# MR-integrated workflows in Radiation Therapy

## for MAGNETOM Systems

usa.siemens.com/magnetom-world-mr-in-rt

SIEMENS Healthineers

# Thank you!

We would like to express our sincere gratitude to the following senior experts and their respective institutions who made this book possible.

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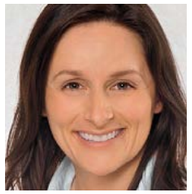

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## Foreword

Radiation Oncology is experiencing growth in the use of magnetic resonance imaging in treatment planning and response assessment. While it can seem daunting to start integrating this technology in Radiation Therapy departments, this trend is inevitable and has been embraced by physicists and physicians alike. Clinical teams of several institutions have created their own solutions to optimize images, in an effort to add valuable clinical insights in treatment planning. This booklet is a compilation of study protocols* and practical tips for several body regions provided by these experts.

This compilation is being shared to foster clinical knowledge among medical professionals. You can download the .edx and .exar1 files at usa.siemens.com/magnetom-world-mr-in-rt

We would like to thank all the contributors who have worked tirelessly and generously shared their knowledge and expertise.

We look forward to hearing your feedback and suggestions so that we at Siemens Healthineers can continuously improve and do our part in the care of our patients.

Note: MAGNETOM systems are indicated for use as magnetic resonance diagnostic devices (MRDD) that produce transverse, sagittal, coronal and oblique cross sectional images, spectroscopic images and/or spectra, and that display the internal structure and/or function of the head, body or extremities. These images and/or spectra and the physical parameters derived from the images and/or spectra when interpreted by a trained physician, yield information that may assist in diagnosis. The study protocols and another information contained in this brochure were developed entirely by the medical professionals identified at the beginning of each section. These medical professionals did not receive financial support or any other kind of assistance from Siemens Healthineers.

Patient results may vary depending on many factors including system, software version, options, coils, technique and patient condition. Siemens Healthineers is not responsible or liable for results.

Discover ways to optimize the use of your MR simulation applications.

Explore the latest clinical cases—from experts for experts!

*Results may vary depending on multiple factors like system, software version, options, coils and technique besides patient condition. Siemens Healthineers will not be liable for any damages."





# Contents

# Glioma 1

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## Overview

This protocol uses a 20-channel head & neck coil without thermoplastic mask immobilisation to maintain homogenous and high image quality acquired with a site specific volume coil. Care should be taken when positioning the patient to ensure they are straight and head tilt matches CT.

## Patient

**Patient Presentation**

High Grade Glioma:
Considered in all patients, especially if interval from Sim to diagnostic imaging >3–4 weeks

Low Grade Glioma:
Considered if no post-operative MRI available, poor quality or non-contemporaneous diagnostic scan

**Treatment Prescribed**

Varies on grade and location of tumor:

- 3D Conformal
- IMRT (intensity-modulated radiation therapy)
- VMAT (volumetric modulated arc therapy)
- Tomotherapy

## Imaging Study

| | |
|---|---|
| **Scanner** | MAGNETOM Skyra 3T |
| **Equipment Required** | • Head/Neck 20 coil<br>• Immobilisation sponges |
| **Patient Prep Needed** | 22-gauge intravenous cannula required prior to imaging |
| **Setup and Landmark** | • Patient positioned head first supine.<br>• Straighten patient through mid forehead, mid nose and mid chin using external lasers.<br>• Use immobilisation sponges on the sides of patient's ears and top of head to prevent movement during imaging.<br>• Landmark over the lower orbital margin (OM) using the bore lasers. |

1 Brain setup using 20-channel head and neck coil.





## Sequences

**Download the .exar1 file at usa.siemens.com/magnetom-world-mr-in-rt**

| Sequence | Scan time | Utility for RT | Characteristics |
|---|---|---|---|
| Localizer | 0:15 min | | |
| T1w MPRAGE 3D sagittal | 5:21 min | Anatomical delineation | |
| T2w FLAIR 2D | 4:26 min | Post-operative changes<br>Target delineation | Use 2 concatenations to minimize cross talk artifacts and maintain grey-white matter contrast |
| T1w MPRAGE 3D sagittal + Gad | 5:21 min | Tumor delineation<br>Residual enhancement post-op | **Injection Rate**<br>Hand bolus<br>**Gad Vol**<br>0.1 mmol/kg (Gadobutrol)<br>**Saline Flush**<br>10 ml before and after Gad |

## Special considerations

**Tips and Tricks**

- When positioning patient copy chin to chest measurements from CT Sim to match head tilt position to minimize variation between CT and MRI.
- Use the same slice position from reconstructed transverse T1w MPRAGE and transverse T2w FLAIR to minimize errors between CT-MRI registration.

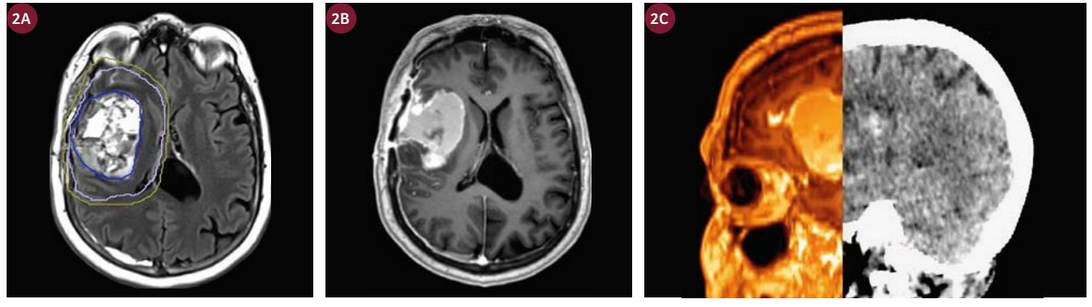
**Preparing Images for Planning**

- Reconstruct the T1w MPRAGE pre and post-contrast in the transverse plane only for planning.

**RTP Requirements**

- Use 3D distortion correction where applicable. If unavailable use 2D.
- Maintain a receiver bandwidth with a ≤1 pixel fat-water shift (≥ 400 Hz/Px at 3T).
- 0 mm interslice gap to eliminate interpolation in radiotherapy treatment planning (RTP) system.
- 2 mm slices should be used for post-operative and high/low grade Glioma cases.
- 1 mm slices should be used for stereotactic patients.

## Example Images




2 T2w FLAIR showing gross tumor volume (GTV), clinical target volume (CTV), and planning target volume (PTV) margins **(2A)**, gadolinium-enhanced T1w MPRAGE demonstrating peripheral enhancement of post surgical margins with clear definition of brain structures **(2B)**, co-registration of non-contrast planning CT and post-contrast T1w MPRAGE, showing accurate registration of bone and soft tissue anatomy **(2C)**.

# Glioma 2

Maja Sohlin, Ph.D.; Christian Gustafsson, Ph.D.
Sahlgrenska University Hospital, Gothenburg, Sweden



## Patient

**Treatment Prescribed** Varies on grade and location of tumor.

## Imaging Study

**Scanner** MAGNETOM Aera 1.5T

**Equipment Required**

- Two Flex 4 Large coils
- Velcro fasteners
- Sand bags

**Setup and Landmark**

- Patient positioned head first supine.
- Line things up based on the markings previously made on the immobilizing mask, if such exist. To ensure that the patient is positioned as straight as possible in the mask, it is particularly important to check that the sagittal laser follows the previously made marking, or is centered on the patient.
- The coils are inserted and clamped in place under the head area of the flat table top so they also cover the rear of the head. They are held together in the front with Velcro fasteners. The spine coil elements are not used with this setup.
- The coils are supported with sand bags on the sides to get closer to the head and prevent them from pressing on the patient's nose and face.

1





## Sequences

| Sequence | Scan time | Utility for RT | Characteristics |
|---|---|---|---|
| Axial T1w | 5:25 min | Matching to CT plus anatomy before contrast | |
| Axial T2w | 5:47 min | Delineating of target and risk organs | |
| Axial T2w FLAIR | 5:02 min | Outlining of vasogenic edema/ infiltrative glioma (bright) | Potential artifacts from CSF pulsation |
| Axial T1w with contrast | 5:25 min | Outlining of areas with defective blood brain barrier and neovascularization (bright) | Post-operative blood products – compare with pre-contrast T1w |

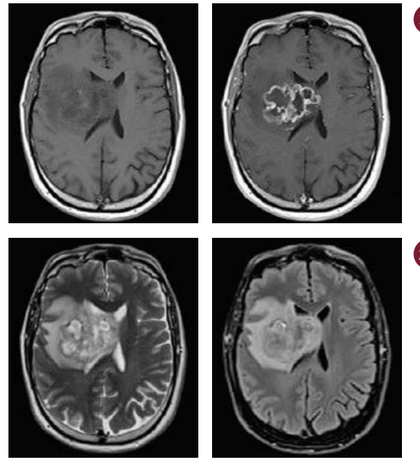
## Special Considerations

**Tips and Tricks**

- If possible, center the target volume in the isocenter to maximize field homogeneity and efficiency of any fat suppression and to minimize distortion caused by non-linear gradients.
- The T1-weighted image is used for matching to the CT and must therefore cover as large an area of the head as possible while maintaining correct registration.
- Other images must cover the target and any risk organs to be delineated.

## Example Images

2A 2B



2C 2D

2 **2A** T1 TSE tra (4:54 min),
**2B** T1 TSE Gd tra, (4:54 min),
**2C** T2 TSE tra (4:43 min),
**2D** T2 TIRM FLAIR tra (5:45 min).

# Small targets for stereotactic treatment

Maja Sohlin, Ph.D.; Christian Gustafsson, Ph.D.
Sahlgrenska University Hospital, Gothenburg, Sweden



## Patient

**Treatment Prescribed**

Stereotactic treatment is used for small target areas that often require high-resolution MR images with thin slices for target delineating. This means that it may be advantageous to use 3D sequences for stereotactic patients.

## Imaging Study

**Scanner**

MAGNETOM Aera 1.5T

**Equipment Required**

- Two Flex 4 Large coils
- Velcro fasteners
- Sand bags

**Setup and Landmark**

- Patient positioned head first supine.
- Line things up based on the markings previously made on the immobilizing mask, if such exist. To ensure that the patient is positioned as straight as possible in the mask, it is particularly important to check that the sagittal laser follows the previously made marking, or is centered on the patient.
- A holder was specially fabricated for the stereotactic frame (CIVCO trUpoint ARCH™ SRS/SRT System, CIVCO Medical Solutions, Kalona, IA, USA). To get the holder in a stable position, it was made to be fastened below the protruding head section of the flat table top. Because of this, the patient must be positioned well down on the examination table, which could potentially be problematic for unusually tall people. The advantage of this setup is that the spine coil elements can be used to cover the rear part of the cranium.
- Two Flex 4 Large coils are wound around the stereotactic frame and are held in place with sand bags on the sides.

1 Coil positioning for MAGNETOM Aera 1.5T system in Gothenburg with two Flex 4 Large coils covering the front part of the head. The rear part of the head is covered by the spine elements in the table.





## Sequences

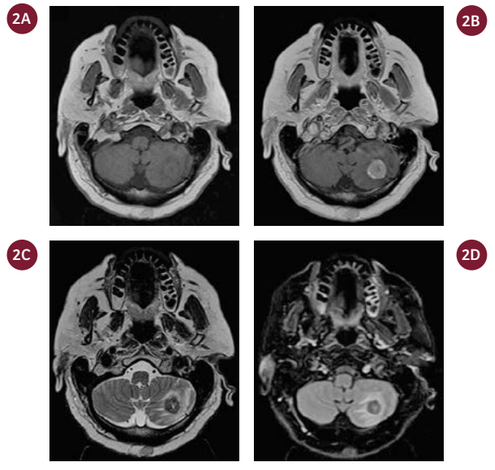
| Sequence | Scan time | Utility for RT | Characteristics |
|---|---|---|---|
| Axial T1w | 5:25 min | Matching to CT plus anatomy before contrast | |
| Axial T2w | 5:47 min | Delineating of target and risk organs | |
| Axial T2w FLAIR | 5:02 min | Outlining of vasogenic edema/ infiltrative glioma (bright) | Potential artifacts from CSF pulsation |
| Axial T1w with contrast | 5:25 min | Outlining of areas with defective blood brain barrier and neovascularization (bright) | Post-operative blood products – compare with pre-contrast T1w |

## Special Considerations

**Tips and Tricks**

- If possible, center the target volume in the isocenter to maximize field homogeneity and efficiency of any fat suppression and to minimize distortion caused by non-linear gradients.
- The T1-weighted image is used for matching to the CT and must therefore cover as large an area of the head as possible while maintaining correct registration.
- Other images must cover the target and any risk organs to be delineated.

## Example Images




2 **(2A)** T1 TSE tra (5:18 min),
**(2B)** T1 Gd tra (5:18 min),
**(2C)** T2 TSE tra (6:20 min),
**(2D)** T2 TIRM FLAIR tra (5:22 min).

# Head & Neck 1

Robba Rai; Gary Liney
Liverpool and Macarthur Cancer Therapy Centre, Ingham Institute for Applied Medical Research, Sydney, Australia

## Overview

Protocol is designed for imaging in thermoplastic immobilisation mask. Coil arrangement has been developed to ensure homogenous signal throughout imaging volume whilst minimizing geometric distortions.

## Patient

**Patient Presentation**

Mucosal Primary:
- All nasopharyngeal primaries
- All other mucosal primaries where extent of disease uncertain after endoscopy/PET

Non-mucosal Primary:
- Consider if primary or nodal disease is close to critical structures.

**Treatment Prescribed**: IMRT or Tomotherapy

## Imaging Study

**Scanner**: MAGNETOM Skyra 3T

**Equipment Required**
- Two Body 18 surface coils
- RF coil bridges
- Flat table overlay
- Velcro straps
- Patient-specific immobilization device/s

**Patient prep needed**: 20-gauge intravenous cannula required prior to imaging

**Setup and Landmark**
- Adjust the flat table overlay by moving it down the MRI bed to ensure the top of the head of the thermoplastic mask is covered by the superior coil element of the integrated spine coil.
- Index patient-specific immobilization devices to flat table overlay.
- Patient to be positioned as per CT Simulation. Head first supine.
- Straighten the patient according to the anatomical landmarks with the external laser system.
- Secure coil bridges to table and use Velcro straps to stabilize the Body 18 surface coil to the bridges. The coil should cover the vertex of the skull to the suprasternal notch.
- Lower the bridges so that it is close to the patient's mask but not touching.
- Place the second Body 18 surface coil over the patient's torso.
- Use longer Velcro straps to attach the two coils together, ensuring that there is minimal separation between the coils to minimize signal drop off in the images.
- Landmark over the chin.

1 Head & Neck planning MRI setup using two 18-channel surface coils.





## Sequences

**Download the .exar1 file at usa.siemens.com/magnetom-world-mr-in-rt**

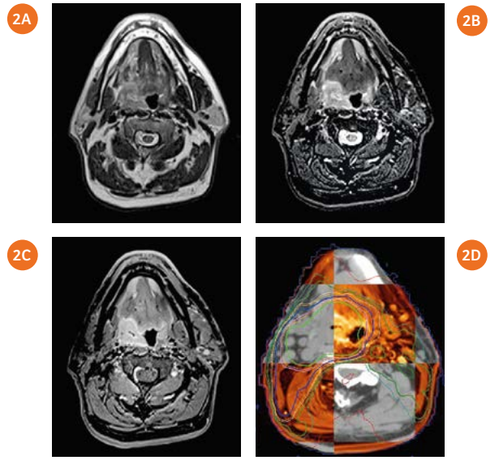
| Sequence | Sequence | Utility for RT | Characteristics |
|---|---|---|---|
| Localizer | 0:15 min | | |
| T2 TSE Fast Dixon | 3:17 min | Primary and nodal delineation (particularly where contrast not given) | Plan with in-phase and water images |
| T1 TSE Fast Dixon | 3:05 min | Primary and nodal delineation (particularly where contrast not given) | In-phase images used for bone registration in RTP system |
| T1 TSE Fast Dixon + Gad | 3:05 min | Primary and nodal GTV delineation | **Injection Rate** 2 ml/s<br>**Gad Vol** 0.1 mmol/kg (Gadobutrol)<br>**Saline Flush** 20 ml before and after Gad |

## Special Considerations

**Tips and Tricks**
- Dixon provides more robust and homogenous fat suppression as well as minimizing geometric distortion in the head and neck and should be considered for Head & Neck protocols.
- Adjust the coil bridges so the patient head is equidistant to the spine and surface coil. This will help create a more homogenous image.
- Landmark over the patient's chin using the in bore lasers before securing any coils in place as the coils will obstruct the view of the patient's external anatomy.

**RTP Requirements**
- Use 3D distortion correction where applicable. If unavailable use 2D.
- Maintain a receiver bandwidth with a ≤1 pixel fat-water shift (≥400Hz/Px at 3T).
- 0 mm interslice gap to eliminate interpolation in radiotherapy treatment planning (RTP) system.
- All sequences should have the same centre slice to maintain consistency with CT-MRI rigid registration in RTP system.
- 2–3 mm slice thickness to encompass entire neck in an ideal acquisition time to maintain image quality.

## Example Images




2 T2 Dixon in-phase **(2A)**, T2 Dixon water demonstrating robust fat suppression and delineation of tumor volume **(2B)**, post-contrast T1 Dixon water showing enhancement of tumor and surrounding vasculature **(2C)**, co-registration of planning CT and planning MRI **(2D)**.

# Head & Neck 2

Jared Robbins, M.D.; Eric Paulson, Ph.D.
Medical College of Wisconsin, Milwaukee, WI, USA

## Patient

| | |
|---|---|
| **Patient Presentation** | Squamous cell carcinoma |
| **Treatment Prescribed** | Volumetric Modulated Arc Therapy |

## Imaging Study

| | |
|---|---|
| **Scanner** | MAGNETOM Verio 3T |
| **Equipment Required** | • Two 6-channel Body Matrix coils<br>• 4-channel extremity coil<br>• Spine array coil<br>• Three Nylon straps<br>• Flat table overlay<br>• Head rest<br>• Patient-specific immobilization device |
| **Patient Prep Needed** | Change into gown and robe. |
| **Setup and Landmark** | • Position flat table overlay over spine array.<br>• Index patient-specific immobilization devices to flat table overlay.<br>• Setup patient head-first supine, using external lasers to align and straighten.<br>• Wrap two 6-channel Body Matrix coils around patient's head and secure with two Nylon straps.<br>• Confirm that the coils overlap anteriorly, are positioned as inferiorly as possible, and are symmetric.<br>• Position 4-channel extremity coil over neck and secure with Nylon strap Landmark over patient chin. |

1 Immobilization device and RF coil positioning.





## Sequences

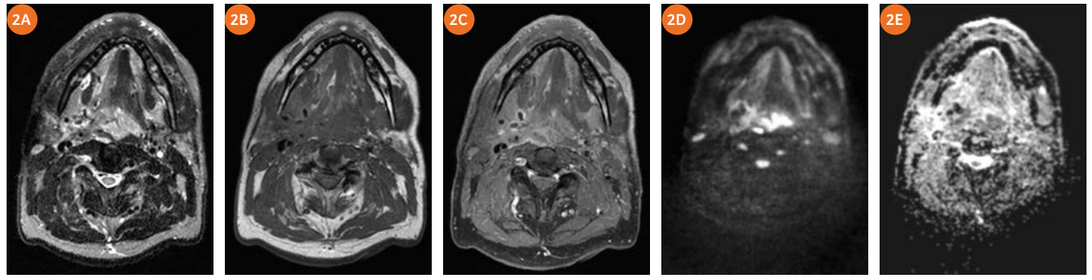
**Download the .exar1 file at usa.siemens.com/magnetom-world-mr-in-rt**

| Sequence | Scan time | Utility for RT |
|---|---|---|
| Localizer | 0:19 min | |
| Ax STIR TSE | 7:00 min | Delineation of gross tumor volume and associated edema |
| Ax T1 TSE | 4:20 min | Organs at risk delineation |
| Ax DWI RESOLVE | 5:30 min | Localization of gross tumor volume |
| Ax fat-suppressed T1 TSE + Gad | 5:30 min | Delineation of gross tumor volume<br>**Injection Rate:**<br>Hand bolus<br>**Gad Vol:**<br>0.1 mmol/kg (Gadobenic acid) |

## Special Considerations

| | |
|---|---|
| **Acquisition** | • Contiguous 3 mm slices with 1 mm in-plane resolution.<br>• Readout bandwidths adjusted to ensure WFS <1 pixel. |
| **Preparing Images for Treatment Planning** | • Apply 3D distortion correction to all images.<br>• Apply image standardization to all non-diffusion images. |

## Example Images




2 Multiparametric images used for target and OAR delineation: STIR **(2A)**, T1w **(2B)**, fat-suppressed T1+Gad **(2C),** RESOLVE DWI b=800 s/mm² **(2D)**, ADC, apparent diffusion coefficient map **(2E)**.

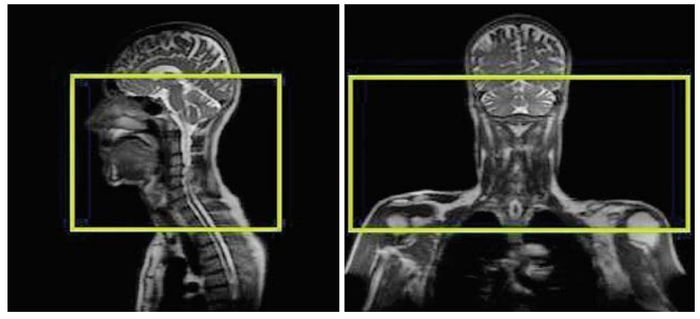
# Head & Neck 3

Maja Sohlin, Ph.D.; Christian Gustafsson, Ph.D.
Sahlgrenska University Hospital, Gothenburg, Sweden

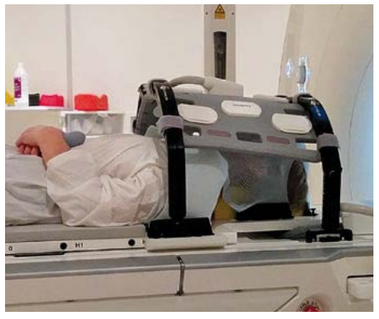


## Imaging Study

| | |
|---|---|
| **Scanner** | MAGNETOM Aera 1.5T |
| **Equipment Required** | • Body 18 Long coil<br>• Flex 4 Small coil<br>• Coil holders<br>• Flat table overlay<br>• Patient-specific immobilization device |
| **Setup and Landmark** | • Position flat table overlay over spine array.<br>• Line things up based on the markings previously made on the immobilizing mask, if such exist. To ensure that the patient is positioned as straight as possible in the mask, it is particularly important to check that the sagittal laser follows the previously made marking, or is centered on the patient.<br>• Coverage area see Figure 1. |



1 Coverage areas (sag, cor) for head and neck. The large FOV used gives the skin contour of the patient and is used for better control of the matching.



2 Coil positioning for Head & Neck with Body 18 Long. There is also a Flex 4 Small coil positioned posteriorly (under the table top) to increase the SNR from the rear skull parts.





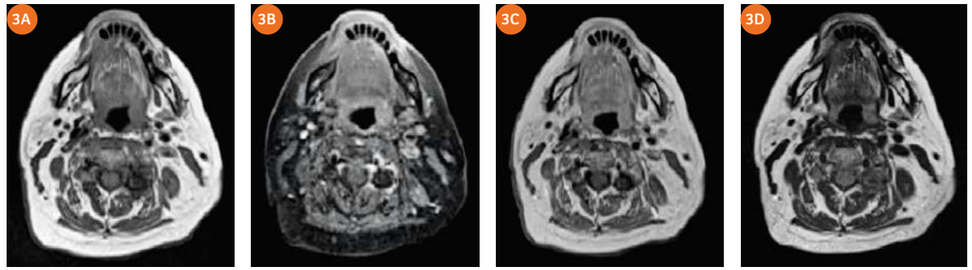
## Sequences

| Sequence | Scan time | Utility for RT | Characteristics |
|---|---|---|---|
| Axial T2 STIR | 6:41 min | Differential edema (bright) | Potential swallowing artifacts, flow artifacts |
| Axial T1 | 6:36 min | Delineating of nerves and teeth | |
| Axial ADC | | Plotting of hypercellularity (dark) | |
| Axial fat-suppressed post-contrast T1 | 6:36 min | Plotting of faulty, leaky tissue (bright) | Potential swallowing artifacts, flow artifacts |

## Special Considerations

If the patient has dental fillings[1], these will appear as streak artifacts in CT. This problem is often avoided in MRI as the artifacts instead become small, local, signal-poor parts. The size of the artifacts in CT depend on what type of material the dental filling is made out of. The same applies to MRI, but the artifact there can instead take the form of a geometric distortion, signal loss and/or signal shift. With such severe geometric distortion, great care should be taken when defining the target and risk organs in or near the artifact.

## Example Images




3 **(3A)** T1 TSE tra 3 mm (6:36 min),
**(3B)** T1 TSE tra 3 mm FatSat (6:36 min),
**(3C)** T1 TSE tra 3 mm GD (6:36 min),
**(3D)** T2 TSE tra 3 mm (6:41 min).
All run with Neck shim and WARP.

[1]The MRI restrictions (if any) of the metal implant must be considered prior to patient undergoing MRI exam. MR imaging of patients with metallic implants brings specific risks. However, certain implants are approved by the governing regulatory bodies to be MR conditionally safe. For such implants, the previously mentioned warning may not be applicable. Please contact the implant manufacturer for the specific conditional information. The conditions for MR safety are the responsibility of the implant manufacturer, not of Siemens Healthineers.

# Head & Neck 4

Yue Cao, Ph.D.; James Balter, Ph.D.
University of Michigan, Ann Arbor, MI, USA

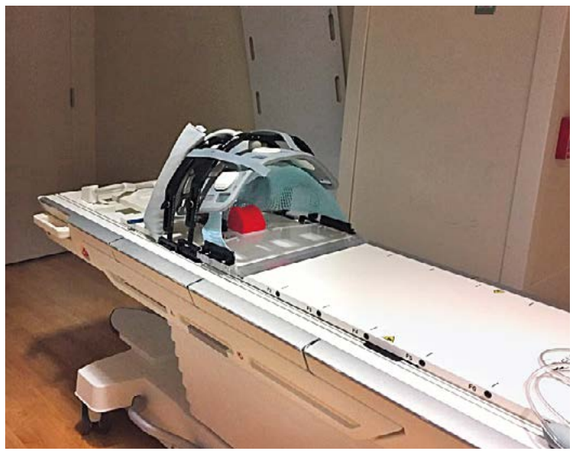
## Patient

| | |
|---|---|
| **Patient Presentation** | A patient is positioned in the treatment configuration using five-point face mask and bit bar as physician indication. |
| **Treatment Prescribed** | Standard 35 fractions of 70 Gy. Protocol scans include local boosting. |

## Imaging Study

| | |
|---|---|
| **Scanner** | MAGNETOM Skyra 3T |
| **Equipment Required** | • Flat table top<br>• Body 18 long and Spine 32 matrix coils<br>• Patient-specific mask, neck rest and bite block/dental guards when indicated<br>• Sand bags<br>• Head/neck board<br>• Arm pulls if/as needed |
| **Setup and Landmark** | • Flat table top is usually already in place, but place if needed.<br>• Mask can be made in CT or in Zone 3 (sag laser on wall).<br>• Patient zeroed at External Auditory Meatus, mask is positioned using indexed head/neck board using the exact bar.<br>• Body 18 placed over mask, sand bags used near head region.<br>• Scan range varies by disease site and diagnosis. |

1







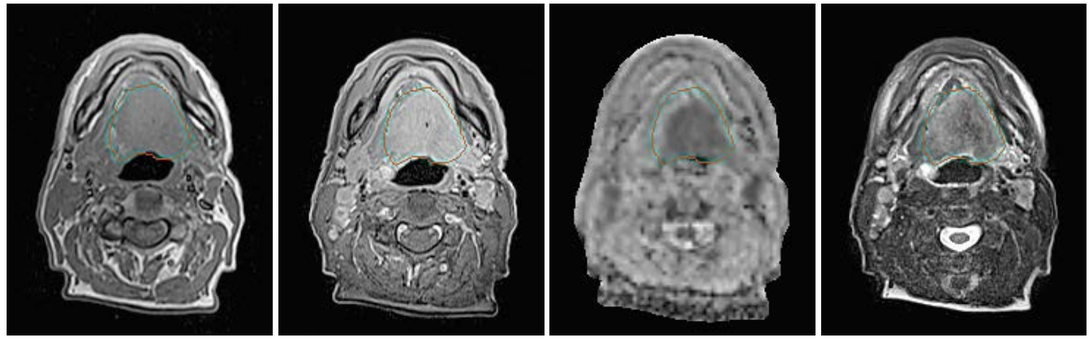
## Sequences

**Download the .exar1 file at usa.siemens.com/magnetom-world-mr-in-rt**

| Sequence | Scan time | Utility for RT |
|---|---|---|
| Localizer | 0:13 min | |
| 2D T1 TSE FS pre Gd | 2:08 min | Assisting GTV delineation |
| 2D DWI RESOLVE | 5:00 min | Boost target delineation |
| 2D T2 TSE fs | 3:14 min | Assisting GTV delineation |
| 2D T1 TSE post Gd | 5:35 min | GTV definition |

## Example Images

2



# Esophagus

Candice Johnstone, M.D.; Paul Knechtges, M.D.; Eric Paulson, Ph.D.
Medical College of Wisconsin, Milwaukee, WI, USA

## Patient

| | |
|---|---|
| **Patient Presentation** | Esophageal cancer |
| **Treatment Prescribed** | 3D conformal radiation therapy |

## Imaging Study

| | |
|---|---|
| **Scanner** | MAGNETOM Verio 3T |
| **Equipment Required** | • Two 6-channel Body Matrix coils<br>• Spine array coil<br>• Two adjustable coil bridges<br>• Two Nylon straps<br>• Flat table overlay<br>• Headphones<br>• ECG leads and Bluetooth transceiver<br>• Patient-specific immobilization device/s |
| **Patient Prep Needed** | • Change into gown and robe.<br>• Attach ECG leads and Bluetooth transceiver.<br>• Place 22-gauge intravenous cannula into antecubital vein. |
| **Setup and Landmark** | • Position flat table overlay over spine array.<br>• Index patient-specific immobilization devices to flat table overlay.<br>• Setup patient head-first supine, using external lasers to align and straighten, and confirm pelvic crest is above S9 on spine array coil.<br>• Place RF coil bridges over thorax and conform to patient surface anatomy.<br>• Wrap two 6-channel Body Matrix coils circumferentially over RF coil bridges and secure with two Nylon straps.<br>• Place headphones on patient.<br>• Landmark over thorax. |

1 Adjustable RF coil bridges and RF coil positioning.





## Sequences

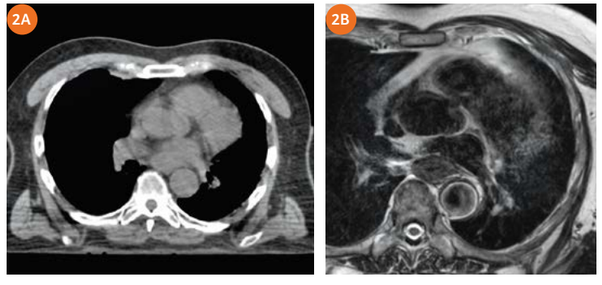
**Download the .exar1 file at usa.siemens.com/magnetom-world-mr-in-rt**

| Sequence | Scan time | Utility for RT | Characteristics |
|---|---|---|---|
| Localizer – free breathing | 0:30 min | | |
| Localizer – breath-hold | 0:17 min | | |
| Ax Restore T2 TSE | 6:00 min | Delineation of gross tumor volume | Cardiac or respiratory gating |
| Ax BH T1 Dixon CAIPI pre | 0:12 min | Reference for gross tumor volume delineation | |
| Care Bolus | | | **Injection Rate:** 2 cc/sec<br>**Gad Vol:** 0.1 mmol/kg (Gadobenic acid) |
| Ax BH T1 Dixon CAIPI + Gad arterial | 0:12 min | Reference for gross tumor volume | |
| Ax BH T1 Dixon CAIPI + Gad venous | 0:12 min | Reference for gross tumor volume delineation | |
| Ax BH T1 Dixon CAIPI + Gad equilibrium | 0:12 min | Reference for gross tumor volume delineation | |

## Special Considerations

| | |
|---|---|
| **Acquisition** | • Respiratory gating performed for tumors close to gastroesophageal junction (GEJ).<br>• Cardiac gating performed for tumors close to heart.<br>• Contrast injection performed using bolus tracking technique.<br>• Readout bandwidths adjusted to ensure WFS <1 pixel. |
| **Preparing Images for Treatment Planning** | • Apply 3D distortion correction to all images.<br>• Apply image standardization to non-DWI images.<br>• Perform local rigid registration over gross tumor volume to align reference MR image with planning CT images. |

## Example Images




2 Planning CT **(2A)** and cardiac and respiratory gated Restore T2 TSE **(2B)**.

# Lung

Gary Liney; Robba Rai
Liverpool and Macarthur Cancer Therapy Centre, Ingham Institute for Applied Medical Research, Sydney, Australia

## Overview

This is a free breathing procedure incorporating morphological and functional imaging protocols. Ultrashort echo time (UTE) imaging is incorporating for the purposes of MRI only planning and lung parenchyma assessment.

## Patient

| | |
|---|---|
| **Patient Presentation** | Treatment response research – free-breathing protocol |
| **Treatment Prescribed** | IMRT or 3D Conformal (Multifield) |

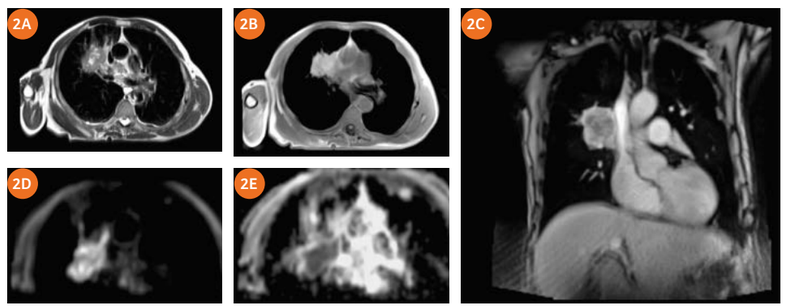
## Imaging Study

| | |
|---|---|
| **Scanner** | MAGNETOM Skyra 3T |
| **Equipment Required** | • Body 18, 18-channel surface coil<br>• Spine 32, 32-channel spine coil<br>• RF coil bridges<br>• Flat table overlay<br>• Velcro straps<br>• Patient-specific immobilization device/s |
| **Patient Prep Needed** | 20-gauge intravenous cannula required prior to imaging |
| **Setup and Landmark** | • Index patient-specific immobilization devices to flat table overlay.<br>• Patient to be positioned as per CT Simulation. Head first supine.<br>• Straighten the patient to AP and rotation tattoos with the external laser system.<br>• Secure coil bridges to table and strap 18-channel surface coil to the bridges.<br>• Lower the bridges so that it is close to the patient's torso but not deforming the external contours.<br>• Ensure that the coil covers the top of lung apices to lower costophrenic angles.<br>• Landmark over the cross hair of the coil (center of the thorax). |

1



2 Free-breathing T2 HASTE using phase navigation for respiratory triggering **(2A)**, free-breathing T1 StarVIBE **(2B)**, free-breathing coronal T1 StarVIBE perfusion used for tumor perfusion analysis **(2C)**, free-breathing diffusion-weighted imaging, b-value 750 s/mm² **(2D)** and ADC map **(2E)**.








## Sequences

**Download the .exar1 file at usa.siemens.com/magnetom-world-mr-in-rt**

| Sequence | Scan time | Utility for RT | Characteristics |
|---|---|---|---|
| Localizer | 0:09 min | | |
| T2_HASTE_transverse | 5:00 min | Target delineation | Respiratory Navigation |
| T1 StarVIBE_transverse | 3:40 min | Node and bone delineation | |
| T2_TRUFI_coronal | 0:19 min | Tumor motion | |
| T2_TRUFI_sagittal | 0:13 min | Tumor motion | |
| ZOOMit_EPI_transverse | 3:18 min | Target delineation | |
| Radial VIBE coronal | 9:04 min | Lung parenchyma delineation and MR-only planning | |
| T1 StarVIBE coronal 2 degree flip angle | 0:14 min | T1 Mapping | |
| T1 StarVIBE coronal 15 degree flip angle | 0:14 min | T1 Mapping | |
| T1 StarVIBE coronal dynamic + Gad | 5:42 min | Tumor perfusion | **Injection Rate:** 4 ml/s<br>**Gad Vol:** 0.05 mmol/kg (Gadobutrol)<br>**Saline Flush:** 20 ml inject after 3 measurements |
| T1 StarVIBE SPAIR post Gad | 4:13 min | Target delineation and nodal enhancement | **Injection Rate:** 2 ml/s<br>**Gad Vol:** 0.05 mmol/kg (Gadobutrol)<br>**Saline Flush:** 20 ml scan after 20 sec. post Gad injection |

## Special Considerations

| | |
|---|---|
| **Tips & Tricks** | • Use phase navigation for T2 HASTE for optimal image quality.<br>• Place cardiac shim box over the heart for TrueFISP imaging to minimize off-resonance and flow related artifacts. |
| **RTP Requirements** | • Use 3D distortion correction where applicable. If unavailable use 2D.<br>• Maintain a receiver bandwidth with a ≤1 pixel fat-water shift (≥400 Hz/Px at 3T).<br>• 0 mm interslice gap to eliminate interpolation in radiotherapy treatment planning (RTP) system.<br>• All sequences should have the same centre slice to maintain consistency with CT-MRI rigid registration in RTP system.<br>• 3–4 mm slice thickness to encompass entire thorax in an ideal acquisition time to maintain image quality. |

# Pancreas

Beth Erickson, M.D.; Paul Knechtges, M.D.; Eric Paulson, Ph.D.
Medical College of Wisconsin, Milwaukee, WI, USA

## Patient

| | |
|---|---|
| **Patient Presentation** | Locally advanced unresectable pancreatic adenocarcinoma |
| **Treatment Prescribed** | Respiratory-gated intensity modulated radiation therapy |

## Imaging Study

| | |
|---|---|
| **Scanner** | MAGNETOM Verio 3T |
| **Equipment Required** | • Two 6-channel Body Matrix coils<br>• Spine array coil<br>• Two adjustable coil bridges<br>• Two Nylon straps<br>• Flat table overlay<br>• Headphones<br>• Patient-specific immobilization device/s |
| **Patient Prep Needed** | • Change into gown and robe.<br>• Place 22-gauge intravenous cannula into antecubital vein. |
| **Setup and Landmark** | • Position flat table overlay over spine array.<br>• Index patient-specific immobilization devices to flat table overlay.<br>• Setup patient head-first supine, using external lasers to align and straighten, and confirm pelvic crest is above S9 on spine array coil.<br>• Place RF coil bridges over abdomen and conform to patient surface anatomy.<br>• Wrap two 6-channel Body Matrix coils circumferentially over RF coil bridges and secure with two Nylon straps.<br>• Place headphones on patient.<br>• Landmark over diaphragm. |

1 Adjustable RF coil bridges and RF coil positioning.

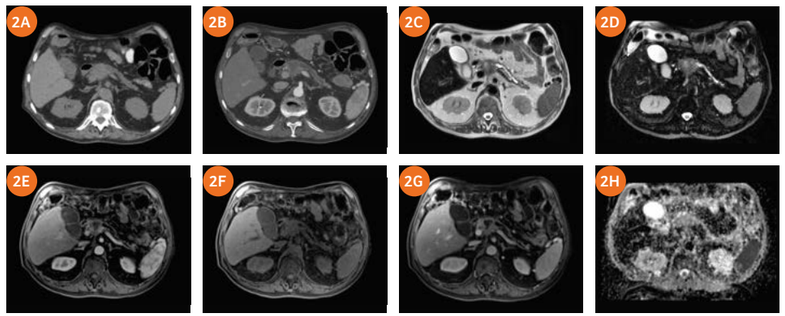




## Sequences

**Download the .exar1 file at usa.siemens.com/magnetom-world-mr-in-rt**

| Sequence | Scan time | Utility for RT | Characteristics |
|---|---|---|---|
| Localizer – free breathing | 0:30 min | | |
| Localizer – breath-hold | 0:17 min | | |
| Ax PACE T2 HASTE | 2:30 min | Organs at risk delineation | |
| Ax PACE fat-suppressed T2 HASTE | 2:30 min | Localization of gross tumor volume | |
| Ax PACE DWI | 5:00 min | Localization of gross tumor volume | |
| Ax BH T1 Dixon CAIPI pre | 0:12 min | Reference for gross tumor volume delineation | |
| Care Bolus | | | **Injection Rate:** 2 cc/sec<br>**Gad Vol:** 0.1 mmol/kg (Gadobenic acid) |
| Ax BH T1 Dixon CAIPI + Gad arterial | 0:12 min | Delineation of gross tumor volume | |
| Ax BH T1 Dixon CAIPI + Gad venous | 0:12 min | Reference for gross tumor volume delineation | |
| Ax BH T1 Dixon CAIPI + Gad equilibrium | 0:12 min | Reference for gross tumor volume delineation | |




2 Multiparametric images used for target and OAR localization and delineation. Planning CT **(2A)**, IV contrast CT **(2B)**, T2 HASTE **(2C)**, fat-suppressed T2 HASTE **(2D)**, pre-contrast Dixon T1 **(2E)**, arterial phase Dixon T1 + Gad **(2F)**, venous phase Dixon T1 + Gad **(2G)**, apparent diffusion coefficient (ADC) map **(2H)**.

# Cholangiocarcinoma

Jared Robbins, M.D.; Paul Knechtges, M.D.; Eric Paulson, Ph.D.; X. Allen Li, Ph.D.
Medical College of Wisconsin, Milwaukee, WI, USA

## Patient

| | |
|---|---|
| **Patient Presentation** | Intrahepatic cholangiocarcinoma |
| **Treatment Prescribed** | Liver stereotactic body radiation therapy |

## Imaging Study

| | |
|---|---|
| **Scanner** | MAGNETOM Verio 3T |
| **Equipment Required** | • Two 6-channel Body Matrix coils<br>• Spine array coil<br>• Two adjustable coil bridges<br>• Two Nylon straps<br>• Flat table overlay<br>• Headphones<br>• Patient-specific immobilization device/s |
| **Patient Prep Needed** | • Change into gown and robe.<br>• Place 22-gauge intravenous cannula into antecubital vein. |
| **Setup and Landmark** | • Position flat table overlay over spine array.<br>• Index patient-specific immobilization devices to flat table overlay.<br>• Setup patient head-first supine, using external lasers to align and straighten, and confirm pelvic crest is above S9 on spine array coil.<br>• Place RF coil bridges over abdomen and conform to patient surface anatomy.<br>• Wrap two 6-channel Body Matrix coils circumferentially over RF coil bridges and secure with two Nylon straps.<br>• Place headphones on patient.<br>• Landmark over diaphragm. |

1 Adjustable RF coil bridges and RF coil positioning.





## Sequences

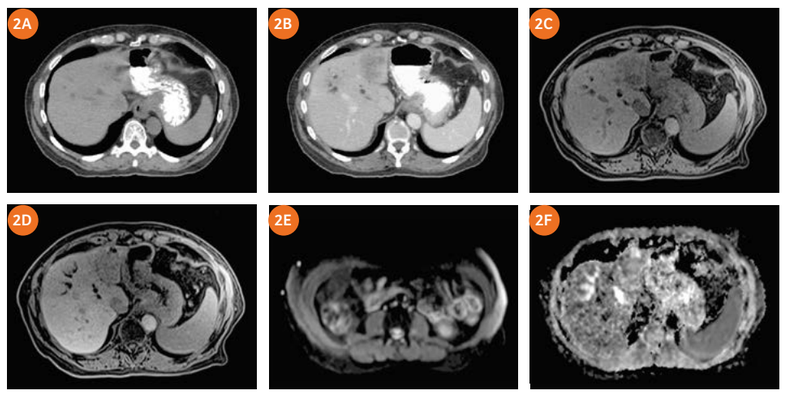
| Sequence | Scan time | Utility for RT | Characteristics |
|---|---|---|---|
| Localizer – free breathing | 0:30 min | | |
| Localizer – breath-hold | 0:17 min | | |
| Ax BH T1 Dixon CAIPI pre | 0:12 min | Reference for gross tumor volume delineation; organs at risk delineation | |
| Care Bolus | | | **Injection Rate:** 2 cc/sec<br>**Agent Vol:** 10 mL (Gadoxetate disodium) |
| Ax PACE fat-suppressed T2 TSE | 4:00 min | Localization of gross tumor volume | |
| Ax PACE DWI | 5:00 min | Localization of gross tumor volume | |
| Ax BH T1 Dixon CAIPI 20 min delay | 0:12 min | Delineation of gross tumor volume | |
| Ax BH T1 Dixon CAIPI 30 min delay | 0:12 min | Delineation of gross tumor volume | |

## Special Considerations

| | |
|---|---|
| **Acquisition** | • Contrast injection performed using bolus tracking technique.<br>• Administer 1 mg Glucagon IV (1/2 at start of exam, 1/2 midway through exam) to suppress peristalsis.<br>• Respiratory gating and breath-holds performed at end expiration to match phase of gating window used for treatment delivery.<br>• Readout bandwidths adjusted to ensure WFS <1 pixel. |
| **Preparing Images for Treatment Planning** | • Apply 3D distortion correction to all images.<br>• Apply image standardization to non-DWI images.<br>• Identify a reference MR image and perform local MR-MR rigid registration over gross tumor volume to correct for inter-sequence motion.<br>• Perform local rigid registration over gross tumor volume to align reference MR image with planning CT images. |

## Example Images

2 Multiparametric images used for target and OAR localization and delineation. Planning CT **(2A)**, IV contrast CT **(2B)**, fat-suppressed T2 TSE **(2C)**, 30-minute delayed Dixon T1 + contrast medium **(2D)**, DWI b=500 s/mm² **(2E)**, ADC map **(2F)**.



# Liver

Karim Boudam; Jean-Charles Côté; Marie-Pierre Campeau; Guila Delouya;
David Donath; David Roberge
Centre hospitalier de l'Université de Montréal, Canada

## Patient

| | |
|---|---|
| **Patient Presentation** | 58-year-old man presenting with metastatic liver lesions from a primary colon cancer. |
| **Treatment Prescribed** | Stereotactic Body Radiation Therapy (SBRT) 45 Gy in 3 fractions |

## Imaging Study

| | |
|---|---|
| **Scanner** | MAGNETOM Aera 1.5T |
| **Equipment Required** | • Spine 32 surface coil<br>• Body 18 surface coil<br>• Wireless respiratory monitoring system |
| **Patient Prep Needed** | Immobilization device: Full-body vacuum cushion (BodyFIX, Elekta Instruments, Crawley, UK) + abdominal compression belt (Aktina Medical, Congers, NY, USA) |
| **Setup and Landmark** | The patients are provided the compression belt and immobilized in treatment position using the vacuum cushion. The positioning on the couch is carried out using the Siemens Healthineers MRI built in lasers. |

1 Patient immobilization setup.





| | |
|---|---|
| **Imaging Protocol** | All the sequences, except the 2D cine, are corrected for geometry distortion using the built in Siemens Healthineers 3D correction algorithm. |

## Sequences

**Download the .exar1 file at usa.siemens.com/magnetom-world-mr-in-rt**

| Sequence | Scan time | Utility for RT | Characteristics |
|---|---|---|---|
| Localizer | 0:48 min | | |
| T1 VIBE tra 3D | 0:15 min | Positioning of the 2D cine slab | 1.7 x 1.7 x 4.0 mm<br>Resample: 1.7 x 1.7 x 2.0 mm |
| 2D cine without compression | 1:00 min | Tumor motion assessment without compression | 1.0 x 1.0 x 10 mm |
| 2D cine with compression | 1:00 min | Tumor motion assessment with compression | 1.0 x 1.0 x 10 mm |
| T1 VIBE tra 3D pre-contrast sequence (Breath-held expiration) | 0:15 min | Differentiation of hepatocytes from tumor (dark) | 1.7 x 1.7 x 4.0 mm<br>Resample: 1.7 x 1.7 x 2.0 mm |
| T1 VIBE tra 3D pre-contrast sequence (Breath-held inspiration) | 0:15 min | Differentiation of hepatocytes from tumor (dark) | 1.7 x 1.7 x 4.0 mm<br>Resample: 1.7 x 1.7 x 2.0 mm |
| T2 FS TSE tra 2D (Triggered expiration) | 5:00 min | Delineation of tumor (bright) | 1.0 x 1.0 x 3.0 mm |
| T2 FS TSE tra 2D mBH | 0:45 min | Optional sequence<br>Delineation of tumor (bright) | 2.0 x 2.0 x 3.0 mm |
| T1 VIBE tra 3D post-contrast: Gadobutrol – 30 seconds delay arterial phase (Breath-held expiration) | 0:15 min | Delineation of hypervascular tumors (bright) | 1.7 x 1.7 x 4.0 mm<br>Resample: 1.7 x 1.7 x 2.0 mm |
| T1 VIBE tra 3D post-contrast: Gadobutrol – venous phase (Breath-held inspiration) | 0:15 min | Delineation of hypervascular tumors (bright) | 1.7 x 1.7 x 4.0 mm<br>Resample: 1.7 x 1.7 x 2.0 mm |
| T1 VIBE tra 3D post-contrast: Gadobutrol – 5 min delay (Breath-held expiration) | 0:15 min | Delineation of hypovascular tumors (dark) | 1.7 x 1.7 x 4.0 mm<br>Resample: 1.7 x 1.7 x 2.0 mm |
| T1 VIBE tra 3D post-contrast: Gadobutrol – 5 min delay (Breath-held inspiration) | 0:15 min | Delineation of hypovascular tumors (dark) | 1.7 x 1.7 x 4.0 mm<br>Resample: 1.7 x 1.7 x 2.0 mm |

## Sequences

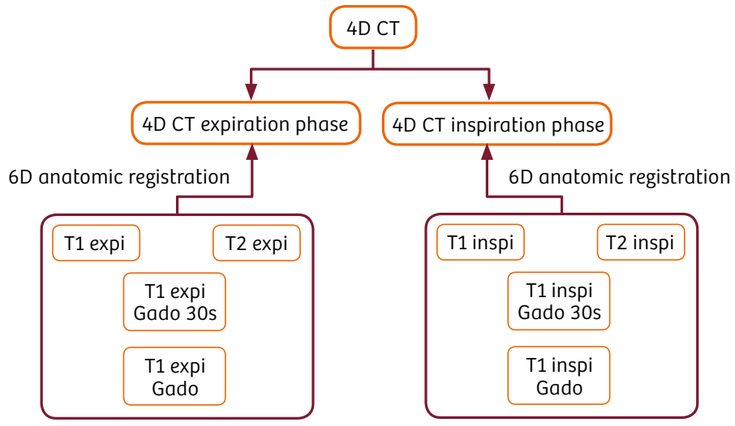
The MR imaging workflow starts with a crude localization sequence followed by a 3D T1 VIBE sequence to identify the target area and thus fine tune the positioning of the 2D cine sequences. Tumor motion assessment is first done without compression then, multiple 2D cine sequences are acquired with increasing abdominal pressure. The belt pressure is chosen to obtain a clinically satisfying reduction in tumor motion within the limits of patient comfort.

Following this iterative evaluation of belt pressure, T1 and T2 sequences are acquired with the selected pressure. The T1 sequences are acquired in breath-hold at expiration and inspiration with and without contrast (30 seconds and 5 minutes post injection). The T2 sequence is obtained at expiration using the triggering module. A T2 multiple breath-hold sequence is also acquired if the tumor is not visible on the T1 inspiration images.

## Special Considerations

**Preparing Images for Planning**

Figure 2 describes the treatment planning registration workflow. A 4D CT scan is acquired in treatment position and the maximum expiration and inspiration phases are identified amongst the 10 binned phases. The MRI sequences are then anatomically registered using a manual 6D rigid transformation. The acquisition of sequences in expiration and inspiration allows us to minimize the differences between the CT and MR images.

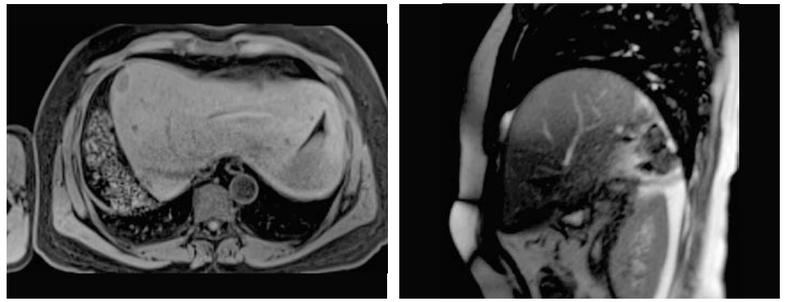



2 Registration workflow between CT and MR images.

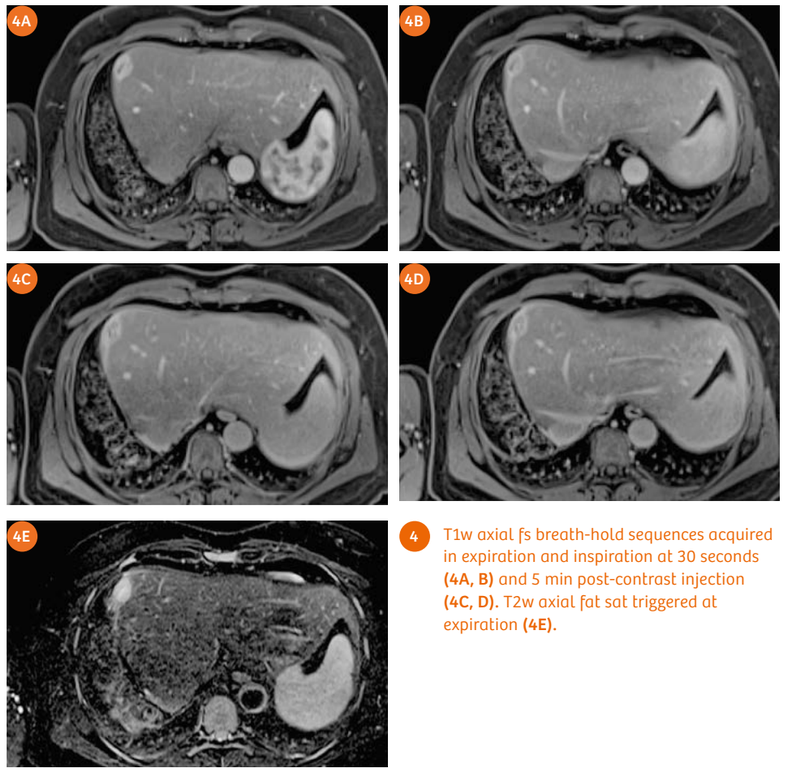




## Example Images



3 T1w axial fs breath-hold sequence acquired in inspiration **(3A)**. 2D cine **(2B)**.




4 T1w axial fs breath-hold sequences acquired in expiration and inspiration at 30 seconds **(4A, B)** and 5 min post-contrast injection **(4C, D)**. T2w axial fat sat triggered at expiration **(4E)**.

# Prostate 1

Cynthia Ménard[1]; Jean-Charles Côté[1]; Guila Delouya[1]; Maroie Barkati[1]; Karim Boudam[1];
Carole Lambert[1]; Gary Liney[2]
[1]Centre hospitalier de l'Université de Montréal, Canada
[2]Liverpool and Macarthur Cancer Therapy Centre, Ingham Institute for Applied Medical Research, Sydney, Australia

## Patient

| | |
|---|---|
| **Patient Presentation** | 67-year-old man presenting with intermediate-risk prostate cancer, clinical stage T1c, Gleason VII (3+4) with 7/18 biopsies positive, PSA 5.46. |
| **Treatment Prescribed** | SBRT 36.25 Gy in 5 fractions, one fraction per week. |

## Imaging Study

| | |
|---|---|
| **Scanner** | MAGNETOM Aera 1.5T |
| **Equipment Required** | • Spine 32 surface coil<br>• Body 18 long surface coil<br>• Foot rest |
| **Patient Prep Needed** | • Fiducial markers (4 in-house 1 x 3mm platinum cylinders) are implanted under transrectal ultrasound (TRUS) guidance at least 7 days prior to treatment planning.<br>• Patients are instructed to empty their bladder before simulation. Bowel prep includes a fleet enema before imaging.<br>• Buscopan 20 mg IM at 1ml/min, 10 to 15 minutes before MRI (unless contraindicated). |
| **Setup and Landmark** | Patients are positioned supine directly on the spine coil with foot rest. |

1





## Sequences

**Download the .exar1 file at usa.siemens.com/magnetom-world-mr-in-rt**

| Sequence | Scan time | Utility for RT | Characteristics |
|---|---|---|---|
| Localizer | 0:18 min | | |
| T2 SPACE tra 3D | 6:22 min | Prostate segmentation | 1.0 x 1.0 x 1.0 mm |
| PD T2 TSE tra 2D | 5:41 min | Marker-based registration and corresponding diagnostic T2w TSE image for tumor identification | 0.8 x 0.8 x 3.0 mm |
| DWI tra b=50, 400, 800 s/mm², 2D | 5:14 min | Tumor segmentation | 1.8 x 1.8 x 4.0 mm ADC and calculated b-value of 1400 |
| T1 SPACE cor 3D | 5:12 min | Diagnostic image highlighting intraprostatic blood (assist tumor segmentation) as well as pelvic bones and lymph nodes | 1.1 x 1.1 x 1.2 mm |

- Table in ISO positioning mode
- 3D distortion correction applied for anatomical images (2D for diffusion)
- Bandwidth of at least 220 Hz/mm (1 mm fat-water separation at 1.5 Tesla)
- Include prostate, seminal vesicles and a part of bladder, rectum
- Save separately PD and T2 of PD T2 TSE TRA 2D
- Save an axial MPR of the T1 SPACE COR 3D

This imaging protocol strives to balance treatment planning requirements (segmentation and registration), while complying with PIRADS v2.0 to permit valid diagnostic reporting. For the purpose of PIRADS reporting, the T2 SPACE image can be reconstructed in sagittal and coronal planes.

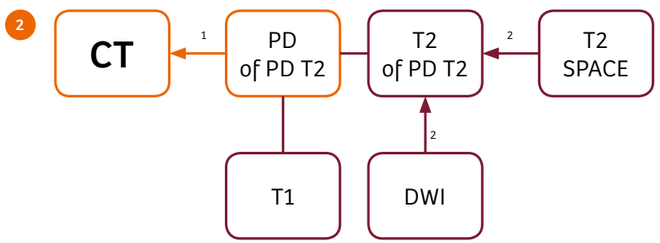
The examination is designed to keep each individual acquisition under 6 minutes to minimize motion related artifacts, and the overall examination under 30 minutes. The imaging range is the prostate gland, with the exception of the final T1-weigthed image, where the range is the entire pelvis.

A dual-echo (PD/T2) 2D acquisition is at the center of a rigid marker-based MRI-CT registration workflow. A volumetric T2w acquisition can be anatomically registered to the 2D T2w dataset if motion is observed between adjacent acquisitions. In that case, anatomic registration (T2 to T2) can be performed. The last two image sets can be used by clinicians to assist in tumor segmentation.

## Special Considerations

**Preparing Images for Planning**

- Send images from MR to PACS.
- Load images (MR and CT) from PACS on fusion console (MIM Vista, MIM Software Inc., Cleveland, OH, USA).
- Register MR to CT (workflow below).
- Send registered images to contouring server.
- Contour volumes on contouring client (Somavision Varian Medical Systems, Palo Alto, CA, USA).
- Send CT and contour from contouring server to planning console.



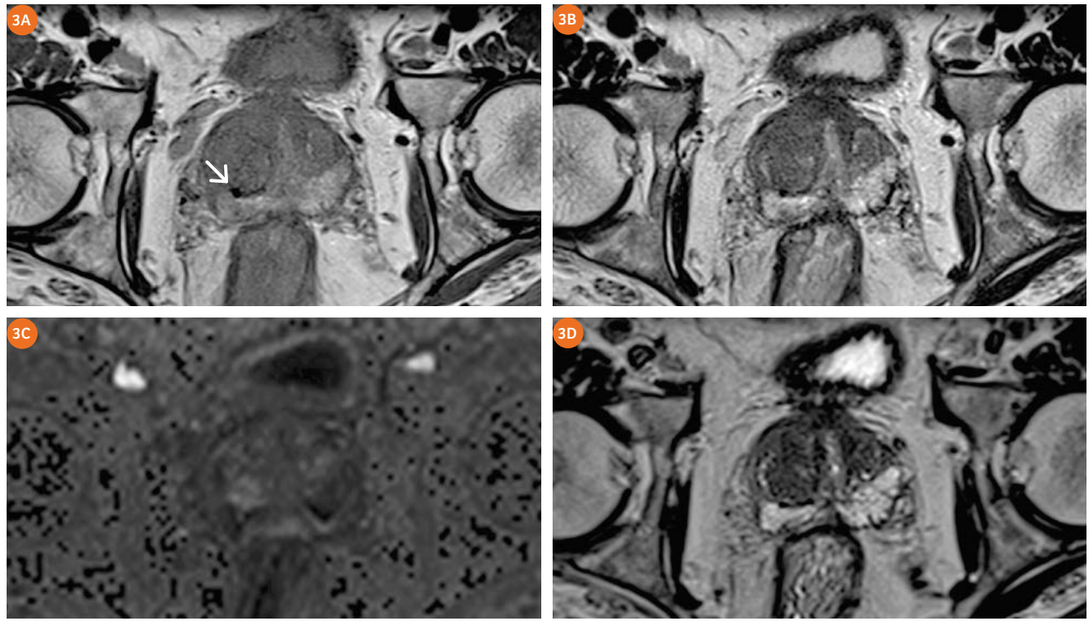

**1** Manual point-based registration (PD to CT) using 4 implanted markers (sup and inf) for a total of 8 points.

**2** If required (due to motion) anatomic automated registration prostate-to-prostate using mutual information algorithm.

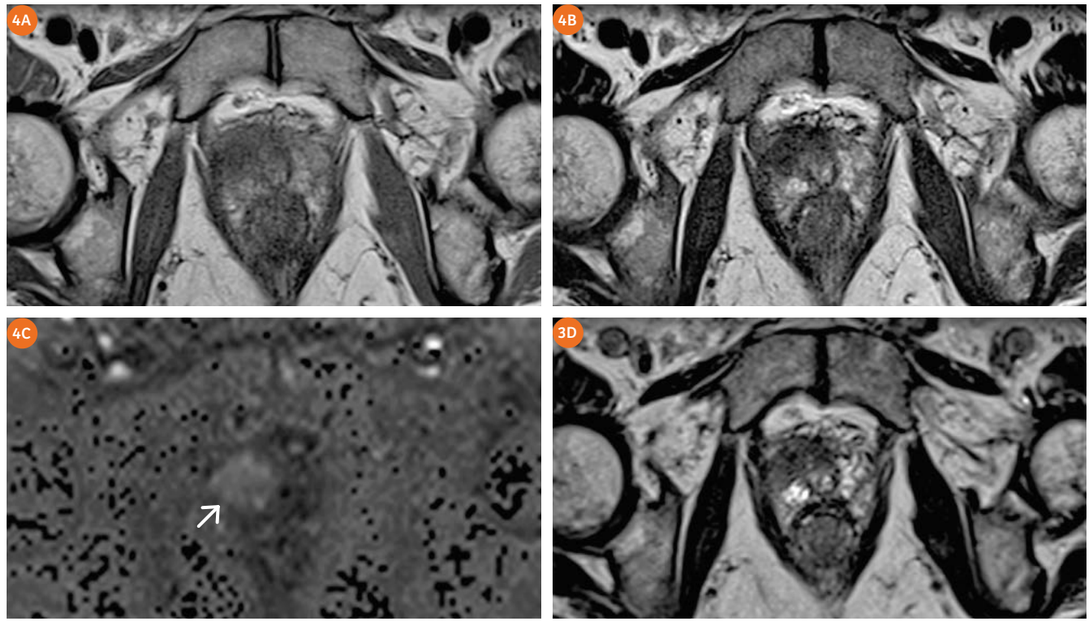




## Example Images




3 Slice corresponding to implanted marker right mid-gland best visualized on PD image **(3A)**.



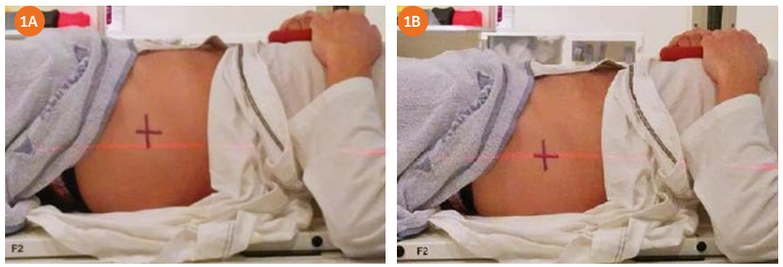

4 Slice corresponding to tumor at right anterior apex best visualized on calculated b=1400 DWI **(4C)**.

# Prostate 2

Maja Sohlin, Ph.D.; Christian Gustafsson, Ph.D.
Sahlgrenska University Hospital, Gothenburg, Sweden


## Imaging Study

| | |
|---|---|
| **Scanner** | MAGNETOM Aera 1.5T |
| **Equipment Required** | • Body 18 Long coil<br>• Coil holders<br>• Flat table overlay (Civco Medical Solutions, Kalona, IA, USA)<br>• Knee support on an in-house moveable rail |
| **Setup and Landmark** | • If the patient comes in for the MRI after undergoing the CT scan and creating a CT treatment plan, then there will already be body markings that were applied to the patient's hip during the CT visit. The position of these body markings are determined by a laser with preset definitions that are the same as the preset definitions for CT and the treatment unit. By matching this laser system with these markings, the patient can be positioned the same way in each radiotherapy fraction and you get a reproducible position for the patient. This avoids rotation of the pelvis, thereby minimizing the prostate's position deviation between different radiotherapy fractions.<br>• When the patient comes in to MRI it is advisable for the same positioning procedure to be used. There is therefore usually a laser system in the MRI room. If the laser system does not align with the body markings, you can rotate the patient's hip by grasping it and rotating.<br>• Once this is done, it is advisable to ask the patient to lift their pelvis straight up in the air slightly and then lower it again. Then check that the laser aligns with the body markings as shown below: |

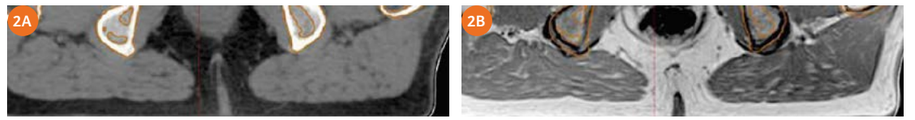



1 **(1A)** Patient's position requires correction, **(1B)** patient's position is correct.





- Because of the manual rotation performed with the hip, there is a risk of the buttocks will end up slightly asymmetrical. By asking the patient to lift their hips slightly, you avoid having the buttocks end up in different positions between the CT image and the MR image, which could make registration between these images more difficult. The separation between the buttocks can be used as a landmark to check whether any asymmetry has occurred in the position:




2 Separation of the buttocks on **(2A)** CT image, and **(2B)** MR image.

- Coverage areas (cor, sag, tra) for a transverse T2-weighted series: cover the entire prostate, approx. 3–4 slices, from above the bladder base down to the penis root.
- Coverage areas (cor, sag, tra) for a transverse T1-weighted series: use a large FOV to visualize the skin contour for better quality control of the registration.

3 Coil positioning with Body 18 Long coil.
The coil holders prevent the coil from pressing on the skin contour. The knee support sits on a moveable rail created at the workshop. The knee support should be the same type as in CT to obtain the best reproducible patient positioning.

## Sequences

| Sequence | Scan time | Utility for RT | Characteristics |
|---|---|---|---|
| Sag T2 | | Delineating of rectum and bladder | |
| Axial T2 | 6:17 min | Delineating of prostate and extracapsular disease (dark) | Potential post-biopsy hemorrhage, difficult to see the marker |
| Axial fat suppressed T2 | | Delineating of extracapsular disease (dark), lymph nodes (bright) | Potential post-biopsy hemorrhage |
| Axial T1 | 3:38 min | Detection of post-biopsy haemorrhaging (bright), visualization of markers | |
| Axial Diffusion ADC | | Delineating of tumor (dark) | |

## Special Considerations

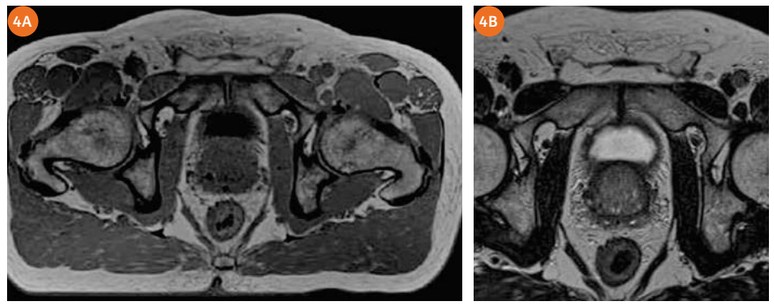
- The use of contrast medium is governed by local procedures. The procedures for when the patient should drink and/or urinate are governed by local regulations, but the recommendation is to use the same method for CT, MRI and the radiotherapy treatment unit for each radiotherapy fraction.
- It is important to pay attention to what type of ink is used for the body markings as certain ink types have been shown to produce artifacts in the form of signal loss on the MR image. This is not acceptable when MRI is used for treatment planning, but in connection with matching the MR image to a CT image it is not as critical since only a small proportion of the skin has disappeared. After automatic matching, always check that the results are correct.
- For patients with MRI-compatible hip prostheses[1], the protocols can be adjusted so that metal artifacts are as small as possible. This is best done by applying any metal artefact reduction functions, such as WARP. If this is not available, a higher bandwidth and reduced echo time could limit the spread of metal artifacts. The artifacts are generally smaller on 1.5T compared to 3T. On CT, streak artifacts penetrate the prostate, while the prostate is intact on the MRI. Bear in mind that automatic matching with CT, if used, may be incorrect. Carefully check the matching manually.
- In order for a T2-weighted image series to be matched against CT data, you often rely on an image series where the gold markers are clearly visible and instead register these to the CT. This image series is often taken with some type of gradient echo-based imaging technique to show the position of the gold seeds in the prostate more clearly. We call this image series the differentiation series. The registration between the T2-weighted image series and the CT data then follows automatically since the T2-weighted image series and the differentiation series are taken in the same frame of reference. A disadvantage of this approach is that there is a risk that the patient and/or the patient's anatomy has moved between the image capture of the T2-weighted image series and the image capture of the differentiation series. This can be addressed by directly visualizing the gold markers in the T2-weighted image series. It may be challenging to visualize the gold markers directly on the T2-weighted image series because the gold markers themselves are small, and the T2-weighted image series is often based on the turbo spine echo technique (TSE), which automatically minimizes and to some degree compensates the susceptibility artifacts from the gold markers. In TSE sequences, there is also smearing in the image as a result of the repeated 180˚ pulses it uses. On a MAGNETOM Aera 1.5T system, the following adjustments have been shown to visualize the gold seeds directly on the T2-weighted image series:

[1]The MRI restrictions (if any) of the metal implant must be considered prior to patient undergoing MRI exam. MR imaging of patients with metallic implants brings specific risks. However, certain implants are approved by the governing regulatory bodies to be MR conditionally safe. For such implants, the previously mentioned warning may not be applicable. Please contact the implant manufacturer for the specific conditional information. The conditions for MR safety are the responsibility of the implant manufacturer, not of Siemens Healthineers.





- Increase the spatial resolution of the image. Approx. 0.7 x 0.7 mm, depending on the size of the gold markers used.
- Reduce the slice thickness to reduce partial volume artifacts. Approx. 2.5 mm.
- Reduce echo train smearing by reducing the echo train length in the TSE sequence.
- Restrict the number of NEX to just 1 to reduce the smearing caused by averaging.
- Eliminate imaging acceleration to increase SNR.
- Restrict imaging to 1 package.
- Use movement correction, if available.
- These measures often lead to a reduction in SNR and thereby an increase in scan time to obtain acceptable image quality.




4 **(4A)** T1 VIBE tra 2 mm (3:38 min), **(4B)** T2 TSE tra 2 mm (6:17 min).

# Prostate 3

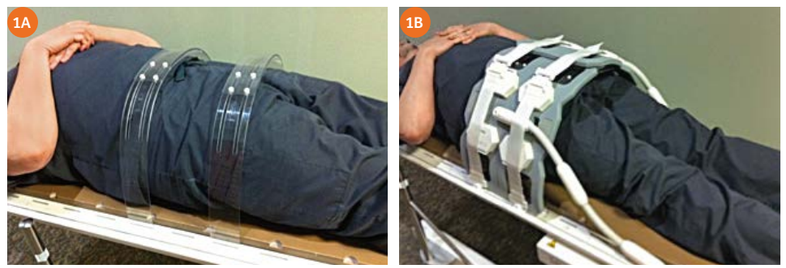
Colleen Lawton, M.D.; Eric Paulson, Ph.D.
Medical College of Wisconsin, Milwaukee, WI, USA

## Patient

| | |
|---|---|
| **Patient Presentation** | Prostate adenocarcinoma |
| **Treatment Prescribed** | Volumetric modulated arc therapy |

## Imaging Study

| | |
|---|---|
| **Scanner** | MAGNETOM 3T Verio |
| **Equipment Required** | • Two 6-channel Body Matrix coils<br>• Spine array coil<br>• Two adjustable coil bridges<br>• Two Nylon straps<br>• Flat table overlay<br>• Patient-specific immobilization device(s) |
| **Patient Prep Needed** | • Change into gown and robe<br>• Bladder filling protocol |
| **Setup and Landmark** | • Position flat table overlay over spine array<br>• Index patient-specific immobilization devices to flat table overlay<br>• Setup patient head-first supine, using external lasers to align and straighten, and confirm pelvic crest is above S9 on spine array coil<br>• Place RF coil bridges over pelvis and conform to patient surface anatomy<br>• Wrap two 6-channel Body Matrix coils circumferentially over RF coil bridges and secure with two Nylon straps<br>• Landmark over diaphragm |




1 Adjustable RF coil bridges and RF coil positioning.





## Sequences

**Download the .exar1 file at usa.siemens.com/magnetom-world-mr-in-rt**

| Sequence | Scan time | Utility for RT | Characteristics |
|---|---|---|---|
| Localizer | 0:30 | | |
| Sag Restore T2 TSE | 3:00 | Delineation of gland and rectum / gland interface | |
| Ax Restore T2 TSE | 5:00 | Delineation of gland | |
| Cor Restore T2 TSE | 3:00 | Delineation of gland and localization of urethra | |
| Ax DWI | 5:00 | Localization of gross tumor volume | Acquired b-values: 200, 600, 1000 s/mm$^2$; calculated b-value: 1400 s/mm$^2$ |

## Special Considerations

| | |
|---|---|
| **Acquisition** | • Readout bandwidths adjusted to ensure WFS < 1 pixel |
| **Preparing Images for Treatment Planning** | • Apply 3D distortion correction to all images<br>• Apply image standardization to non-DWI images<br>• Perform local rigid registration over prostate gland to align reference MR image with planning CT images |

## Example Images


2 Multiparametric images used for target and OAR localization and delineation.

Planning CT **(2A)**, sagittal T2 TSE **(2B)**, axial T2 TSE **(2C)**, and coronal T2 TSE **(2D)**.

# Cervix—Brachytherapy

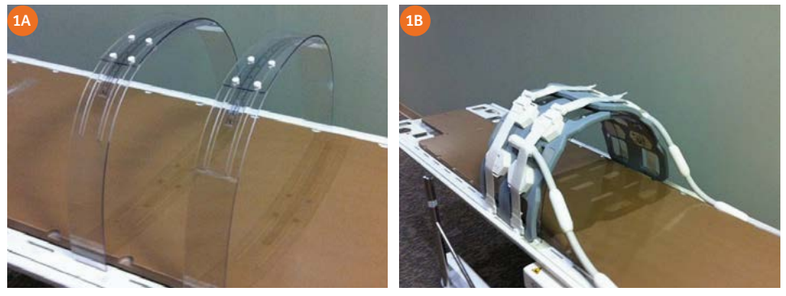
Beth Erickson M.D.; Jason Rownd MS; Eric Paulson Ph.D.
Medical College of Wisconsin, Milwaukee, WI, USA

## Patient

| | |
|---|---|
| **Patient Presentation** | Cervix cancer |
| **Treatment Prescribed** | High dose rate brachytherapy boost |

## Imaging Study

| | |
|---|---|
| **Scanner** | MAGNETOM 3T Verio |
| **Equipment Required** | • Two 6-channel Body Matrix coils<br>• Spine array coil<br>• Two adjustable coil bridges<br>• Two Nylon straps<br>• Flat table overlay<br>• MR-compatible physiological monitoring equipment |
| **Patient Prep Needed** | • Brachytherapy preparation (including anesthesia) |
| **Setup and Landmark** | • Position flat table overlay over spine array<br>• Transfer patient from brachytherapy suite to MR table, setting up patient foot-first supine and confirm pelvic crest is below S9 on spine array coil<br>• Attached physiological monitoring devices<br>• Place RF coil bridges over pelvis and conform to patient surface anatomy<br>• Wrap two 6-channel Body Matrix coils circumferentially over RF coil bridges and secure with two Nylon straps<br>• Landmark over diaphragm |




1 Adjustable RF coil bridges and RF coil positioning.





## Sequences

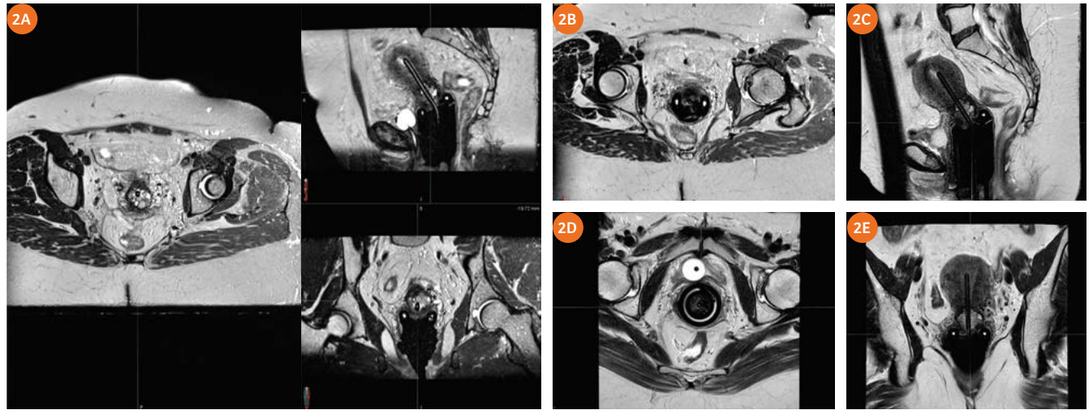
**Download the .exar1 file at usa.siemens.com/magnetom-world-mr-in-rt**

| Sequence | Scan time | Utility for RT | Characteristics |
|---|---|---|---|
| Localizer | 0:30 | | |
| 3PL T2 HASTE | 0:59 | Confirmation of applicator positioning and absence of perforation | Aligned to applicator in three planes |
| Ax 3D T2 SPACE | 12:00 | Planning MR image, delineation of targets and OAR | 1 x 1 x 1.5 $mm^3$ voxels |
| Ax T2 TSE | 4:00 | Delineation of gross tumor volume and high risk clinical target volume | Para-axial, parallel to ring |
| Sag T2 TSE | 3:00 | Delineation of gross tumor volume and high risk clinical target volume | Para-sagittal, parallel to tandem |
| Cor T2 TSE | 3:00 | Delineation of gross tumor volume and high risk clinical target volume | Para-coronal, parallel to tandem |

## Special Considerations

| | |
|---|---|
| **Acquisition** | • Administer 1 mg Glucagon IV (1/2 at start of exam, 1/2 midway through exam) to suppress peristalsis<br>• Readout bandwidths adjusted to ensure WFS < 1 pixel |
| **Preparing Images for Treatment Planning** | • Apply 3D distortion correction to all images<br>• Apply image standardization to all images |

## Example Images




2 Multiparametric images used for target and OAR localization and delineation. **2A:** Axial 3D T2 SPACE planning MR images displayed with sagittal and coronal reformats. A saline filled dummy catheter, inserted into the tandem lumen, is visible on the sagittal image. Registered 3D T2 SPACE **(2B),** para-sagittal 2D T2 TSE **(2C),** para-axial 2D T2 TSE **(2D),** and para-coronal 2D T2 TSE **(2E)** images. A saline filled dummy catheter, inserted into the ring lumen, is visible on the para-axial images. The saline filled dummy catheters assist in aligning applicator templates during brachytherapy treatment planning.

# Musculoskeletal

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## Overview

Coil and protocol selection will vary depending on the anatomical site of interest and patient positioning. For areas greater than 30 cm in scan length, TimCT should be considered to maintain geometrical integrity of scans for accurate CT-MRI rigid registration in radiotherapy treatment planning system.

## Patient

| | |
|---|---|
| **Patient Presentation** | Any peripheral primary or secondary lesions<br>• Sarcoma<br>• Osteosarcoma<br>• Metastatic disease |
| **Treatment Prescribed** | Dependent on location and disease extent |

## Imaging Study

| | |
|---|---|
| **Scanner** | MAGNETOM Skyra 3T |
| **Equipment Required** | • Flex 4 Large and Small (Site dependant)<br>• Body 18 surface coil (Site dependant)<br>• Flat table overlay (CIVCO)<br>• Velcro straps<br>• Patient-specific immobilization device/s |
| **Patient Prep Needed** | 22-gauge intravenous cannula required prior to imaging if gadolinium is requested |
| **Setup and Landmark** | • Index patient-specific immobilization devices to flat table overlay<br>• Patient to be positioned as per CT Simulation<br>• Straighten the patient's anatomy of interest using the rotation tattoos with the external laser system<br>• Depending on the region of interest |

1 MR Sim setup using vacuum bag for immobilisation over tricep Sarcoma. 18-channel surface coil used over centre over affected arm. Patient was offset to position arm in the isocentre of the MRI scanner.





2 MR Sim setup in prone position for gluteal sarcoma. 18-channel surface coil used over centre of affected area.

3 MR Sim setup for TimCT of femur using a combination of coils including 18-channel surface coils and two 4-channel flex coils.

## Sequences

**Small region of interest**

**Download the .exar1 file at usa.siemens.com/magnetom-world-mr-in-rt**

| Sequence | Scan time | Utility for RT | Characteristics |
|---|---|---|---|
| Localizer | 0:09 min | | |
| T1 TSE | 2:04 min | Bone registration to CT | |
| T2 TSE Dixon | 2:40 min | Delineation of gross tumor volume, nodes and associated edema | |
| T1 TSE Dixon + Gad | 2:40 min | Delineation of gross tumor volume | **Injection Rate:** Hand bolus<br>**Gad Vol:** 0.1 mmol/kg (Gadobutrol)<br>**Saline Flush:** 10 ml before and after Gad |

**Long bones and larger regions of interest (TimCT)**

| Sequence | Scan time | Utility for RT |
|---|---|---|
| Localizer | 0:09 min | |
| T1 FLASH TimCT | 4:48 min | Bone registration to CT |
| T2 HASTE FS TimCT | 6:43 min | Delineation of gross tumor volume and nodes |
| T2 HASTE TimCT | 6:43 min | Delineation of gross tumor volume and associated edema |

## Special Considerations

**Tips & Tricks**

- Use MRI markers over reference tattoos to help with CT-MRI registration in radiotherapy treatment planning system.
- Use immobilisation methods such as sponges and tape to ensure patient does not move during image acquisition.
- Run two localizers for upper extremities e.g. arm with the second localizer offset to the affected side. Acquire second localizer in ISO positioning mode.
- If possible, MR staff to be present at CT Sim to assist with positioning and provide advice on immobilisation to ensure compatibility with MRI.
- Use Dixon where applicable for robust fat suppression particularly for upper extremities.
- For areas longer than 30 cm, such as long bones, consider TimCT to maintain geometrical integrity of anatomy.

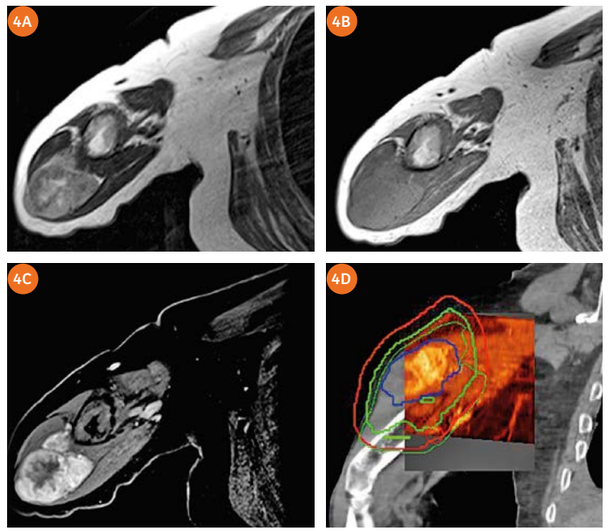
**RTP Requirements**

- Use 3D distortion correction where applicable. If unavailable use 2D.
- Maintain a receiver bandwidth with a ≤ 1 pixel fat-water shift (≥ 400 Hz/Px at 3T).
- 0 mm interslice gap to eliminate interpolation in radiotherapy treatment planning (RTP) system.
- All sequences should have the same centre slice to maintain consistency with CT-MRI rigid registration in RTP system.
- 2–3 mm slice thickness will vary on anatomical site of interest. Ensure that the slices encompass entire extremity in an ideal acquisition time to maintain image quality.



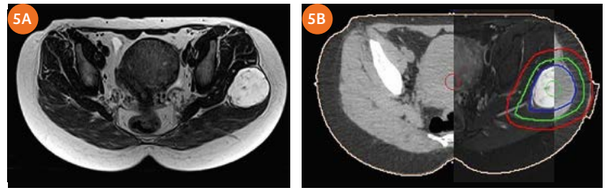


## Example Images



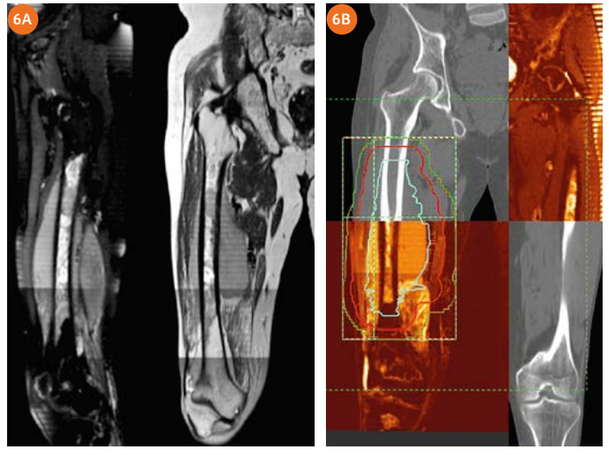

**4 Tricep Sarcoma**

**Figure 4:** T2 Dixon in-phase **(4A),** T1 Dixon in-phase **(4A),** T2 Dixon water **(4C),** co-registration of post-contrast T1 Dixon water (thermal window) with planning CT, showing agreement between two scans and good registration of tumor volume.




**5 Gluteal Sarcoma**

**Figure 5:** T2 Dixon in-phase **(5A),** co-registration of planning CT and T2 Dixon water sensitive planning MRI, showing robust fat suppression over a large field of view and excellent registration of bony and soft tissue anatomy **(5B).**




**6 Metastatic disease in femur using TimCT for a 60 cm scan length**

**Figure 6:** Reconstructed T2 HASTE with SPAIR showing hyperintense metastic disease in bone marrow of femoral shaft **(6A),** coronal reconstructed T1 FLASH used for bone registration to planning CT **(6B),** accurate co-registration of planning CT with T2 HASTE planning MRI.

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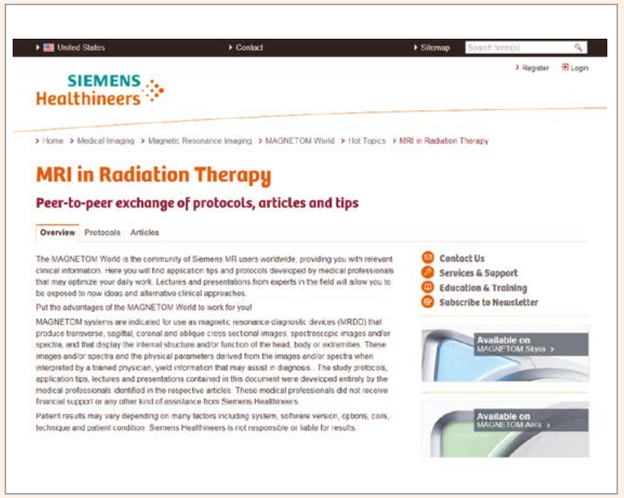


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