Integrating Dedicated MRI into Radiotherapy Treatment Planning: Clinical Experience at the University of Osaka Hospital

Masataka Nakai, M.D.[1]; Takero Hirata, M.D., Ph.D.[2]; Keisuke Tamari, M.D., Ph.D.[1]

[1] Department of Radiation Oncology, Graduate School of Medicine, The University of Osaka, Japan
[2] Department of Radiation Oncology, Nara Medical University, Nara, Japan

Introduction

The University of Osaka Hospital (UOH) is located in Suita City, Osaka, Japan, and is one of the major cancer centers in the Osaka region. Approximately 800–900 patients receive radiotherapy at UOH per year. Ten physicians, 3 medical physicists, 17 radiation technologists, and 6 nurses comprise the radiation oncology team. We routinely employ intensity-modulated radiotherapy (IMRT) for definitive treatment of all primary sites, and also use stereotactic radiotherapy for brain tumors, lung cancer, liver cancer, prostate cancer, and oligometastases. UOH is one of the most advanced radiotherapy facilities in Japan.

In Japan, it is uncommon for radiation oncology departments to have a dedicated MRI scanner; most institutions share MRI resources with the diagnostic radiology department, which can limit scheduling flexibility and the use of radiotherapy-specific immobilization devices. Our department relocated to a new building in 2025 and now operates four linear accelerators: TrueBeam, TrueBeam Edge, Ethos (Siemens Healthineers, Forchheim, Germany), and Radixact (Accuray Inc., Madison, WI, USA). The imaging suite includes two CT scanners — an Aquilion ONE (Canon Medical, Ōtawara, Japan) and a SOMATOM go.Open Pro (Siemens Healthineers, Forchheim, Germany) — and, notably, a dedicated 1.5T MRI scanner (MAGNETOM Sola RT Pro Edition, Siemens Healthineers, Forchheim, Germany) exclusively assigned to the radiation oncology department.

For MRI simulation, patients are positioned using the INSIGHT MR RT Overlay (CQ Medical, Coralville, IA, USA), a flat tabletop overlay compatible with the treatment position, which ensures reproducible setup between MRI and CT simulation. Treatment planning and oncology information management are performed using Eclipse and Aria (Siemens Healthineers, Forchheim, Germany), respectively (Fig. 1).

1 The 1.5T MAGNETOM Sola RT Pro Edition installed in the radiation oncology department at The University of Osaka Hospital. The INSIGHT MR RT Overlay (CQ Medical) mounted on the scanner table enables patient positioning in the radiotherapy treatment position, ensuring reproducible setup identical to that used for CT simulation.

Precise delineation of tumors and organs at risk is essential for radiotherapy treatment planning. MRI provides superior soft-tissue contrast compared with CT, enabling clearer delineation of the boundary between tumors and surrounding normal tissues. This characteristic may contribute to improved accuracy in target volume definition. In addition, multiplanar imaging with MRI facilitates a more accurate understanding of the three-dimensional extent of tumors and their spatial relationships with adjacent organs. In recent years, functional imaging techniques such as diffusion-weighted imaging (DWI) have also become available, and imaging data reflecting the biological properties of tumors are increasingly being incorporated into treatment planning. It should be noted that MRI is susceptible to geometric distortions; therefore, the use of a dedicated RT-edition MRI scanner with built-in 3D distortion correction is essential to ensure spatial accuracy for treatment planning.

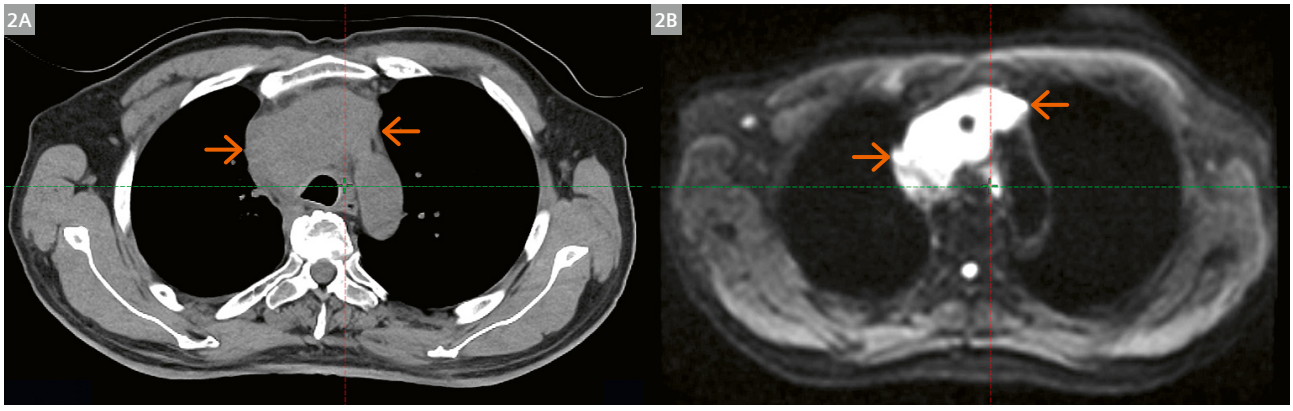
PET-CT is also useful for tumor delineation; however, in Japan, its application in routine cancer care is restricted by the national health insurance system, limiting the frequency with which it can be performed. Therefore, the ready availability of a dedicated MRI scanner may contribute to improving the quality of radiotherapy by enabling more accurate target definition. Having a dedicated MRI scanner within the department also offers significant practical advantages in terms of time and resource efficiency. At UOH, MRI simulation is routinely performed on the same day as CT simulation, reducing the number of hospital visits required for treatment planning. The ability to scan patients in the identical treatment position using the same immobilization devices not only improves image fusion accuracy but also streamlines the overall planning workflow, reducing the time from simulation to treatment plan completion. In the following sections, we present representative cases in which MRI proved particularly useful for treatment planning.

Thoracic cancer

MRI is particularly useful in thoracic malignancies where soft-tissue contrast is critical for accurate tumor delineation. Figure 2 shows imaging of a 76-year-old man with thymic carcinoma involving the great vessels. Contrast-enhanced CT could not be performed because of impaired renal function. In such cases, it has traditionally been difficult to accurately determine the extent of the tumor and perform precise delineation. However, by utilizing MRI sequences including T2-weighted imaging (T2WI) and DWI, the extent of the tumor could be clearly visualized, allowing accurate target delineation. Based on these imaging findings, we were able to deliver radiotherapy using volumetric modulated arc therapy (VMAT) with a total dose of 60 Gy in 30 fractions.

Respiratory motion imaging using MRI

Respiratory tumor motion is of particular concern for radiation oncologists in the treatment of primary lung cancer and pulmonary metastases. Accurate assessment of this motion is essential for delineating the internal target volume (ITV). Four-dimensional CT (4D-CT) is widely



2 A 76-year-old male patient with thymic carcinoma involving the great vessels. Plain CT without contrast enhancement shows a mediastinal mass with poorly defined borders (**2A**, arrows). Diffusion-weighted imaging (DWI) on simulation MRI clearly delineates the tumor extent, enabling accurate target volume definition for radiotherapy planning (**2B**, arrows).

used to evaluate respiratory motion and to define the ITV in thoracic radiotherapy. However, 4D-CT involves additional exposure to ionizing radiation and may suffer from motion-related artifacts or limited soft-tissue contrast. In contrast, four-dimensional MRI (4D-MRI) provides excellent soft-tissue contrast and enables dynamic assessment of respiratory motion without ionizing radiation. These characteristics make 4D-MRI a promising imaging modality for motion assessment and target definition in radiotherapy planning.

Figure 3 shows imaging of a 70-year-old woman with a pulmonary metastasis from hepatocellular carcinoma in the left lower lobe, who received stereotactic body radiation therapy (SBRT). 4D-MRI was used to assess respiratory tumor motion and delineate the ITV, clearly demonstrating the displacement of the tumor between end-inspiration and end-expiration phases.

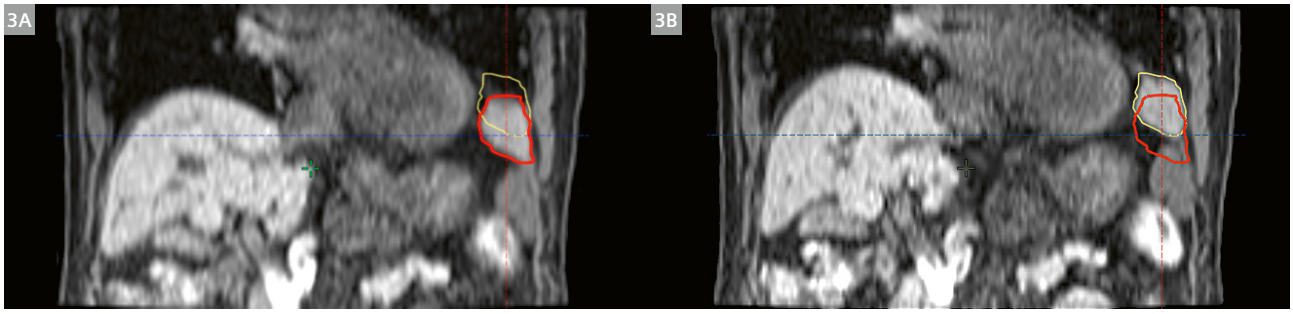
Prostate cancer

We perform salvage SBRT for locally recurrent prostate cancer after prior definitive radiation therapy. The standard prescription doses are 34 Gy in five fractions for post-external beam cases, and 36 Gy in six fractions for post-brachytherapy cases. Particularly in cases following external beam radiation therapy, treatment plans were created and optimized to deliver high doses to the gross tumor volume (GTV), with the prescription isodose line set at approximately 50%. Figure 4 shows CT and MRI images, as well as the dose distribution, from a case in which stereotactic radiotherapy was administered as a re-irradiation treatment for local recurrence following heavy-ion beam therapy. As a principle, no new androgen deprivation therapy (ADT) is initiated in conjunction with salvage SBRT. This policy allows for a clear assessment of local therapy efficacy and avoids ADT-induced target volume changes that could compromise the accuracy of target delineation. The treatment preparation process begins with the insertion of three gold fiducial markers and a rectal spacer into the prostate. Simulation CT and MRI are performed 1–2 weeks later. During the CT scan, a urinary catheter is inserted to visualize the urethra; the patient voids through the catheter, 100 mL of saline is instilled into the bladder, and the catheter is clamped to ensure reproducible bladder filling.

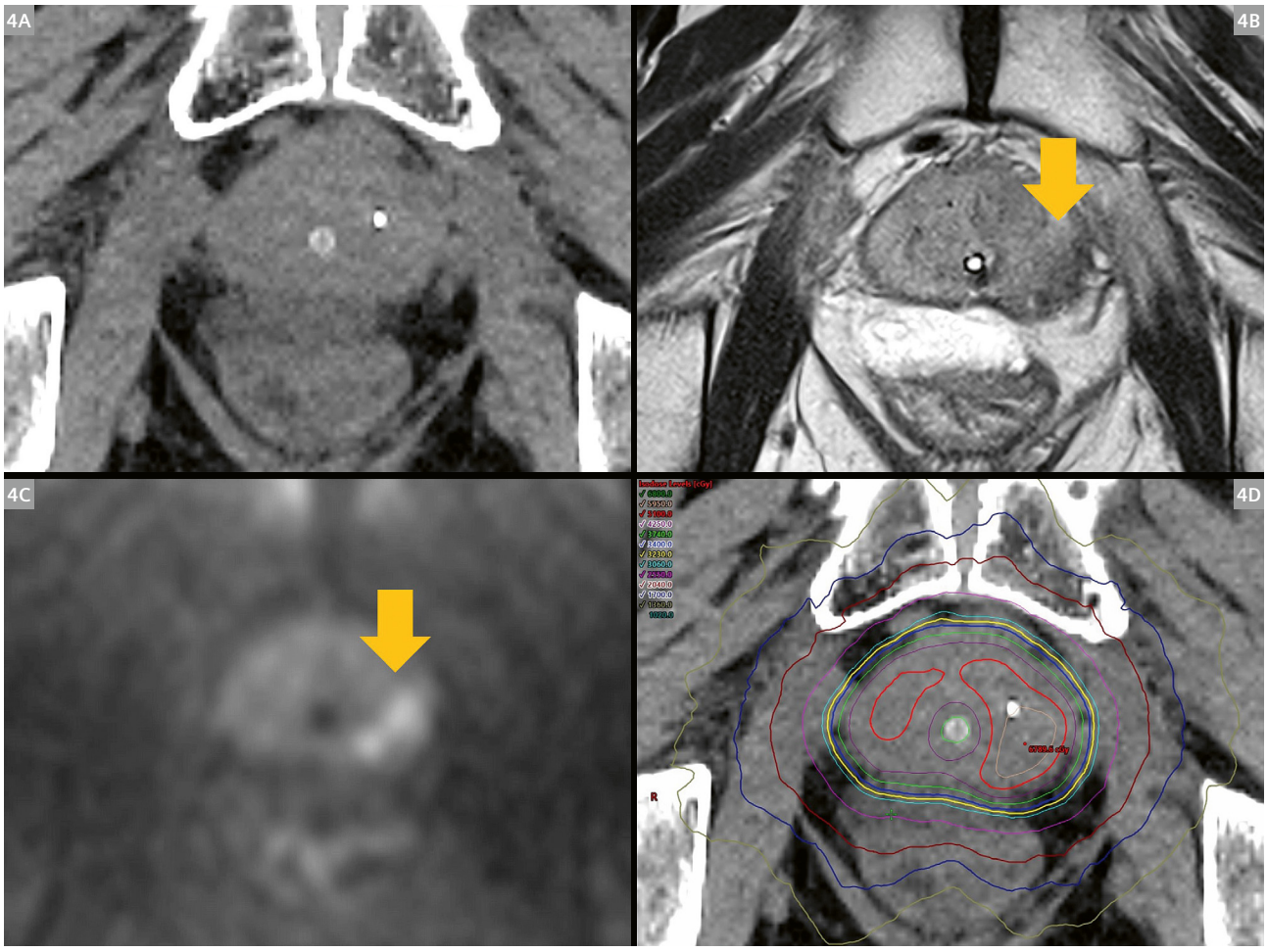
Importantly, the MRI scan is acquired with the patient positioned to match the treatment setup defined during the simulation CT. This approach minimizes positional discrepancies between the two datasets and enables highly accurate image fusion, ensuring that the tumor location identified on MRI corresponds precisely to the coordinate system of the treatment plan. Because the prostate can shift and deform depending on body position and immobilization, performing MRI under treatment conditions — rather than in a standard diagnostic position — is critical for reliable target volume delineation.

For target volume delineation, MRI and sometimes prostate-specific membrane antigen (PSMA)-PET are fused with the simulation CT. The MRI provides superior soft-tissue contrast, which is essential for accurately delineating the GTV and prostate boundary. In the salvage re-irradiation setting, precise identification of the prostate contour is particularly important because we define the clinical target volume (CTV) as the prostate itself, without adding a margin, and even a small contouring error may result in either geographic miss or unnecessary dose to previously irradiated organs at risk. CT alone tends to overestimate the prostate volume owing to its limited ability to distinguish the prostate from surrounding structures such as the Santorini venous plexus; it also has difficulty identifying the prostate apex, the boundary of the rectal spacer. MRI overcomes these limitations and enables confident delineation of the target volumes and organs at risk, all of which are critical for the steep dose gradients required in salvage SBRT.

In addition, MRI assists in confirming the spatial relationship between the PSMA-avid lesion and the biopsy-proven recurrent focus, thereby adding anatomical validation to the functional information provided by PET. Gold



3 Respiratory tumor motion assessed by 4D-MRI in a 70-year-old female patient with a pulmonary metastasis from hepatocellular carcinoma in the left lower lobe, undergoing stereotactic body radiotherapy (SBRT). Gross-target-volume (GTV) contours at end-inspiration (yellow) and end-expiration (red) are overlaid on the end-inspiration phase image **(3A)** and the end-expiration phase image **(3B)**, illustrating the range of respiratory motion used to define the internal target volume (ITV).



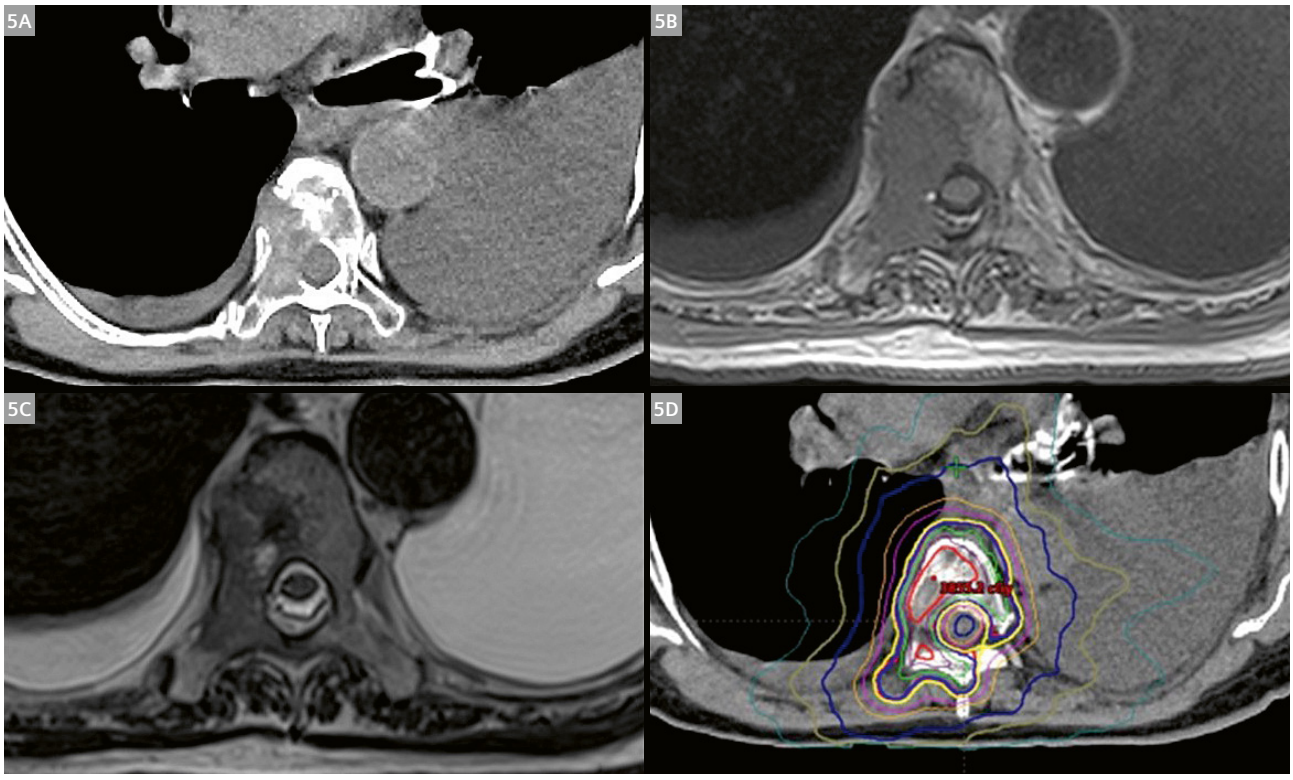
4 Simulation CT and MRI for salvage stereotactic body radiotherapy (SBRT) planning in a representative case of locally recurrent prostate cancer. **(4A)** Axial simulation CT image showing the gold fiducial markers. **(4B)** Axial T2-weighted MRI acquired in the same immobilization device and patient position as the simulation CT, demonstrating the recurrent lesion as a low-signal-intensity focus within the prostate. **(4C)** Apparent diffusion coefficient (ADC) map showing restricted diffusion corresponding to the recurrent lesion, aiding in tumor localization. **(4D)** Dose distribution of the salvage SBRT plan. The high-dose region exceeding 150% of the prescribed dose is concentrated within the gross tumor volume, while steep dose gradients spare the adjacent rectum and urethra.

fiducial markers are clearly visualized on CT but can also be identified on specific MRI sequences, which facilitates accurate image co-registration. Prior to each treatment fraction, a verification CT is acquired with the same urinary catheter and bladder-filling protocol as the planning session, and the position of the gold markers relative to the prostate and urethra is confirmed to ensure the absence of intrafraction displacement. Based on our experience, we consider the fusion of MRI and CT to be indispensable for safe and effective salvage re-irradiation of the previously treated prostate.

Spinal metastases

Radiotherapy for spinal metastases has long been widely performed with the aims of pain relief, prevention of pathological fractures, and improvement of neurological deficits. In recent years, however, the use of SBRT for spinal metastases in the setting of oligometastatic disease has been increasing. In our department, the standard prescription doses for spinal SBRT are 26 Gy in two fractions or 35 Gy in five fractions for oligometastatic disease.

In SBRT to the spine, in order to reduce the radiation dose to the spinal cord located posterior to the vertebral body, it is essential not only to achieve highly precise irradiation but also to accurately contour both the target volume and the organs at risk (OARs).



5 Simulation CT and MRI images, along with the dose distribution, for a 76-year-old patient with lung adenocarcinoma, who underwent SBRT for a metastasis to the sixth thoracic vertebra. **(5A)** Axial image of the planning CT; **(5B)** Axial T1-weighted image of the planning MRI; **(5C)** Axial T2-weighted image of the planning MRI; **(5D)** Dose distribution. On the planning MRI, the tumor extending from the right side of the vertebral body to the right pedicle is clearly delineated. The dose distribution demonstrates that an adequate dose was delivered to the target volume while the dose within the spinal canal was reduced.

MRI clearly delineates the boundary between metastatic lesions and normal bone. In addition, on T2WI, cerebrospinal fluid within the spinal canal appears as high signal intensity, allowing accurate visualization of both the tumor and the spinal cord (an organ at risk) in cases where the tumor extends into the spinal canal. By fusing MRI with planning CT images, these anatomical structures can be identified more precisely. It is also important to note that the position of the spinal cord can vary depending on patient positioning; therefore, acquiring MRI in the same treatment position as the planning CT is essential to ensure accurate correspondence between the two image datasets and to avoid underestimating the dose to the spinal cord.

Figure 5 shows radiological images and the dose distribution for a 76-year-old patient with lung adenocarcinoma, who underwent SBRT for spinal metastasis. Figure 5A presents the planning CT image. Osteolytic changes are observed extending from the right side of the vertebral body to the right pedicle, suggesting progression of bone metastasis; however, the boundary with normal bone and surrounding soft tissues, including the spinal cord, is not clearly defined. Figures 5B and 5C show T1-weighted and T2-weighted MRI images of the same region used for treatment planning. The metastatic lesion is depicted as a low-signal area on both T1WI and T2WI, with a clear boundary from the surrounding bone tissue. Furthermore, on T2WI, the boundary between the tumor extending into the spinal canal and the cerebrospinal fluid can be clearly identified, enabling precise delineation of the spinal cord within the canal.

At our institution, SBRT of 26 Gy in two fractions was delivered for this spinal metastasis. Figure 5D shows the dose distribution. After fusing MRI with the planning CT images, the target volume and OARs were contoured, and the dose to the spinal cord was kept within acceptable limits (spinal cord Dmax = 15.5 Gy, V13Gy = 0.35 cc).

Conclusions

In this article, we have presented representative cases in which a dedicated simulation MRI proved particularly valuable for radiotherapy treatment planning at UOH. MRI enabled accurate tumor delineation, and 4D-MRI allowed precise assessment of respiratory tumor motion.

The introduction of a dedicated MRI scanner within our radiation oncology department has expanded the scope

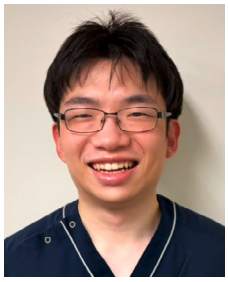
of treatment planning beyond what CT alone can offer, particularly in cases where soft-tissue contrast is critical or where functional imaging provides additional biological information. Acquiring MRI in the treatment position using the same immobilization devices as CT further enhances the reliability of CT–MRI co-registration, contributing to the overall precision of radiotherapy.

We hope that our experience at UOH will serve as a practical reference for institutions that are considering integrating MRI into their radiotherapy workflows, and that it will contribute to the broader adoption of MRI-guided treatment planning in the region. While dedicated simulation MRI remains uncommon in Japanese radiation oncology departments, the cases presented here clearly demonstrate its transformative value. Based on our experience, we strongly recommend the introduction of a dedicated MRI scanner within the radiation oncology department. Having immediate access to simulation MRI has fundamentally transformed our treatment planning process, enabling more accurate target delineation, reducing patient burden through same-day CT and MRI simulation, and streamlining the overall workflow. We are firmly convinced that a dedicated MRI scanner is no longer a luxury but an essential component of a modern, high-precision radiotherapy department, and we strongly advocate for its broader adoption, particularly in Japan, where access to dedicated MRI in radiation oncology remains limited.

Contact

Keisuke Tamari, M.D., Ph.D.
Lecturer, Department of Radiation Oncology
Graduate School of Medicine
The University of Osaka
2-2 Yamadaoka
Suita, Osaka 565-0871
Japan
Tel.: +81-6-6879-3482
tamari@radonc.med.osaka-u.ac.jp

Takero Hirata, M.D., Ph.D.
Lecturer, Department of Radiation Oncology
Nara Medical University
840 Shijo-cho, Kashihara
Nara 634-8522, Japan
Tel.: +81-744-29-8908
t_hirata@maramed-u.ac.jp



Masataka Nakai, M.D.
Staff Physician, Department of
Radiation Oncology
Graduate School of Medicine
The University of Osaka
2-2 Yamadaoka, Suita
Osaka, 565-0871, Japan
m.nakai@radonc.med.osaka-u.ac.jp