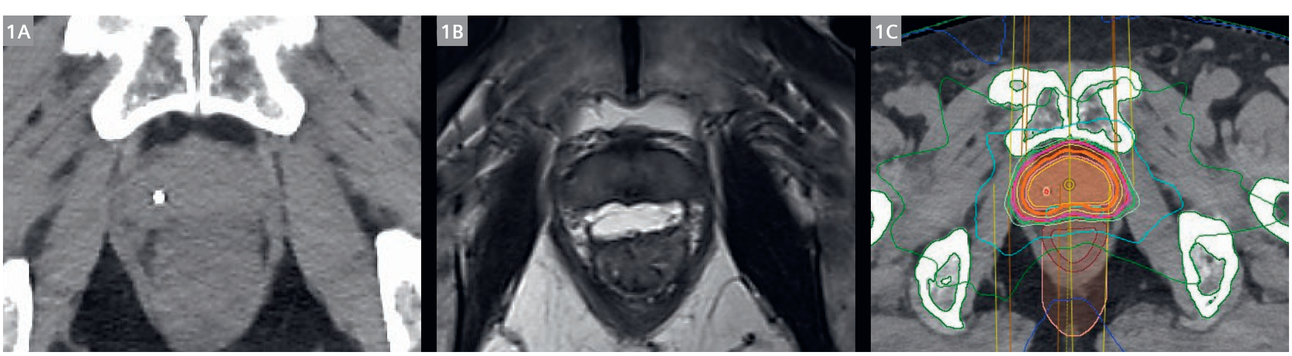
The Application and Utility of Radiotherapy Planning MRI at the Cancer Institute Hospital of JFCR

Yasuo Yoshioka, M.D., Ph.D.

Director of the Department of Radiation Oncology, Cancer Institute Hospital of the Japanese Foundation for Cancer Research (JFCR), Tokyo, Japan

The Japanese Foundation for Cancer Research (JFCR) is the oldest cancer institute in Japan. It consists of the Cancer Institute and the Cancer Institute Hospital of JFCR. The Cancer Institute Hospital of JFCR, located in Koto Ward, Tokyo, is one of the largest cancer hospitals in Japan. The hospital has six linear accelerator rooms with five linear accelerators: three TrueBeam systems and one Clinac EX system (Varian, a Siemens Healthineers Company, Palo Alto, CA, USA), and one Radixact system (Accuray, Sunnyvale, CA, USA). They are constantly running to provide radiotherapy to approximately 1,800 patients per year. All these systems allow for intensity-modulated radiation therapy (IMRT)/image-guided radiation therapy (IGRT). Currently, volumetric-modulated arc therapy (VMAT) or TomoHelical is used for all IMRT patients. IMRT accounted for approximately half of irradiations performed in 2020.

The Department of Radiation Oncology has two CT systems for radiotherapy planning: a SOMATOM Confidence RT Pro (Siemens Healthcare, Forchheim, Germany) and an Aquilion ONE (Canon, Ōtawara, Tochigi, Japan). It also has one self-propelled CT system that incorporates a brachytherapy unit (SOMATOM Definition AS, Siemens Healthcare, Forchheim, Germany). The hospital has five MRI systems, all of which are located in the Diagnostic Imaging Department. Of these, one system – a 3T MAGNETOM Skyra (Siemens Healthcare, Erlangen, Germany) – is shared by the Diagnostic Imaging Department and the Department of Radiation Oncology. The Department of Radiation Oncology has priority to use the MAGNETOM Skyra system for three sessions (1.5 hours) during the day. These are primarily used for radiotherapy planning and also partly for follow-up after the completion of radiotherapy. This article provides details about the application and utility of radiotherapy planning MRI at the Cancer Institute Hospital of JFCR.



1 A patient who received ultra-hypofractionated radiotherapy for prostate cancer. **(1A)** CT imaging is not good at making a clear distinction between Santorini's plexus surrounding the prostate and the prostate itself, often visualizing the prostate larger than it actually is. Also, CT imaging fails to show a clear border between the hydrogel spacer and the prostate/rectum. **(1B)** MRI clearly visualizes the contour of the prostate and the hydrogel spacer. **(1C)** Structures and isodose lines used for radiotherapy planning. The structure shown in the innermost yellow line is the prostate. The treatment was planned so that the orange bold line (a 100% isodose line) would be generally consistent with the CTV, and the outer bold line in pink (a 90% isodose line) would be generally consistent with the planning target volume (PTV).

Prostate cancer

We use four different radiation modalities for prostate cancer: moderately hypofractionated IMRT (70 Gy in 28 fractions), ultra-hypofractionated stereotactic body radiation therapy (SBRT, 36.25 Gy in 5 fractions), permanent implant brachytherapy (145 Gy), and high dose-rate interstitial irradiation (27 Gy in 2 fractions). Clinically indicated patients can voluntarily choose a treatment from this selection. The radiotherapy planning process is almost the same for IMRT and SBRT: the insertion of a gold marker and a hydrogel spacer 23 days prior to treatment initiation; CT and MRI scans for radiotherapy planning 14 days prior to treatment initiation; input of outline data for two days; radiotherapy planning for two days; and validation and registration for five days.

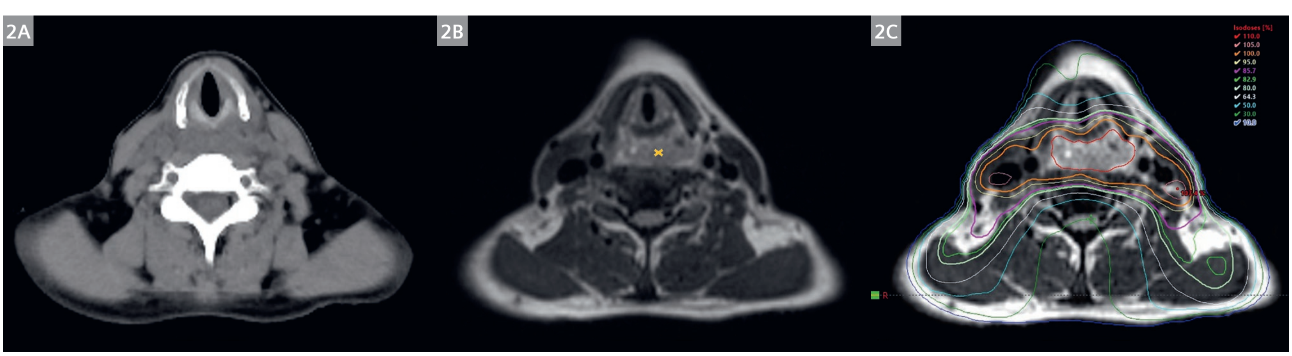
For the radiotherapy planning CT scan, the patient receives an enema one hour prior to the scan to promote defecation and urination, and then drinks water for urine collection. First, an immobilization device is prepared using the HipFix Thermoplastic Positioning System (CIVCO Radiotherapy, Orange City, IA, USA) and the CT scan is performed. Then the patient moves to the Diagnostic Imaging Department. The radiology technologist also moves to the Diagnostic Imaging Department with the immobilization device. While waiting, with sufficient time allowed for urine collection, the patient is instructed to urinate once and then store urine for one hour. Since the images for qualitative diagnosis are already acquired during preoperative staging MRI, the sequence focusing on prostate outlining is used for radiotherapy planning MRI. A total of three scans are performed: The T2-weighted (T2W) and VIBE FatSat scans provide excellent outlining, and a 3D MEDIC scan enables clear detection of the gold marker. It is known that CT images are not good at making a clear distinction between Santorini's plexus surrounding the prostate and the prostate itself; they visualize the prostate larger than it actually is. It is also difficult to identify the prostate apex and the edge of the hydrogel spacer when CT imaging is used, whereas MRI can detect them more clearly (Fig. 1). Based on these findings, we believe that MRI fusion is mandatory for high-precision radiotherapy for prostate cancer.

Head and neck cancer

At the Cancer Institute Hospital of JFCR, a setup similar to the one used for radiotherapy planning CT imaging is reproduced during radiotherapy planning for IMRT to treat head and neck cancer, and the MR imaging is performed on the same day. This allows an accurate fusion of CT and MRI images, resulting in precise contouring. We also use diagnostic MRI, but it often results in inaccurate fusion due to the difference in imaging postures. The basic type of scan we use is T2W, with the field of view (FOV) being adjusted for each case.

By visualizing not only primary lesions but also cervical lymph node metastases, MRI accurately captures the exact positioning of the target in relation to tissues such as blood vessels, muscles, bone, and nerves, and helps improve the quality of the contouring of the target (Fig. 2). MRI also provides clearer images of postoperative structural changes than plain CT imaging does. This enables better recognition of the muscles around the hyoid bone; the digastric, sternocleidomastoid, and scalene muscles; adipose tissue; and the carotid arteries (Fig. 3).

Generally, the diagnostic MRI is essential for determining the range of the progression of tumors that have invaded the skull base and those found in the head and face areas. Additional scans are also often performed to acquire MRI images for radiotherapy planning, which are

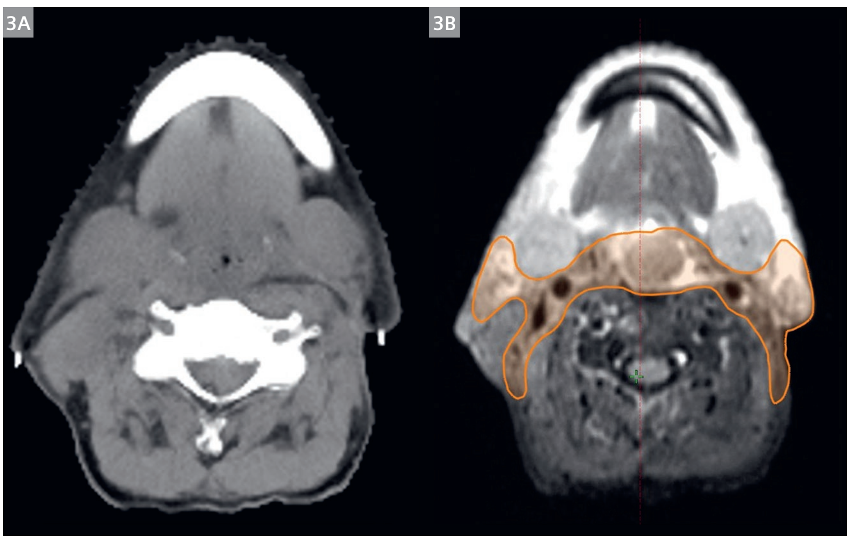


2 Hypopharynx cancer (posterior wall T3). **(2A)** On the radiotherapy planning plain CT scan, the tumor is poorly distinguished from the surrounding structures. **(2B)** On the MRI scan (T2W), the tumor (×) is easily recognized and its border with the prevertebral muscles is clearly visualized. The carotid arteries and cervical veins that serve as an indicator for enclosing the lymphatic region are clearly visualized as a flow void, which makes it easy to recognize the sternocleidomastoid and scalene muscles. **(2C)** A VMAT radiation dose distribution map. This allows for radiotherapy planning that accurately covers the target while avoiding OARs.

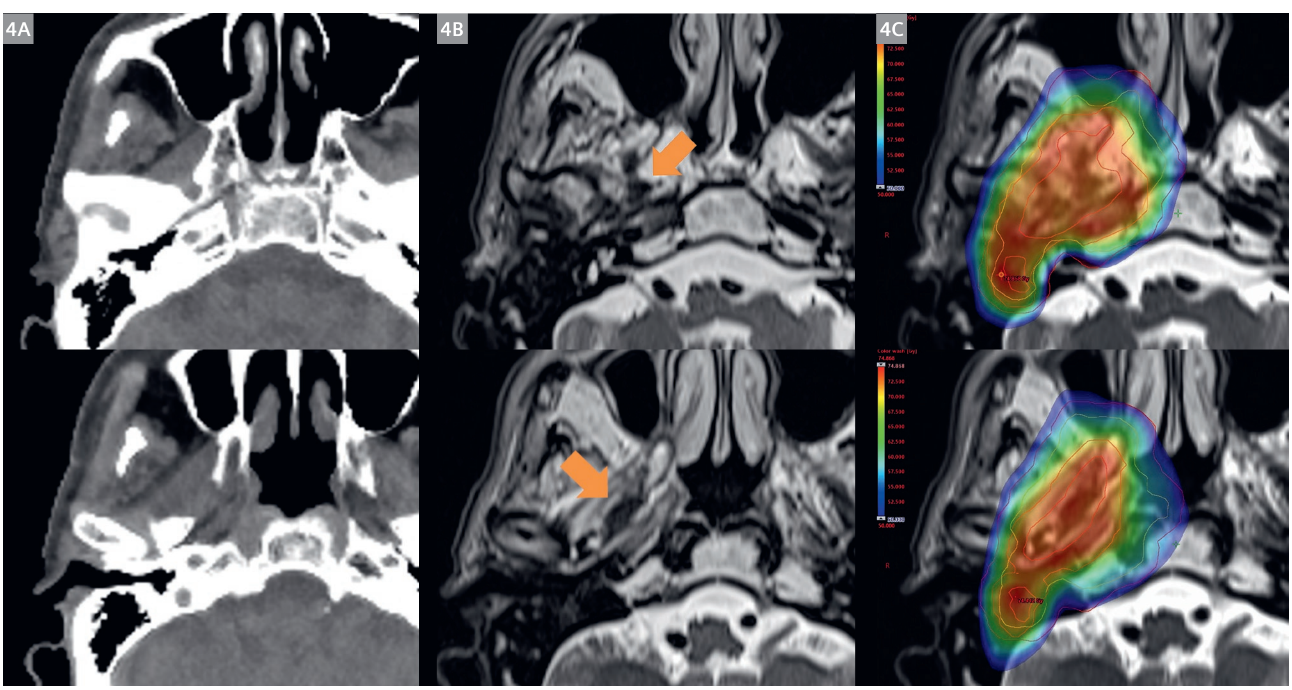
fused with diagnostic images for accurate contouring (Fig. 4). MRI can also successfully visualize the sites that are not well visualized by CT imaging because of scattered radiation caused by metal crowns in the mouth.

Conventional fractionation (66 to 70 Gy) to treat head and neck cancer requires a treatment duration of six to seven weeks, during which the tumor lesion changes in size and shape. There are many cases in which extensive cervical lymph node metastases have not completely disappeared at the end of scheduled concurrent chemoradiotherapy (CCRT). If this is the case, one needs to determine whether additional treatment should be provided. We leverage the assessment of the tumor size and signal changes using MRI during CCRT to determine the need for additional administration of anticancer drugs or resection.

MRI is very useful in clinical practice for precision radiotherapy for head and neck cancer and is expected to be indispensable in the future.



3 Postoperative radiotherapy for larynx cancer (after removal of the entire hypopharynx and larynx, followed by bilateral cervical lymph node dissection, resection of the left sternocleidomastoid muscle, and free jejunal reconstruction). **(3A)** On the radiotherapy planning CT (plain), it is difficult to distinguish each organ, with little adipose tissue in the lymphatic region following cervical lymph node dissection. **(3B)** The use of radiotherapy planning MRI (T2W) makes it easy to identify a postoperative structural change, and to enclose the lymphatic region (orange line) using the carotid arteries and cervical veins, muscles, and submaxillary gland as indicators.

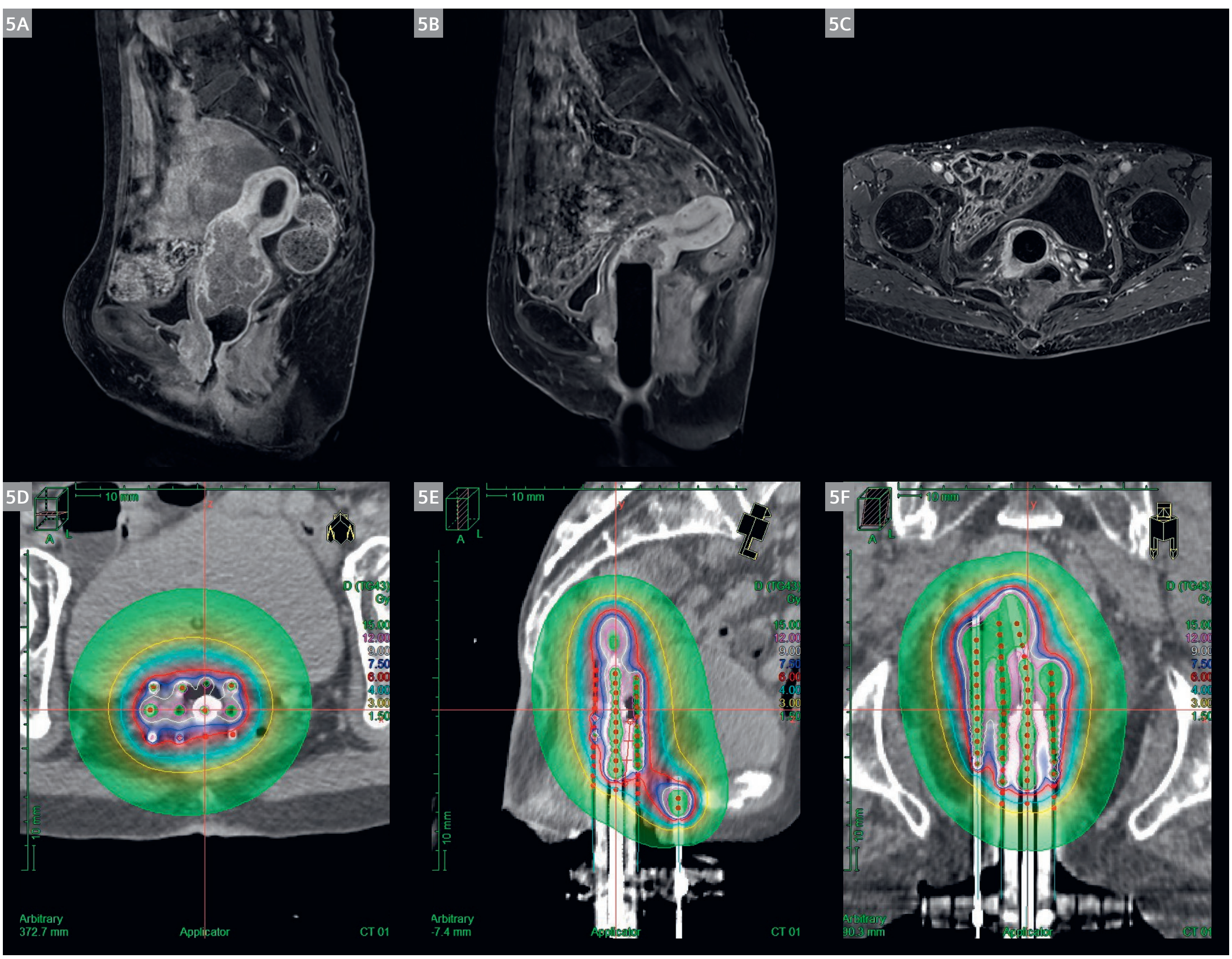


4 Tumor recurrence around the trigeminal nerve following surgery for oral floor cancer. **(4A)** On the plain CT, it is difficult to recognize the lesion. **(4B)** Radiotherapy planning MRI (T2W). The lesion is observed along with the trigeminal nerve (arrow). In addition, the image clearly shows the contrast of the soft tissue or bones at the skull base. **(4C)** A VMAT radiation dose distribution map. Optimal radiotherapy planning is achieved by accurately enclosing the target using MRI.

Vertebral stereotactic irradiation, cervical cancer, and others

Based on the recent idea that radiotherapy for oligometastases may improve the overall survival rate, stereotactic irradiation, which enables local delivery of high radiation doses, began to be actively used for oligometastases. Since the vertebral body is adjacent to vital organs such as the spinal cord and the esophagus, vertebral stereotactic irradiation requires extremely precise radiotherapy planning.
As MRI is superior to CT imaging in terms of providing information about how deep the tumor extends inside the vertebral body and visualizing the spinal cord as an organ at risk (to distinguish it from the spinal fluid), we always use MRI in combination with CT imaging when planning vertebral stereotactic irradiation therapy.

The Cancer Institute Hospital of JFCR uses brachytherapy for cervical and prostate cancers. For cervical cancer, external irradiation during the first half of radiotherapy often dramatically reduces the tumor size, resulting in a remarkable difference in the size and shape of the tumor between staging (Fig. 5A) and initiation of intracavitary irradiation (Fig. 5B, C). We use images from the self-propelled CT system that partly incorporates a brachytherapy unit to create plans for intracavitary radiotherapy (Fig. 5D–F). By performing MRI scans immediately before intracavitary irradiation, we have a reference for inputting contours of the clinical target volume (CTV) during intracavitary radiotherapy planning (fusing is difficult due to uterus deformation related to tandem insertion). If intracavitary irradiation fails to give a sufficient dose to the tumor, we use interstitial irradiation. In this case, the



5 A patient who received concurrent chemoradiotherapy for cervical cancer. **(5A)** Staging MRI. **(5B)** An MRI image acquired immediately before interstitial irradiation (with a cylinder inserted for interstitial irradiation); a sagittal section image. **(5C)** A horizontal section image of 5B. **(5D)** A radiation dose distribution map of high dose-rate interstitial irradiation (with CT used as a base); a horizontal section image. **(5E)** A sagittal section image of 5D. **(5F)** A coronal section image of 5D.

cylinder used for interstitial irradiation (which is attached to the template during needle insertion) is inserted into the vagina to acquire MRI images (Fig. 5D–F), and a prior simulation is performed to select the grid point on the template that will be used as the site of needle insertion. In other cases where it is difficult for CT scans to distinguish the tumor from the soft tissue (e.g., esophageal and lung cancers with mediastinal invasion, and pancreatic cancer), we might include radiotherapy planning MRI. For patients with a brain metastasis, on the other hand, we usually use diagnostic contrast-enhanced MRI images directly for radiotherapy planning because endocranial fusion is unlikely to be affected by the base plate or the immobilization device. In this case, we take care to assign it to the radiotherapy planning MRI system (3T MAGNETOM Skyra) at our hospital at the time of the diagnostic MRI scan. This is because the positional accuracy for radiotherapy is guaranteed only for that system.

Summary

The Cancer Institute Hospital of JFCR has two radiotherapy planning CT systems in the Department of Radiation Oncology, and five MRI systems in the Diagnostic Imaging Department. One of the five MRI systems is used for radiotherapy planning during three sessions every day. For radiotherapy planning for IMRT to treat prostate or head and neck cancer, and for vertebral stereotactic irradiation, the following procedures are established:

1) Preparation of the immobilization device using one of the CT systems in the Department of Radiation Oncology
2) CT scan and
3) MR imaging at the Diagnostic Imaging Department.

The negative aspects of these procedures include the following:

a) It takes the patient half a day to complete the imaging examinations due to the time interval between the appointment times for CT and MRI.
b) There may be a change in urine output, stools, and gas during this time interval in patients with prostate cancer.
c) The radiology technologist needs to go back and forth between the two departments carrying the immobilization device, and change the MRI base plates.

From a management point of view, however, sharing with the Diagnostic Imaging Department is a reasonable solution to maintain the utilization rate of the expensive MRI systems. We have been operating in this manner for five years and we currently do not have any major problems. As a radiation oncologist, I realize that the use of MRI has certainly contributed to high-precision radiotherapy planning; however, I see it as our future responsibility to provide clinical data that will improve the local control rate and reduce adverse events. We will be pleased if the way we use MRI helps the readers in some way.

Contact

Professor Yasuo Yoshioka, M.D., Ph.D.
Director, Radiation Oncology Department
Cancer Institute Hospital of the Japanese
Foundation for Cancer Research (JFCR)
3 Chome-8-31 Ariake, Koto-ku
Tokyo 135-8550
Japan
Phone: +81 3-3520-0111
yasuo.yoshioka@jfcr.or.jp