact with MRI many years ago when I was interning in hospitals. Then about 12 years ago, I joined Philips, where I worked as an MR Clinical Application Specialist for six years and then as an Oncology Application Leader for four years.

My background means I have a solid understating of MR technology and diagnostic radiology. I'm proficient in clinical MRI examinations of all anatomical structures, including basic and advanced procedures. I make sure I keep abreast of the state of art in MRI and the associated skills. I'm experienced in protocol development, image-quality optimization, artifact analysis, and workflow improvements. I also have extensive experience of MRI training, including the development of training materials and programs, presentations, and hands-on training.

What do you find most fascinating about MRI in RT?
MRI has two main applications in radiotherapy: the MR simulation before treatment, and the tumor efficacy assessment and follow-up after treatment.

MRI is becoming increasingly important as regards precision. Many recent advances in MRI have been shown to be promising for MRI-guided radiotherapy and for improved treatment outcomes. This is thanks to its excellent soft tissue contrast and versatile scanning options.
I think the most fascinating thing is the new MRI technology, such as MR fingerprinting, oscillating-gradient spin-echo sequences (OGSE), synthetic CT, and 4D MRI, to name just a few.

What do you find most motivating about your job?
The most motivating aspect of my job is collaborating with users, who are usually hospital doctors or physicists, to accomplish technological innovations and publish books and articles.

I have collaborated with many customers on books and articles. In 2019, Professor Jihong Wang of MD Anderson Cancer Center invited me to co-write a book about MR-guided radiotherapy and clinical application. We published it in 2021. It was the first book about MR in RT in China.

How do you perceive the impact of MRI in RT?
In radiation oncology, there are at least four main applications of MR imaging:

1) Pre-treatment imaging for treatment planning
2) Online MRI-guided radiation therapy
3) Intra-treatment assessment of response and early signs of toxicity
4) Post-treatment follow-up to assess the treatment outcome and future prognosis

What would you do if you could spend a month doing whatever you wanted?
I have several hobbies, including singing, playing badminton, practicing Taekwondo, and traveling. If I were given a month to do anything I wanted, I would choose to travel to different countries. There are still so many places in the world I haven't explored yet, and I love learning about new cultures and meeting people from different backgrounds.

Terumasa Takemaru

Terumasa Takemaru graduated from Japan's Kumamoto University Graduate School of Health Sciences in 2011. He joined Siemens Healthineers the same year, working as a senior application MR specialist and team lead in Japan until 2020. He then changed roles, moving to Siemens Healthineers in Germany to become a global clinical education specialist. In this role, he was responsible for internal and external global education, and provided congress support at ASTRO, ESTRO, and JASTRO. In 2024, he moved to Singapore, where he is now clinical market development manager at Siemens Healthineers.

Singapore

How did you first come into contact with MRI?
My initial encounter with MRI occurred during my master's degree studies. However, my deeper involvement with MRI truly began when I started working professionally in the field of diagnostic MRI, bringing advanced MRI technology directly to customers and patients.

Experiencing firsthand how MRI can deliver exceptional visualization of soft tissue, vascular structures, and functional details significantly deepened my interest. With a deeper theoretical understanding and mastery of MRI parameters, I discovered ways to further expand visualization capabilities, unlocking new possibilities for medical imaging.

What do you find most fascinating about MRI in RT?
What fascinates me most is how MRI in radiation therapy transforms patient care by integrating new MRI techniques. The exceptional clarity provided by MRI enables clinicians to personalize treatments, precisely target tumors, and spare healthy tissues, significantly improving patient outcomes and quality of life.

Additionally, the continuous evolution and rapid advancement of MRI technologies keep expanding the potential and possibilities of radiation therapy, making it an exciting and ever-developing field.

What do you find most motivating about your job?
My biggest motivation is knowing that my work contributes directly to better patient outcomes and advances in cancer care. Being at the forefront of medical innovation, collaborating closely with clinicians, researchers, and colleagues across different regions, and seeing tangible improvements in patient care continually inspires me and gives my work a profound sense of purpose.

How do you perceive the impact of MRI in RT?
I perceive MRI as revolutionary in radiation therapy, as it shifts the treatment paradigm toward truly personalized, precise, and adaptive care. MRI facilitates superior tumor visualization and adaptive treatment strategies, significantly enhancing the sparing of healthy tissues, reducing side effects, and improving overall treatment effectiveness. Furthermore, the availability of advanced functional imaging without additional irradiation, combined with AI-driven analytics, enriches clinical insights and further personalizes patient care.

In the long term, I believe MRI will establish a new standard of care, positively influencing healthcare economics by reducing treatment complications.

What would you do if you could spend a month doing whatever you wanted?
Having recently moved from Germany to the Asia region, I would dedicate the time to extensive travel, immersing myself deeply in the diverse cultures of Southeast Asia. I would seek fresh perspectives by connecting with nature alongside my family. Additionally, I would set aside ample time for reading extensively about healthcare innovations, engaging in creative thinking for future projects, and reflecting on how these new experiences could enrich both my professional career and personal growth.

Lucas Thompson

Lucas Thompson is Director of MR Cancer Therapy Business Development at Siemens Healthineers. In this role, he drives the growth and adoption of MRI technologies in radiation oncology, supporting efforts to enhance treatment planning, therapy guidance, and response evaluation for cancer patients. Passionate about advancing the role of imaging in cancer care, Lucas works closely with healthcare providers to implement innovative MR solutions that increase access, improve clinical workflows, and deliver better outcomes for patients.

Lucas joined Siemens Healthineers over 14 years ago and has held a variety of roles across education, sales, marketing, and business development. Throughout his career, he has been recognized for his deep technical expertise, strategic insight, and strong partnerships with customers and colleagues. Before taking on his current role, Lucas led initiatives focused on regional sales in the Western United States.

Dedicated to fostering education and training, Lucas collaborates with clinical experts to develop programs that empower radiation oncology teams to maximize the benefits of MRI. Lucas has complemented his technical background with extensive experience in commercial strategy and customer engagement.

How did you first come into contact with MRI?
Growing up, I had exactly zero interest in following in my dad's footsteps. None. Zilch. The man was a radiologic technologist, as was my uncle, and their dinner table conversations were filled with talk of X-rays, CT scans, and angiograms – none of which I found remotely exciting. To me, their world was all barium swallows and lead aprons, and I had no intention of spending my life in a hospital basement staring at grainy black-and-white images.

But then, something changed.

I started hearing more and more about MRI. At first, I tuned it out like all the rest, but then my dad mentioned something that caught my attention – MRI wasn't just another way to see inside the body; it was a *better* way. The detail, the contrast, the ability to spot things that X-ray and CT sometimes missed – it was like upgrading from an old tube TV to 4K.

I started reading about MRI, and what I discovered completely flipped the script. This wasn't some static, old-school technology – it was advancing at an incredible speed, getting sharper, faster, and more capable every year. It wasn't just about taking pictures; it was about changing the way we diagnose and treat disease. Before I knew it, I was hooked.

So, the kid who swore he'd never follow in the family business found himself not just following – but running full speed ahead. Now, after years in the industry, I can't imagine doing anything else.

What do you find most fascinating about MRI in RT?
When most people think about MRI in radiation therapy, they focus on the obvious advantage – better soft tissue visualization. And don't get me wrong, that's a huge deal. Seeing tumors more clearly, defining treatment margins more precisely – it's an essential step forward. But to me, that's just scratching the surface.

The real magic? Functional imaging.

MRI isn't just showing us what a tumor looks like. It's showing us how it behaves. Blood flow, oxygen levels, metabolism – these are the things that make every tumor unique. And if we can see that? We can personalize treatment in a way that wasn't possible before. Instead of treating every patient with a one-size-fits-all approach, we can adapt therapy, making smarter, more targeted decisions based on how a tumor is responding.

That's next-level. That's when MR in RT goes from being a useful tool to a game changer. And the best part? We're just getting started.

What do you find most motivating about your job?
There are plenty of things I love about my job – the technology, the innovation, the way MRI keeps pushing the boundaries of what's possible in radiation therapy. But at the end of the day, what keeps me going isn't the science. It's the people.

It's easy to get caught up in the technical side of things – field strengths, pulse sequences, treatment

planning workflows. But every scan, every image, every breakthrough we make in MR-informed radiation therapy comes down to one simple fact: there's a patient on the other end of it. A person with a family, with hopes, with a life they want to keep living.

That's what motivates me. Knowing that the work we do isn't just about making MRI smarter or more efficient – it's about making treatment better. It's about giving patients more options, more precision, and ultimately, more time. That's worth everything.

How do you perceive the impact of MRI in RT?
MRI isn't just refining radiation therapy – it's redefining it. Functional imaging, response assessment, treatment adaptation – these aren't just incremental improvements. They're transformational shifts in how we fight cancer.

The impact? We're making radiation therapy smarter, more dynamic, and more precise than ever before. And as MRI technology continues to evolve, so will the way we treat patients. We're not just improving outcomes – we're rewriting the rules. And that's the kind of change worth being a part of.

What would you do if you could spend a month doing whatever you wanted?
If I had one month to do anything, I wouldn't travel the world or chase some bucket list adventure. I'd spend it with my family.

As I've gotten older, I've started looking at time differently. Not in years, but in moments. I used to think, I have another 10, 15, maybe 20 years with my parents – plenty of time. But then I did the math. I see them, on average, once a year. That means, realistically, I might only have 10, 15, maybe 20 more times with them. And that's a very different way to look at things.

That realization changed me. It made me want to be more intentional about the time I do have – to close the gap between *someday* and *right now*. Because at the end of the day, careers are important, accomplishments are fulfilling, but time with the people who matter most? That's something you never get back.

So if I had a month? I'd use it to add to that number. Because in the end, the moments we make now are the ones that truly last.

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Siemens Healthineers AG
Magnetic Resonance,
Karl-Schall-Str. 6, D-91052 Erlangen, Germany

Editor-in-chief:
Antje Hellwich
antje.hellwich@siemens-healthineers.com

Guest Editors:
Professor Daniela Thorwarth, Ph.D.
Head, Research Section for Biomedical Physics
Department of Radiation Oncology
University of Tübingen
Hoppe-Seyler-Str.
72076 Tübingen, Germany
Tel. +49 7071 29-86055
daniela.thorwarth@med.uni-tuebingen.de
www.medizin.uni-tuebingen.de

Professor Daniel Zips, M.D.
Medical director, Department of Radiation Oncology and Radiotherapy
Charité – Universitätsmedizin Berlin
Augustenburger Platz 1
13353 Berlin, Germany
Tel. +49 30 8445 3051
daniel.zips@charite.de

Editorial Board:
Kera Westphal, Ph.D.; Kathrin El Nemer, M.D.; Wellesley Were; Jane Kilkenny; Heiko Meyer, Ph.D.

Review Board:
Arun Antony Joseph, Ph.D.; Martin Requardt, Ph.D.; Elena Nioutsikou, Ph.D.; Daniel Fischer

Copy Editing:
Sheila Regan, Jen Metcalf, UNIWORKS,
www.uni-works.org
(with special thanks to Kylie Martin)

Layout:
Agentur Baumgärtner,
Friedrichstr. 4, D-90762 Fürth, Germany,
www.agentur-baumgaertner.com

PrePress and Image Editing, Production:
Clemens Ulrich, Paul Linssen,
Siemens Healthineers AG

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Siemens Healthineers Headquarters
Siemens Healthineers AG
Siemensstr. 3
91301 Forchheim, Germany
Phone: +49 9191 18-0
siemens-healthineers.com

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