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Practical Radiation Oncology® (2026) 000, e1−e6

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Technical Report

Real-Time Magnetic Resonance Imaging Guidance to Enable Brachytherapy: A Case Series

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Received 23 May 2025; accepted 12 December 2025

Abstract Real-time magnetic resonance (MR) guidance during brachytherapy (MRgBT) offers superior soft tissue definition and precise target identification during catheter implantation while minimizing treatment-related complications. This report reviewed the use of MRgBT in a series of complex clinical situations where brachytherapy would have been impossible without MR guidance, and alternate treatment modalities would have involved potentially significant morbidity to the patients. We highlighted the safety and efficacy of MRgBT in controlling targetable disease in a specific group of patients without precluding the ability to go for subsequent treatment options when indicated.
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Introduction

Magnetic resonance guided brachytherapy (MRgBT), whereby patients undergo real-time MR imaging (MRI) scan during brachytherapy, offers superior soft tissue definition, enabling precise target identification while minimizing treatment-related complications.[1] Integrated MRgBT suites allow implant placement, image acquisition, and treatment delivery in the same physical location, reducing positional variations (ie, that could happen during patient transport) between catheter placement and treatment and ensuring efficient time utilization.[2,3]

Usually, MR is incorporated into brachytherapy planning using diagnostic MRs, which can be fused with real-time ultrasound (US) images, but this presents challenges, for example, the uncertainty of fusion and instances where conventional imaging fails to visualize target volumes or where performing them might be technically challenging.[2] MRgBT has the potential to improve target delineation and thereby reduce treatment volumes, which has been associated with excellent local control and lower toxicity rates in cervical cancer, where it has been most well studied.[4] The reduction in unintentionally irradiated volumes is particularly beneficial for patients previously treated with radiation therapy (RT), where MRgBT presents an alternative to morbid surgery or palliative systemic therapy.[5,6]

Sources of support: This work had no specific funding.

Further data regarding the manuscript may be obtained by contacting the corresponding author.

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https://doi.org/10.1016/j.prro.2025.12.009
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Table 1 Summary of cases treated with magnetic resonance guided brachytherapy (MRgBT)

Cases	Primary site	Site of current treatment	Previous RT to pelvis	Present MRgBT dose	Adjuvant treatment	Local control
1	Prostate	Prostate	Yes	15 Gy in 1 fraction	46 Gy in 23 fractions (EBRT)	Yes
2	Prostate	Mesorectal nodule	Yes	33 Gy in 2 fractions	None	Yes
3	Sarcoma	Para coccygeal soft tissue	Yes	12 Gy in 1 fraction	30 Gy in 15 fractions (EBRT)	Yes
4	Bladder	Positive urethral margin	No	21 Gy in 3 fractions	Cisplatin-based chemotherapy	Yes
5	Bladder	Positive urethral margin	No	15 Gy in 1 fraction	37.5 Gy in 15 fractions (EBRT)	No
6	Anus	Mesorectal node	Yes	21 Gy in 3 fractions	None	No

Abbreviations: EBRT = external beam radiation therapy; RT = radiation therapy.

Herein, we sought to review our institutional experience of nongynecologic patients treated with MRgBT where brachytherapy would not have been feasible without real-time MR guidance.

Procedure

We conducted a review of a prospectively maintained institutional database approved by the institutional research ethics board of patients with nongynecologic primary cancers who were treated in our MRgBT suite from January 2017 to December 2024.

Patients underwent a prebrachytherapy planning MRI scan for target delineation. Implant placement, planning, imaging, and treatment were done in the integrated MRgBT facility.[7] The suite had an open bore magnetic resonance imaging device on rails (1.5 T Magnetom Espree; Siemens, Munich, Germany), a C-arm (Philips Veradius Neo), and a remote afterloader, RAL (Elekta microSelectron v3).

Patients received a bowel preparatory regimen and antibiotic prophylaxis. Procedures were performed under general anesthesia. Patients had a Foley catheter inserted and were positioned head-first on a flat-topped MR couch, immobilized with custom leg straps, and remained in this position throughout treatment. An initial scan was performed using a transabdominal or endorectal coil and a high dose rate (HDR) perineal template (Hologic) fixed to the MR couch. Three-plane scout images were acquired to confirm the alignment of the coil and template.

An MRI scan was performed for disease characterization, including T2-weighted and, when necessary, diffusion-weighted sequences. A 3.5-mm spaced grid representing the template was fused with the images. Needle insertion was performed iteratively, with proton density-weighted scans verifying placement, followed by high-resolution T2-weighted axial imaging for planning.

Target volumes were delineated on the RayStation platform, and margins were added per institutional protocols to create planning volumes.[8] In parallel, the images were opened in the treatment planning workstation (Oncentra Brachy v4.3.1 or v4.5.2, Elekta), where catheters were reconstructed. Finalized contours from RayStation were imported into the treatment plan, and inverse optimization was performed. Prescriptions balanced organ-at-risk tolerances with maximum target dosing. After treatment, the template and catheters were removed, and hemostasis was confirmed before emergence from anesthesia.

Table 1 shows the summary of cases treated with MRgBT.

Prostate Cancer

Case 1

A 71-year-old man was diagnosed with unfavorable intermediate-risk prostate cancer, on a background of pelvic RT (45 Gy in 25 fractions followed by 9 Gy boost) and abdominoperineal resection (APR) for rectal cancer approximately 25 years prior. Prostatectomy was not recommended in the multidisciplinary tumor board (MDT), given the potential for morbidity. Radical external beam RT (EBRT) was planned initially, but the bladder base and urethra dose constraints were excessively high on the background of prior RT. The treatment plan was revised to include a whole-gland prostate brachytherapy boost followed by EBRT (46 Gy in 23 fractions) and 6 months of hormone therapy. The absence of a rectum precluded the use of transrectal ultrasound, which would typically be used for delivering image guided HDR prostate brachytherapy, so MRgBT was used to accurately place catheters under image guidance.

Under MR guidance using a transabdominal coil (because of prior APR, transrectal coil placement was not possible), 14 catheters were inserted. A standard dose of 15 Gy was delivered to the target volume, followed by

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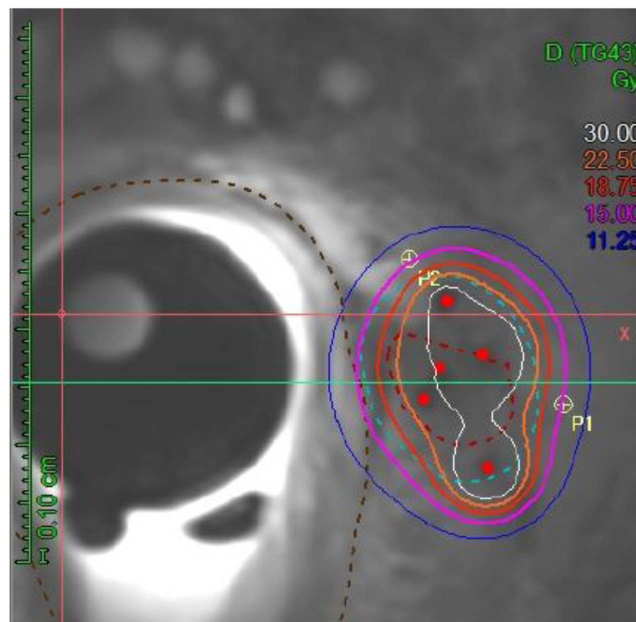

Figure 1 Pelvic magnetic resonance imaging (MRI) scan with dose distribution for the mesorectal nodule recurrence in prostate cancer (case 2).

EBRT. No toxicities were observed at the last follow-up, with an excellent biochemical response (prostate-specific antigen [PSA] 7.4 μg/mL at diagnosis to 0.05 μg/mL 9 months posttreatment).

Case 2

A 68-year-old man with a history of low-dose-rate brachytherapy for favorable intermediate-risk prostate cancer developed biochemical recurrence and a solitary mesorectal nodule on a prostate-specific membrane antigen positron emission tomography scan 6 years later. MDT opined that surgery could result in considerable morbidity, systemic therapy should be reserved for more widespread disease, and EBRT would result in a significant dose to the rectum; therefore, brachytherapy was recommended.

Visualization of the mesorectal nodule would have been challenging with US- or computed tomography (CT) scan guided brachytherapy. Accurate target visualization facilitated using MR MRI scans enabled brachytherapy treatment. The mesorectal nodule was treated with MRgBT using an endorectal coil and HDR template with 4 interstitial catheters (Fig. 1), with doses of 18 Gy and 15 Gy in 2 fractions, 1 week apart, which was well tolerated with no significant acute toxicities and no late toxicity at the last follow-up. Although he experienced an initial decline in PSA levels after brachytherapy (6.8 μg/mL before the procedure to 0.17 μg/mL 2 months after) with radiological regression of the nodule, his PSA levels subsequently rose, and restaging revealed metastatic disease to bone. The treated nodule remained under local control at the last follow-up.

Sarcoma

Case 3

A 42-year-old man was diagnosed with myxoid liposarcoma in his right ischiorectal fossa. He received preoperative radiation (50 Gy in 25 fractions), followed by wide local excision because he opted against definitive APR. Three years later, he recurred with a 1 cm nodule near the coccyx on an MRI scan with no other disease. Surgical salvage with APR and coccyx resection was recommended, but the patient declined because of the associated morbidity. Radical-dose EBRT was not recommended given the volume of reirradiation. The MDT consensus was to proceed with brachytherapy boost followed by lower-dose EBRT. Visualizing and targeting the recurrent disease with alternative imaging modalities was challenging, and hence, it was decided to proceed with MRgBT delivering 12 Gy using 4 interstitial needles (Fig. 2a). This was followed by 30 Gy in 15 fractions of EBRT (Fig. 2b). Posttreatment imaging demonstrated disease regression (Fig. 2c), and the patient experienced minimal toxicity (radiographic fat necrosis in the gluteal muscle) with no evidence of disease 7 years following treatment.

Bladder Cancer

Case 4

A 69-year-old woman underwent cysto-hysterectomy for muscle-invasive bladder cancer (pT2aN0) with a

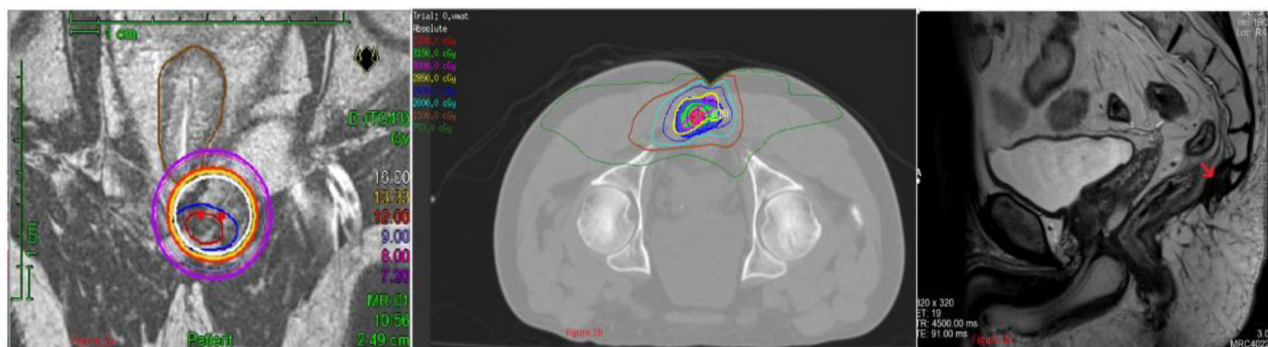

Figure 2 (a) Pelvic magnetic resonance imaging (MRI) scan with catheters in situ showing dose distribution for the recurrent sarcoma with para coccygeal soft tissue deposit (case 3). (b) External beam radiation therapy dose distribution (patient in prone position). (c) Posttreatment resolution of the para coccygeal soft tissue sarcoma (red arrow).

positive urethral margin. Restaging the MRI scan did not show residual disease. MDT recommended adjuvant RT given the positive urethral margin. Given this location and the aim of limiting the volume of radiation, the patient underwent MRgBT using a vaginal cylinder with a perineal template. A total of 6 interstitial catheters and 2 peri-cylinder catheters were positioned under MR guidance (Fig. 3), and 21 Gy in 3 fractions (7 Gy per fraction, mimicking postoperative endometrium dose) was delivered weekly over 3 weeks. She subsequently received adjuvant chemotherapy and remains disease-free after 8 years with no associated RT toxicities.

Case 5

A 77-year-old man with a prior radical prostatectomy was diagnosed with muscle-invasive bladder cancer. He received neoadjuvant chemotherapy followed by radical cystectomy (ypT2N0) with a positive urethral margin. At 1-year follow-up, urine cytology showed malignant cells, and the restaging MRI scan revealed no residual disease. In view of the positive urethral margin with malignant cytology, he was planned for salvage brachytherapy followed by EBRT to the urethral stump and anastomotic site. The brachytherapy catheter was initially inserted into a Foley catheter initially placed in the remnant urethra and advanced into the urethral stump under MR guidance, and 15 Gy was delivered to the urethral stump. The positive urine cytology and the preference to avoid chemotherapy influenced the decision to supplement the brachytherapy with a lower dose of EBRT (37.5 Gy in 15 fractions) (Fig. 4a, b), which was well tolerated. Nine months later, he had persistently positive cytology and underwent intravesical Bacillus Calmette-Guérin therapy with negative cytology at the last follow-up.

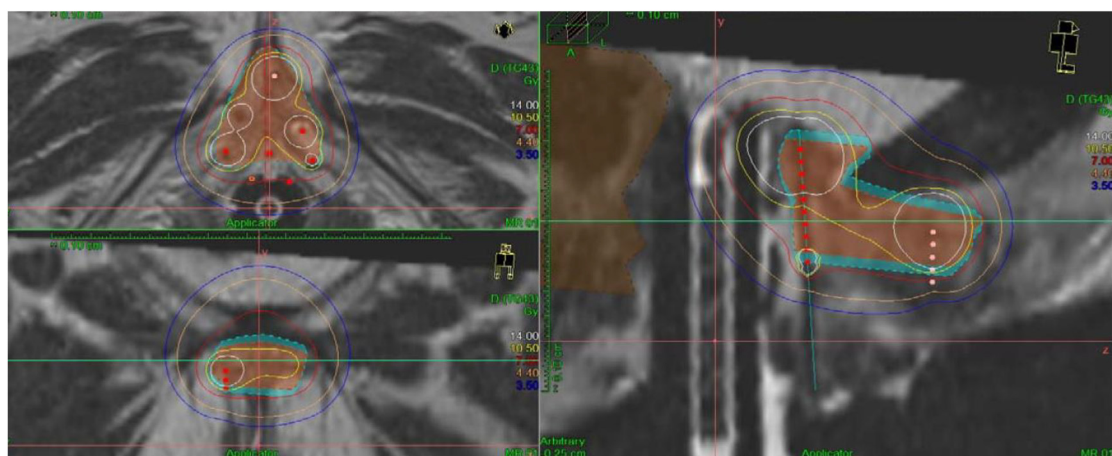

Figure 3 Pelvic magnetic resonance imaging (MRI) scan of margin-positive bladder cancer with catheters and vaginal cylinder in situ with dose distribution (case 4).

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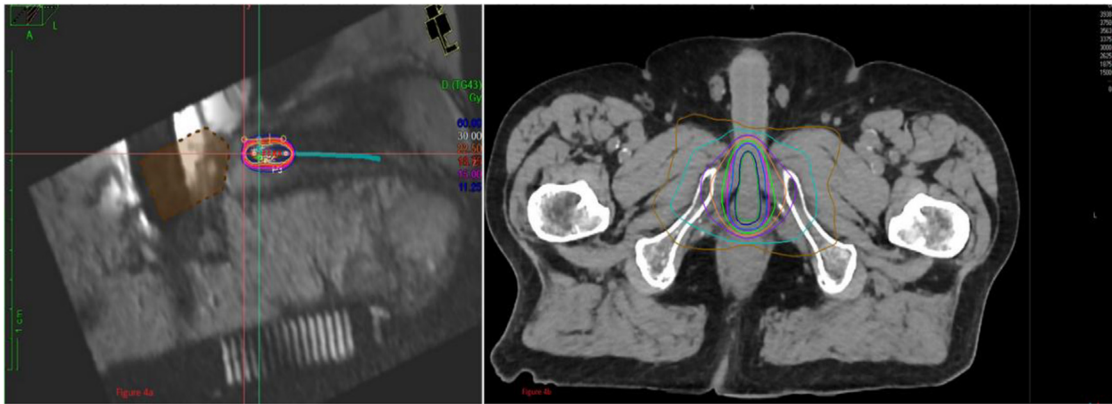

Figure 4 (a) Magnetic resonance imaging (MRI) scan of the pelvis showing brachytherapy dose distribution to the urethral stump (case 5). (b) Planning computed tomography (CT) scan showing the external beam brachy therapy dose distribution to the target volumes (urethral stump and site of anastomosis).

Anal Cancer

Case 6

A 68-year-old man diagnosed with cT2N2M0 anal canal cancer was treated with concomitant chemo-RT (57.6 Gy in 32 fractions with concurrent 5-fluorouracil and mitomycin). He subsequently developed periaortic lymph node recurrence 2 years later, treated with stereotactic body RT (SBRT). He subsequently developed a left mesorectal nodule recurrence (1.7 × 1.5 cm) 1 year after stereotactic body RT, potentially involving the rectal wall. Given the overlap from his prior treatment, further EBRT was not recommended. Surgery would have involved salvage APR, which he declined, and the preference was to preserve systemic therapy for more extensive disease. Optimum visualization and targeting of the recurrent nodule was possible with an MRI scan, and he received MRgBT (7 Gy × 3 fractions; dose limited caused by rectal tolerance). An endorectal coil with the perineal template was used, and 6, 7, and 8 catheters were used in the 3 sessions to target the mesorectal nodule (Fig. 5). Posttreatment, there were a few episodes of rectal incontinence, which resolved at 3 months with no subsequent late toxicities. Two years later, there was a subsequent enlargement of the treated node on follow-up imaging, which was positive for cancer on biopsy, and he underwent salvage APR, which showed squamous carcinoma in the nodule removed with positive radial margins with no other nodal involvement. He has a slowly enlarging asymptomatic presacral mass on follow-up, which has been deemed unresectable.

Discussion

In this case series, we have demonstrated how MRgBT allows for dose-escalated treatment to tumors in special cases where conventional methods of delivering radiation therapy may not be feasible.

Targeted radiation with MRgBT can be used in situations where (1) conventional US/CT scan guided brachytherapy may be difficult because of challenges in visualizing the tumor (ie, cases 2, 3, and 6) or visualizing

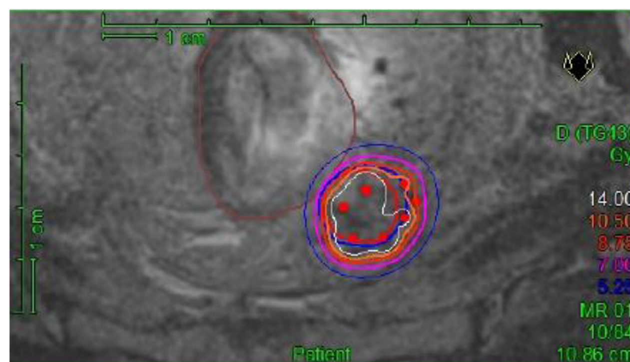

Figure 5 Pelvic magnetic resonance imaging (MRI) scan with catheters in situ showing the dose distribution around the mesorectal nodule abutting the rectum (case 6).

the area of interest (ie, the urethral stump in cases 4 and 5) accurately; (2) performing conventional US/CT scan guided brachytherapy would be technically unfeasible (ie, case 1); (3) when EBRT is limited by prior radiation treatment courses (ie, cases 1, 2, 3, and 6); or (4) where treatment volumes might otherwise be large with concerns of toxicity (ie, cases 4 and 5).

Two out of the 6 patients we treated failed locally, and 1 patient failed distantly. The local failure observed in the patient with anal cancer (case 6) was in the targeted node receiving the high-dose brachytherapy to a total cumulative dose of 21 Gy in 3 fractions at 7 Gy per fraction weekly. Our ability to deliver escalated doses to the recurrent disease was limited by the previous course of radiation he had received in the radical setting for the primary treatment of the anal canal carcinoma. The second failure occurred in a postoperative bladder cancer patient (case 5) who had persistently positive urine cytology after treatment of the urethral stump (site of positive margin). However, his treatment was initiated almost a year after the primary surgery, after detection of positive urine cytology, and not in the immediate postoperative setting, because of case 4, which could have a role in the suboptimal local control in the situation. In case 2, distant metastatic disease to the bone with maintained local control was seen in a patient with prostate cancer with a solitary mesorectal nodule treated with MRgBT (case 2).

The occurrence of such recurrences emphasizes the need for careful patient selection, multidisciplinary discussion, and informed decision-making in special situations like the ones described. Fortunately, no patients in this series experienced grade 3 or higher toxicities, highlighting the safety of MRgBT and the possibility of escalating doses to improve local control in the future. Furthermore, MRgBT did not prohibit the use of salvage therapies, which were performed in the 2 patients with local failure following treatment.

However, MRgBT is not a widely available resource and has associated limitations. First, developing such a facility within a Radiation Oncology division can be challenging because of logistics, high cost, and a likely low cost-benefit ratio if its use is limited to the relatively rare situations where real-time MRgBT is the only feasible treatment option. This may be partly offset by sharing the suite with colleagues (ie, interventional radiology), for whom real-time MR visualization can optimize the management of patients.[9] Currently, the availability of MRgBT is a limiting factor, with very few centers having access to such facilities. Awareness among radiation oncologists about specific situations where such treatment options could be used will enable referral to such centers, thereby maximizing their utility for patients.[6,10,11] Efforts to set up a registry for MRgBT to track patient indication and treatment outcomes can help serve as a guide in helping oncologists better select patients who would benefit from this treatment and understand its utility from a health system and cost-effectiveness perspective.

Conclusion

MRgBT with real-time visualization offers the ability to perform customized treatments in situations where alternative therapies pose significant morbidity or safety concerns. Its safety, tolerability, and efficacy in controlling targeted disease can be used to maximum advantage with proper patient selection and realistic expectations of outcomes.

Disclosures

Rachel M. Glicksman reports grant funding from TerSera and Astellas, unrelated to the current work, and honoraria from Bayer, TerSera, Knight, AbbVie, and Tolmar, unrelated to the current work. The other authors have nothing to disclose.

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