MR-integrated Workflows in Radiation Therapy

for MAGNETOM Systems

Eric Paulson, Ph.D.
Medical College of Wisconsin, Milwaukee, USA

Yue Cao, Ph.D.
University of Michigan, Ann Arbor, USA

Leah Best
Calvary Mater Hospital, Newcastle, NSW, Australia

Trina Herbert
The Royal Marsden NHS Foundation Trust, Sutton, UK

Maja Sohlin, Ph.D.
Sahlgrenska University Hospital, Gothenburg, Sweden

Robba Rai, MHlthSc and Gary Liney, Ph.D.
Liverpool and Macarthur Cancer Therapy Centre, Ingham Institute for Applied Medical Research, Sydney, Australia

Cynthia Ménard, M.D., FRCPC
and David Roberge, M.D., FRCPC
Centre hospitalier de l’Université de Montréal, Canada

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David Roberge graduated from the University of Montreal, Canada, with an MD in medicine in 1997 and completed a residency in radiation oncology from McGill in 2002. In 2002–2003 he completed two fellowships — at Stanford University Medical Center and St. Jude Children’s Research Hospital. Following his training he joined as staff at the McGill University Health Center and the Sir Mortimer B. Davis Jewish General Hospital. In 2010 he completed a transition to the University of Montreal as head of radiation oncology for CHUM and researcher at the CRCHUM. He remains adjunct professor of oncology at McGill University and is associate professor of radiology/radiation-oncology/nuclear medicine at the University of Montreal.

Dr. Roberge recently oversaw the move into a new cancer center in downtown Montreal where clinical and research priorities will increasingly feature imaging dedicated to radiation oncology. The departmental philosophy has been to implement a wide variety of radiation delivery devices. As well, the department now operates in a single facility four CT simulators (including a Siemens dual source system), a PET/CT simulator and a dedicated 1.5T Siemens Healthineers MAGNETOM Aera MR simulator.

Dr. Roberge has held a variety of administrative and leadership positions in radiation oncology, notably leading the association of Quebec radiation oncology department heads. He has co-authored reference documents for the IAEA and ICRU. He has supervised and co-supervised a number of students from medicine, radiation-oncology and medical physics. He has published more than 100 manuscripts and traveled the world for more than 60 presentations as visiting professor.

Although his interests are varied (cutaneous lymphoma, liver malignancies, radiotherapy of benign disease, ...), stereotactic radiation features prominently in his research funding, manuscripts and teachings. Most notably, he is co-principle investigator of a multinational randomized trial of adjuvant radiosurgery for brain metastases and principle investigator of an upcoming intergroup trial of radiosurgery for multiple brain metastases.
Dear colleagues, dear readers,

What is MR in RT in 2018? MRI integration into radiation planning is nothing new. I personally can remember in 1995 using an overhead projector to overlay (‘fuse’) a sagittal MRI of the brain onto a 2D simulator film in order to define the posterior fossa for a medulloblastoma boost plan. Over the next three decades, co-registration of diagnostic MR images with planning CT images acquired in radiation oncology has become commonplace. In 2018, MR units are seen in radiation oncology departments and MR in RT is much more than sporadic diagnostic images overlaid on simulator films.

**Why MR in RT: Motivation and effect on clinical outcome**

While CT still remains an essential part of RT planning, across many tumor types, the improved target visualization in MR can be dramatic – one need only think of low-grade brain tumors or epidermoid cancers of the base of tongue. Across tumor types, there is compelling data demonstrating altered delineations when MR is co-registered to CT. The evidence that improvements in target delineation lead to improved clinical outcomes has been weaker. Retrospective comparisons do however suggest benefits such as reduced bowel toxicity in prostate cancer and improved tumor control for carcinoma of the uterine cervix.

In some circumstances similar information can be obtained by CT but at greater risk and discomfort for the patient – for example, one would not want to return to routine CT cisternograms to visualize trigeminal nerves.

Although the radiation dose from CT-simulation is not generally a concern in the context of radiotherapy, the non-ionizing nature of MR does open up opportunities such as evaluating motion management techniques over multiple respiratory cycles.

Without high-level evidence of benefits to the patient, what motivates some departments to invest in MR units dedicated to radiotherapy? For some it will be the hope of attracting more patients, for others a desire for technological preeminence, and others a striving for clinical excellence.

**Clinical workflow incorporating CT and MR in external beam RT**

The current standard backbone of radiotherapy planning is computed tomography. There remain notable exceptions – whether it be to plan superficial irradiation of a basal cell carcinoma or frame-based radiosurgery of a small brain metastasis. Current CT simulators offer the radiotherapy team:

- Large bore sizes which allow flexibility in patient positioning
- Large imaging field of view with reliable geometry
- Information on electron density which permits inhomogeneity corrections during treatment planning
- Fast examinations and large field 4D images
- High in-plane and through-plane resolution

Where does the MR fit in to the planning workflow? This will vary from one hospital to another and will depend on the clinical scenario. As MR in RT matures we are likely to see many changes in how MR is integrated. In 2018, the most common MR in RT paradigm will see the patient imaged with both MR and CT prior to treatment – MR used for tumor delineation and the CT for dose calculation. The following chapters will outline some of the variation in how MR is integrated as various institutional experiences with MR simulation are described. In many cases, the solutions selected represent compromises where target visualization, patient comfort and finances may be at odds. General considerations include the following:

**Scheduling**

When both CT and MR simulation are to be acquired, they are ideally done on the same day, in the same department. When this is possible, the patient need only have one venous access for contrast and one visit to the hospital. There is no strict rule as to what order the procedures should be done in but it will make sense to do the CT first if the immobilization is to be customized in the imaging device (as opposed to a ‘mould room’) as the CT has less restrictions (for ovens, pumps and other accessories used to fashion immobilization) and is less costly on an hourly basis. The counter argument is that the MR bore is more restrictive and acquiring the MR first ensures that the patient positioning will be compatible with both devices.
Lasers and immobilization
External lasers are not mandatory at MRI and will add little in cranial imaging, in cases with ‘body frames’, or when organs are co-registered using internal fiducials. On the other hand, lasers will be required for marking patients during MR-only simulation and aligning patients with looser immobilization systems.

Optimal patient position for treatment and ease of CT-MR registration are sometimes at odds and it will usually make more sense to chose a position which can be imaged in the MRI bore rather than using deformable registration between CT and MR. These compromises are somewhat lessened in the larger 70 cm MR bores.

The battle for SNR
Clinicians who need to work with MR images, whether for interpretation or radiotherapy segmentation will always favor images with as little noise as possible. Unfortunately, image quality will always be the result of compromises. Although the physics of MR imaging do not vary, the compromises around SNR will generally be tainted by the needs specific to radiotherapy.

Factors associated with improved SNR
- Increased magnet field strength
- Larger voxels
  (larger FOV, smaller matrix size, thicker slices)
- Closer proximity of the receive coils to the patient
- Larger number of coil elements
- Lower readout bandwidth
- Longer scan times

Once the MR device is purchased, one has no control on field strength. Although the higher field 3T magnets will typically allow for better SNR (and/or shorter scan times) the costs will not only be financial, there will also be added patient and staff safety issues as well as a greater potential for image distortions/artifacts.

The high overall level of accuracy in radiotherapy delivery would ideally lead one to choose isotropic 1 mm voxels for most applications. In order to improve SNR, one may need to compromise for larger voxels when not dealing with stereotactic cranial applications.

The use of immobilization devices, especially thick vacuum cushions set on MR radiotherapy table inserts, will move the patient away from the coils. Similarly, the use of aquaplast masks may force the use of flexible coils which will be further from the patient (and contain fewer coil elements) than dedicated multi-channel head coils.

When imaging the generally rigid anatomy of the cranium, it may make more sense to forgo immobilization at the MR and rely on image registration. The tradeoff here is potential loss of spatial resolution due to registration of images obtained with patients set up in two different positions.

The impact of distortions
The geometric accuracy of MR images is limited by the homogeneity of the static field ($B_0$), the linearity of the applied gradients, the magnetic susceptibility distribution of the patient, and chemical shift artifacts. While geometric distortions may not significantly impact the diagnostic usefulness of the images, they may lead to radiotherapy targeting inaccuracies or errors in dose calculation.

The distortions will depend on: the MR device used, the magnet strength, the distance from the MR isocenter (the image is most accurate near the isocenter), the pulse sequence used (diffusion images notoriously demonstrate distortions), readout bandwidth, and patient anatomy. Using distortion-correction algorithms provided on the MR device can reduce the severity of the gradient nonlinearity distortions.

The various distortions can be characterized by imaging phantoms with embedded grids. Patient-related distortions can be visualized in susceptibility maps (they will be worse at tissue-air interfaces and around metal implants), anthropomorphic phantom images and CT to MR registration.

It is important to understand how images are to be used, where the distortions occur and the magnitude of distortions. If one is registering a prostate on MR to a prostate on CT, the impact of geometric inaccuracies will be less than in planning pelvic radiotherapy without a CT. One should work towards inaccuracies of 1 mm for the central 20 cm of the magnetic field and 2 mm or less the patient periphery for anatomy outside of the head and neck.

A regular QA protocol will be required to insure that tolerances have not drifted over time.

Volume imaged, scan plane and slice thickness
The volume imaged is at odds with image distortion and scan time (scan time is a currency which must also be spent on other aspects of MR “quality”, whether SNR or resolution). Obviously MR-only simulation requires imaging out to the skin. In other cases, image a volume too small and the target may be missed or image registration
made imprecise. When voxels are cubic, scan plane will typically be along the shortest axis of the area to be imaged. This will usually mean sagittal images of the brain or spine but axial images of the pelvis. While the image acquisition plane and parameters will often be optimized for speed, the format for export will depend on the constraints of the treatment planning system (TPS). Does the TPS require axial images? Does the TPS have a limit on the maximum number of slices?

**The presence of fiducials**

Many radiation treatments rely on the presence of implanted fiducials for in-room image-guidance. Because of its high atomic number and biocompatibility, gold is often the preferred material for these fiducials. Gold fiducials do not provide MR signal but are seen as a signal void. All sequences are not created equal as to how prominent this signal loss will be. It may be that an additional sequence is acquired specifically for the fiducials or that a compromise is made between target segmentation and fiducial identification (for example, selecting a T2* instead of a T2). An alternative is to segmentation and fiducial identification (for example, fiducials or that a compromise is made between target segmentation and fiducial identification (for example, selecting a T2* instead of a T2). An alternative is to consider magnetic susceptibility when selecting fiducials. This may mean replacing gold with platinum or using a hybrid gold/polymery fiducial.

**From images to a treatment plan**

With an MR dataset compatible with the treatment planning system, the images are transferred. The precise workflow will depend on the software available and the experience of the treatment planning team. In most cases, the MR will need to be co-registered to a planning CT. It may or may not be possible to segment the MR prior to image registration. When this is possible, segmented contours can be used to evaluate the registration. Deformable image registration could be the subject of its own treatise and must be used with caution – it may be preferable to perform a rigid registration focused on the volume of interest or even use more than one rigid registration.

**Errors**

The small discrepancies in where the radiation beam is aimed and where the tumor and organs are positioned can be random or systematic. The current means of dealing with these errors is to aim the radiation at a larger volume – the planning target volume. For patients treated with multiple fractions the impact of systematic error where the dose is consistently moved in the same direction is greater than that of random error through which there is a smearing of the dose. A significant source of systematic error is inaccurate delineation of targets on the planning images. The promise of MR in radiotherapy planning is that the improved soft tissue contrast will improve the quality of delineation and thus reduce systematic error. One needs to be cautious that this benefit is not lost to new sources of systematic error: chemical shift, geometric distortion, misregistration of the MR to the planning CT, misidentification of implanted fiducials. … Until MR-only workflows become commonplace, it is prudent to always confirm segmentation on the planning CT.

**Image-guidance for external beam radiotherapy**

Treatment devices are becoming increasingly sophisticated at verifying and correcting the alignment of the patient to the treatment beam. Nonetheless, initial patient positioning remains important and surface markings made at simulation will help the therapist get the patient straight and centered prior to image-guidance.

Daily image-guidance procedures vary depending on the treatment device, the clinical scenario and institutional preference. The two most common modalities will be either a set of planar X-rays or a cone-beam CT performed prior to treatment. These images are compared to either the planning CT or simulated planar X-rays computed using the CT (so-called digitally reconstructed radiographs or DRRs). The images of the day are aligned to the planning images based on the target, surrogate anatomy or implanted fiducials. As examples, a lung tumor may be directly visualized on cone-beam CT, the skull may serve as a reliable surrogate for a brain tumor and implanted radio-opaque fiducials may guide treatment of a liver cancer. Patient translations and sometimes rotations are used to fine-tune the target alignment. In some cases compromises will be required when the anatomy is deformed or the position of the tumor has shifted in relation to a critical organ.

More sophisticated delivery paradigms aim to track tumor and/or patient position during treatment. The technologies used may involve structured light for surface mapping, continuous ultrasound, orthogonal X-rays, fluoroscopy or repeated CT imaging.

The nascent integration of MRI in the treatment delivery process promised to lessen reliance on implanted fiducials and other tumor surrogates. MRI also enables continuous daily soft tissue imaging without extra radiation dose. MRI-guided radiation is not without challenges – in dosimetry, safety and health economics. However MRI-guidance has a bright future as the field moves to adapting daily treatments to account for patient deformation and tumor response rather than simply translating the patient within pre-set treatment fields.
Special considerations in brachytherapy

Use of MR in brachytherapy shares many of the same issues of MR in external beam radiotherapy. In addition it has its own unique issues in the different steps of the workflow. Scheduling of brachytherapy cases is more difficult – the exact duration of the procedures can be unpredictable, scheduling is inflexible, the time the patient spends in the MR suite is typically longer and transport of the patient from the brachytherapy unit and/or operating room excludes use of a geographically removed MR unit. Additional MR-compatible hardware may be required to monitor the patient while in the magnet and shuttle the patient from a stretcher to the MR couch. Some concerns in designing imaging sequences are unique: precise visualization of the brachytherapy applicator, lessened importance of geographic distortions removed from the site of the brachytherapy implant, image distortion caused by the brachytherapy applicator and specific absorption rate (SAR) limits to prevent heating of metal applicators*. Despite the challenges, brachytherapy is a compelling application for an MR unit in the radiotherapy department.

The patient perspective

The hope is that MRI simulation will improve patient quality of life and possible overall survival. To achieve these potential benefits, patients will be exposed to potential dangers and discomforts of MRI imaging. While injury caused by exposure to magnetic fields or gadolinium-based contrast agents should be exceedingly rare with proper screening and precautions, other inconveniences will be more commonly encountered. The most common will be claustrophobia, discomfort from immobilization systems and the inconvenience of added appointments. Measures can be taken to improve the patient experience:

• Can all planning appointments be given on the same day? This is certainly easier when all simulation work is performed in the same physical location.

• Have the number and duration of MRI sequences been optimized? Are the most important sequences acquired first in cases when the patient may not tolerate the entire procedure?

• What is the bore size of the MRI? Are patients screened for claustrophobia? Does the department have access to psychological counseling?

Looking into the future of MR in RT

MRI in radiotherapy has the advantage of ‘trialability’. Prior to investing in a device dedicated to radiotherapy, departments can increase the number of clinical scenarios in which they integrate MRI from their diagnostic radiology departments, if the scanners are accessible.

As the volume of radiotherapy examinations increases, so will the number of devices installed in radiotherapy departments. Training programs in therapy, oncology and physics will increasingly include courses in MR safety, science and interpretation. An important step in increasing adoption may be the development of simple and reliable MRI-only simulation workflows. Thus, as the contraindications to MR-imaging ever decrease, MRI-simulators may not so much cohabit with CT-simulators but replace them.

As the number of units installed in radiation oncology increase, so will the demand for true MR-simulators with hardware uniquely designed to meet the needs of treatment planning.

As daily MR guidance also gains adoption, deep-learning assisted segmentation will accelerate daily anatomical replanning. When devices can acquire functional data during treatment – thus without any time penalty – a large database will be mineable for clues to test dose painting strategies based on functional data. Adoption of such paradigms will likely be slower than those based on anatomical data and will require prospective validation – possibly in more innovative trial designs than the traditional randomized trial (registry randomized trials).

What is certain is that the future of MR in RT is bright!

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* 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.
Thank you!

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

Yue Cao, Ph.D.
University of Michigan,
Ann Arbor, USA

Eric Paulson, Ph.D.
Medical College of Wisconsin,
Milwaukee, USA

Maja Sohlin, Ph.D.
 Sahlgrenska University Hospital,
Gothenburg, Sweden

Leah Best, MSc
Calvary Mater Hospital,
Newcastle, Newcastle,
NSW, Australia

Trina Herbert
The Royal Marsden
NHS Foundation Trust,
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Cynthia Ménard, M.D., FRCP and
David Roberge, M.D., FRCP
Centre hospitalier de l’Université de Montréal,
Canada

Maja Sohlin, Ph.D.
Sahlgrenska University Hospital,
Gothenburg, Sweden

Gary Liney, Ph.D. and Robba Rai, MtlthSc
Liverpool and Macarthur Cancer Therapy Centre,
Ingham Institute for Applied Medical Research,
Sydney, Australia

You can download the .edx and .exar1 files at

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We look forward to hearing your feedback and suggestions, so that we at Siemens Healthineers can continually improve and do our part in the care of your patients. Please contact us at: magnetomworld.team@siemens-healthineers.com
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Liverpool and Macarthur Cancer Therapy Centre,
Ingham Institute for Applied Medical Research, Sydney, Australia
Glioma 1

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

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

<table>
<thead>
<tr>
<th>Patient presentation</th>
<th>High Grade Glioma: Considered in all patients, especially if interval from Sim to diagnostic imaging &gt; 3–4 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low Grade Glioma: Considered if no post-operative MRI available, poor quality or non-contemporaneous diagnostic scan</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Treatment prescribed</th>
<th>Varies on grade and location of tumor:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• 3D Conformal</td>
</tr>
<tr>
<td></td>
<td>• IMRT (intensity-modulated radiation therapy)</td>
</tr>
<tr>
<td></td>
<td>• VMAT (volumetric modulated arc therapy)</td>
</tr>
<tr>
<td></td>
<td>• Tomotherapy</td>
</tr>
</tbody>
</table>

Imaging study

<table>
<thead>
<tr>
<th>Scanner</th>
<th>MAGNETOM Skyra 3T</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Equipment required</th>
<th>• Head/Neck 20 coil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Immobilisation sponges</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Patient prep needed</th>
<th>22-gauge intravenous cannula required prior to imaging</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Setup and landmark</th>
<th>• Patient positioned head first supine.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Straighten patient through mid forehead, mid nose and mid chin using external lasers.</td>
</tr>
<tr>
<td></td>
<td>• Use immobilisation sponges on the sides of patient’s ears and top of head to prevent movement during imaging.</td>
</tr>
<tr>
<td></td>
<td>• Landmark over the lower orbital margin (OM) using the bore lasers.</td>
</tr>
</tbody>
</table>

Figure 1:
Brain setup using 20-channel head and neck coil.
**Imaging protocol**

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Scan time</th>
<th>Utility for RT</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Localizer</td>
<td>0:15 min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T1w MPRAGE 3D sagittal</td>
<td>5:21 min</td>
<td>Anatomical delineation</td>
<td></td>
</tr>
<tr>
<td>T2w FLAIR 2D</td>
<td>4:26 min</td>
<td>Post-operative changes</td>
<td>Use 2 concatenations to minimize cross talk artifacts and maintain grey-white matter contrast</td>
</tr>
<tr>
<td>T1w MPRAGE 3D sagittal + Gad</td>
<td>5:21 min</td>
<td>Tumor delineation</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Residual enhancement post-op</td>
<td></td>
</tr>
</tbody>
</table>

**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**

![Image](image1)

**Figure 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

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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.

Figure 1: Patient setup using two Flex 4 Large coils supported by sandbags.
# Imaging protocol

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

## 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

*Figure 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

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Patient

T reatment 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.

* The information shown herein refers to products of 3rd party manufacturers and thus are in their regulatory responsibility. Please contact the 3rd party manufacturer for further information.
Imaging protocol

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

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

Figure 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).
Small targets for stereotactic treatments – Schwannoma

Maja Sohlin; Karin Petruson
Sahlgrenska University Hospital, Gothenburg, Sweden

Coverage

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Scan time</th>
<th>Utility for RT</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Localizer</td>
<td>0:32 min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Axial T2 SPACE</td>
<td>6:03 min</td>
<td>Delineation of target and risk organ</td>
<td>1 mm slice thickness 44 mm slab thickness</td>
</tr>
<tr>
<td>Axial T1 SPACE + Gd</td>
<td>7:04 min</td>
<td>Delineation of target and risk organ</td>
<td>1 mm slice thickness</td>
</tr>
<tr>
<td>Axial T2 SPACE (Optional)</td>
<td>9:01 min</td>
<td>Delineation of target and risk organ</td>
<td>1 mm slice thickness 160 mm slab thickness</td>
</tr>
</tbody>
</table>

Imaging protocol

Example images

Figure 1: Patient image showing the coverage on the localizer.

Figure 2:
(2A) Axial T2 SPACE
(2B) Axial T1 SPACE
Advance your clinical capabilities with the MAGNETOM RT Pro edition

- MR compatible laser bridge with direct laser steering for precise patient marking and positioning
- RT Dot Engine with optimized RT protocols for consistent scans
- RT specific coil holders for proper positioning
- Flex, UltraFlex and BioMatrix coils for excellent image quality
- RT compatible indexed flat table tops and high accuracy table (z positioning accuracy +/- 0.5 mm)
- Dedicated QA recommendations

1 Optional
2 Accuracy for repositioning from one direction

siemens.com/magnetom-world-rt
# Framed stereotactic radiosurgery

Christopher Schultz, M.D.; Colette Gage, BS RTR(MR); Eric Paulson, Ph.D.

Medical College of Wisconsin, Milwaukee, WI, USA

## Patient

<table>
<thead>
<tr>
<th>Patient presentation</th>
<th>Brain metastases and pituitary adenoma</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment prescribed</td>
<td>Gamma Knife</td>
</tr>
</tbody>
</table>

## Imaging study

<table>
<thead>
<tr>
<th>Scanner</th>
<th>MAGNETOM Verio 3T</th>
</tr>
</thead>
</table>
| Equipment required | - 6-channel body matrix coils  
- Spine array coil  
- Two Nylon straps  
- Two sandbags  
- Flat table overlay  
- Head frame holder |
| Patient prep needed | - Change into gown and robe.  
- Patient will arrive at MRI with head frame positioned. |
| Setup and landmark | - Position flat table overlay over spine array.  
- Index head frame bracket at S2 over spine array.  
- Setup patient head-first supine and secure head frame into head frame holder.  
- Attach fiducial box to head frame.  
- Wrap two 6-channel body matrix coils circumferentially around head frame and fiducial box and secure with two Nylon straps.  
- Position sandbags to conform coils tightly against head frame.  
- Landmark over orbits. |

---

**Figure 1:**
Custom fiberglass head frame holder (1A), patient positioning over spine array (1B), RF coil positioning (1C), adjust volume and scan volume prescription (1D).
**Imaging protocol**

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Scan time</th>
<th>Utility for RT</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Localizer</td>
<td>0:30 min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ax B₀ Map</td>
<td>1:12 min</td>
<td>Generation of voxel shift map</td>
<td></td>
</tr>
<tr>
<td>Ax 3D T1+C</td>
<td>5:30 min</td>
<td>Target delineation</td>
<td>A/P phase encode</td>
</tr>
</tbody>
</table>

**Special considerations**

**Acquisition**
- Confirm Quiet gradient mode set for all sequences and readout bandwidth set at 440 Hz/pixel (at 3T) to reduce eddy current-induced distortions.
- Confirm ISO positioning mode (scan with prescribed volume at isocenter).
- Prescribe adjust volume over brain.
- Confirm A/P phase encode direction to minimize flow artifacts from fiducials.

**Preparing images for treatment planning**
- Apply 3D Distortion Correction to all images.
- Inspect voxel shift map for local geometric distortions.
- Avoid registering images in treatment planning system using fiducials within 2 cm of SRS frame.

**Example images**

![Figure 2: 3D post-contrast T1 images. Fiducial box markers use for registration in treatment planning system are visible.](image)
Head & neck

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

<table>
<thead>
<tr>
<th>Patient presentation</th>
<th>Mucosal Primary:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• All nasopharyngeal primaries</td>
</tr>
<tr>
<td></td>
<td>• All other mucosal primaries where extent of disease uncertain after endoscopy/PET</td>
</tr>
<tr>
<td>Non-mucosal Primary:</td>
<td>• Consider if primary or nodal disease is close to critical structures.</td>
</tr>
</tbody>
</table>

| Treatment prescribed | IMRT or Tomotherapy |

Imaging study

<table>
<thead>
<tr>
<th>Scanner</th>
<th>MAGNETOM Skyra 3T</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Equipment required</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Two Body 18 surface coils</td>
</tr>
<tr>
<td>• RF coil bridges</td>
</tr>
<tr>
<td>• Flat table overlay</td>
</tr>
<tr>
<td>• Velcro straps</td>
</tr>
<tr>
<td>• Patient-specific immobilization device/s</td>
</tr>
</tbody>
</table>

| Patient prep needed | 22-gauge intravenous cannula required prior to imaging |

<table>
<thead>
<tr>
<th>Setup and landmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>• 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.</td>
</tr>
<tr>
<td>• Index patient-specific immobilization devices to flat table overlay.</td>
</tr>
<tr>
<td>• Patient to be positioned as per CT simulation. Head first supine.</td>
</tr>
<tr>
<td>• Straighten the patient according to the anatomical landmarks with the external laser system.</td>
</tr>
<tr>
<td>• 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.</td>
</tr>
<tr>
<td>• Lower the bridges so that it is close to the patient’s mask but not touching.</td>
</tr>
<tr>
<td>• Place the second Body 18 surface coil over the patient’s torso.</td>
</tr>
<tr>
<td>• 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.</td>
</tr>
<tr>
<td>• Landmark over the chin.</td>
</tr>
</tbody>
</table>

Figure 1: Head & neck planning MRI setup using two 18-channel surface coils.
Imaging protocol

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Scan time</th>
<th>Utility for RT</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Localizer</td>
<td>0.15 min</td>
<td>Primary and nodal delineation (particularly where contrast not given)</td>
<td>Plan with in-phase and water images</td>
</tr>
<tr>
<td>T2 TSE Fast Dixon</td>
<td>3:17 min</td>
<td>Primary and nodal delineation (particularly where contrast not given)</td>
<td>In-phase images used for bone registration in RTP system</td>
</tr>
<tr>
<td>T1 TSE Fast Dixon</td>
<td>3:05 min</td>
<td>Primary and nodal delineation (particularly where contrast not given)</td>
<td></td>
</tr>
<tr>
<td>T1 TSE Fast Dixon + Gad</td>
<td>3:05 min</td>
<td>Primary and nodal GTV delineation</td>
<td></td>
</tr>
</tbody>
</table>

**Injection Rate**
- 2 ml/s

**Gad Vol**
- 0.1 mmol/kg (Gadobutrol)

**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

Figure 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**

<table>
<thead>
<tr>
<th>Patient presentation</th>
<th>Squamous cell carcinoma</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment prescribed</td>
<td>Volumetric Modulated Arc Therapy</td>
</tr>
</tbody>
</table>

**Imaging study**

<table>
<thead>
<tr>
<th>Scanner</th>
<th>MAGNETOM Verio 3T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment required</td>
<td></td>
</tr>
<tr>
<td>• Two 6-channel Body Matrix coils</td>
<td></td>
</tr>
<tr>
<td>• 4-channel extremity coil</td>
<td></td>
</tr>
<tr>
<td>• Spine array coil</td>
<td></td>
</tr>
<tr>
<td>• Three Nylon straps</td>
<td></td>
</tr>
<tr>
<td>• Flat table overlay</td>
<td></td>
</tr>
<tr>
<td>• Head rest</td>
<td></td>
</tr>
<tr>
<td>• Patient-specific immobilization device</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Patient prep needed</th>
<th>Change into gown and robe</th>
</tr>
</thead>
</table>

**Setup and landmark**

- Position flat table overlay over spine array.
- Index patient-specific immobilization devices to flat table overlay.
- Setup patient head-first supine, using external lasers to align and straighten.
- Wrap two 6-channel Body Matrix coils around patient’s head and secure with two Nylon straps.
- Confirm that the coils overlap anteriorly, are positioned as inferiorly as possible, and are symmetric.
- Position 4-channel extremity coil over neck and secure with Nylon strap. Landmark over patient chin.

---

**Figure 1:**
Immobilization device and RF coil positioning.
Imaging protocol

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

**Special considerations**

**Acquisition**
- Contiguous 3 mm slices with 1 mm in-plane resolution.
- Readout bandwidths adjusted to ensure WFS < 1 pixel.

**Preparing images for treatment planning**
- Apply 3D distortion correction to all images.
- Apply image standardization to all non-diffusion images.

**Example images**

Figure 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).

Download the .exar file at www.siemens.com/magnetom-world-rt
Head & neck 3

Maja Sohlin, Ph.D.; Christian Gustafsson, Ph.D.
Sahlgrenska University Hospital, Gothenburg, Sweden
Reproduced with permission from the "Method book for the use of MRI in radiotherapy" (Version 3) of the Swedish Vinova project.

Imaging study

<table>
<thead>
<tr>
<th>Scanner</th>
<th>MAGNETOM Aera 1.5T</th>
</tr>
</thead>
</table>

**Equipment required**
- Body 18 Long coil
- Flex 4 Small coil
- Coil holders
- Flat table overlay
- Patient-specific immobilization device

**Setup and landmark**
- Position flat table overlay over spine array.
- 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.
- Coverage area see Figure 1.

Figure 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.

Figure 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.
Imaging protocol

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

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

![Figure 2](3A) T1 TSE tra 3 mm (6:36 min) ![Figure 2](3B) T1 TSE tra 3 mm FatSat (6:36 min) ![Figure 2](3C) T1 TSE tra 3 mm GD (6:36 min) ![Figure 2](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 Healthcare.
Head & neck

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
                    • Body 18 long and Spine 32 matrix coils
                    • Patient-specific mask, neck rest and bite block/dental guards when indicated
                    • Sand bags
                    • Head/neck board
                    • Arm pulls if/as needed

Setup and landmark  • Flat table top is usually already in place, but place if needed.
                    • Mask can be made in CT or in Zone 3 (sag laser on wall).
                    • Patient zeroed at External Auditory Meatus, mask is positioned using indexed head/neck board using the exact bar.
                    • Body 18 placed over mask, sand bags used near head region.
                    • Scan range varies by disease site and diagnosis.

Figure 1:  Body 18 coil placed over mask, with sand bags mounted on top near head region.
Imaging protocol

Download the .exar file at [www.siemens.com/magnetom-world-rt](http://www.siemens.com/magnetom-world-rt)

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Scan Time</th>
<th>Utility for RT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Localizer</td>
<td>0:13 min</td>
<td></td>
</tr>
<tr>
<td>2D T1 TSE FS pre Gd</td>
<td>2:08 min</td>
<td>Assisting GTV delineation</td>
</tr>
<tr>
<td>2D DWI RESOLVE</td>
<td>5:00 min</td>
<td>Boost target delineation</td>
</tr>
<tr>
<td>2D T2 TSE fs</td>
<td>3:14 min</td>
<td>Assisting GTV delineation</td>
</tr>
<tr>
<td>2D T1 TSE post Gd</td>
<td>5:35 min</td>
<td>GTV definition</td>
</tr>
</tbody>
</table>

Example images

![Image 2A](2A)
![Image 2B](2B)
![Image 2C](2C)
![Image 2D](2D)

Figure 2:
(2A) T1 TSE FS pre-Gd,
(2B) T1 TSE FS post-Gd,
(2C) ADC map,
(2D) T2 TSE fs.
### Spine 1
Giuseppina Laura Masucci, Jean-Charles Côté, Philip Wong, Karim Boudam
Centre hospitalier de l’Université de Montréal, Canada

#### Patient

<table>
<thead>
<tr>
<th>Patient presentation</th>
<th>Considered in all patients treated for spinal metastasis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Considered in all patients treated for primary spinal tumors</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Treatment prescribed</th>
<th>Varies based on tumor location and extent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IMRT (intensity-modulated radiation therapy)</td>
</tr>
<tr>
<td></td>
<td>VMAT (volumetric modulated arc therapy)</td>
</tr>
<tr>
<td></td>
<td>Helical tomotherapy</td>
</tr>
<tr>
<td></td>
<td>Robotic radiosurgery (Cyberknife)</td>
</tr>
</tbody>
</table>

#### Imaging study

<table>
<thead>
<tr>
<th>Scanner</th>
<th>MAGNETOM Aera 1.5T</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MAGNETOM Avanto® 1.5T</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Equipment required</th>
<th>For tumors of the cervical and upper thoracic spine (C1-T3):</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Spine 32</td>
</tr>
<tr>
<td></td>
<td>• Body 18 long</td>
</tr>
<tr>
<td></td>
<td>• 2x Flex 4 Small</td>
</tr>
<tr>
<td></td>
<td>• Flat table top</td>
</tr>
<tr>
<td></td>
<td>• Thermoplastic mask (used for MAGNETOM Aera, removed before entering tunnel for MAGNETOM Avanto®)</td>
</tr>
</tbody>
</table>

For tumors of the thoracic, lumbar and sacral spine (T3-S5):

|                    | • Spine 32 |
|                    | • Body 18 |
|                    | • Full-body vacuum cushion when treatments are administered using IMRT, VMAT or tomotherapy (used for MAGNETOM Aera, a small reproduction of the spinal area is made for the MAGNETOM Avanto®) |
|                    | • Vacuum cushion for patients treated using Cyberknife |

| Patient prep       | 20-gauge intravenous cannula required prior to imaging if contrast is to be used (considered in patients with paraspinal disease and in the post operative setting) |

| Setup and Landmark | • Patients are positioned head-first supine. |
|                   | • Setup shown here for a thoracic tumor with full-body vacuum cushion. |
Imaging protocol

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Scan time</th>
<th>Utility for RT</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2 SPACE sag 3D</td>
<td>5:07 min</td>
<td>Allows better definition of the spinal cord and thecal sac</td>
<td>1.0 x 1.0 x 1.0 mm</td>
</tr>
<tr>
<td>T1 SPACE sag 3D</td>
<td>4:55 min</td>
<td>To define tumor and spinal cord volumes</td>
<td>1.0 x 1.0 x 1.0 mm</td>
</tr>
<tr>
<td>T1 SPACE FS sag 3D</td>
<td>4:55 min</td>
<td>Contrast usually used in the presence of paraspinal disease or in the post-operative setting to define tumor volumes</td>
<td>1.0 x 1.0 x 1.0 mm</td>
</tr>
</tbody>
</table>

Special considerations

Tips & tricks

- Table in ISO positioning mode.
- 3D distortion correction applied (image outside correction zone not used).
- Bandwidth of at least 220 Hz/mm (1 mm fat-water separation at 1.5 Tesla).
- Save an axial MPR of all the SPACE.

Preparing images for planning

- Send images from MR to PACS.
- Load images (MR and CT) from PACS on image registration console (MIM Vista, MIM Software Inc., Cleveland, OH, USA).
- Rigid registration of MR to CT.
- Send registered images to contouring server.
- Contour volumes on contouring client (Somavision Varian Medical Systems, Palo Alto, CA, USA).
- Send CT and contours from contouring server to planning console.

Example images
Patient

Patient presentation 69-year-old male, prostate cancer, treated with ADT and radiotherapy, completed 2014. Biochemical relapse with PSA 2.7. Intensely PSMA avid lesion at the left pedicle/transverse process of the L4 is consistent with bony metastatic disease seen on PET.

Treatment prescribed SBRT (Stereotactic Body Radiation Therapy) – 24 Gy – 2 fractions to his spine with VMAT (volumetric moderated arc therapy) – nonconsecutive days

Imaging study

Scanner MAGNETOM Skyra 3T system

Equipment required
- Spine array 32-channel surface coil
- CIVCO flat table overlay
- CIVCO Vac-Loc cushion – patient specific
- Knee rest if needed

Immobilisation
CIVCO Vac-Loc cushion – patient specific

Patient prep needed
22-gauge cannula

Setup and landmark
- Position flat table overlay spine array.
- Patient to be positioned head first supine.
- Patient positioned as per positioning for CT simulation.
- Patient aligned using rotation tattoos and external laser bridge.
- Position and centre region of interest to isocentre
- Position patient specific Vac-Loc cushion on table.
- Consider positioning patient closer to the foot end of table to enable the emergency buzzer to reach when arms above head.
- Consideration should be made when making Vac-Loc cushion to enable it to fit in the bore of scanner without movement.
- Patients unable to use the Vac-loc cushion use grey Siemens cushions to replicate treatment position.

* The information shown herein refers to products of 3rd party manufacturers and thus are in their regulatory responsibility. Please contact the 3rd party manufacturer for further information.
### Imaging protocol

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Scan time</th>
<th>Utility for RT</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haste_3plane_loc</td>
<td>0:19 min</td>
<td>Localization of region of interest</td>
<td></td>
</tr>
<tr>
<td>T2_tse_tra</td>
<td>3:38 min</td>
<td>Tumor contouring/anatomical contouring</td>
<td></td>
</tr>
<tr>
<td>T2_space_tra</td>
<td>4:39 min</td>
<td>Tumor contouring/anatomical contouring</td>
<td>Better for upper spinal lesions. No CSF flow voids.</td>
</tr>
<tr>
<td>T1_vibe_fs_tra_pre</td>
<td>1:05 min</td>
<td>Baseline for contrast</td>
<td></td>
</tr>
<tr>
<td>T1_vibe_tra_pre</td>
<td>0:59 min</td>
<td>Tumor contouring</td>
<td></td>
</tr>
<tr>
<td>Contrast</td>
<td></td>
<td></td>
<td>Gadobutrol 0.1 mmol/kg</td>
</tr>
<tr>
<td>T1_vibe_fs_tra_pre</td>
<td>1:05 min</td>
<td>Tumor contouring</td>
<td></td>
</tr>
<tr>
<td>T1_vibe_tra_pre</td>
<td>0:59 min</td>
<td>Tumor contouring</td>
<td></td>
</tr>
</tbody>
</table>

### Special considerations

**Tips & tricks**

- Ensure the Vac-loc bag is made as little thickness as possible at the spine region to minimize distance from the spine coil.
- Can consider using anterior coil for extra signal however then need to adjust parameters to compensate for respiratory artifact.
- Use saturation bands to reduce respiratory ghosting (Thoracic region).
- Ensure patient is positioned so that region of interest is aligned to a spinal coil element.

**Preparing images for planning**

- No specific changes made. Images exported as is to RT Treatment planning software.

**RTP requirements**

- Patient positioned as per positioning for CT simulation.
- Patient aligned using rotation tattoos and external laser bridge.

Figure 2:

(2A) T2w TSE transversal.
(2B) T1w VIBE transversal, pre-contrast.
(2C) T1w VIBE transversal with fat sat post-contrast.
(2D, E) Dose distribution shown on T1w VIBE images pre/post contrast. Treatment isodose shown in orange.
# Esophagus

Candice Johnstone, M.D.; Paul Knechtges, M.D.; Eric Paulson, Ph.D.

Medical College of Wisconsin, Milwaukee, WI, USA

## Patient

<table>
<thead>
<tr>
<th>Patient presentation</th>
<th>Esophageal cancer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment prescribed</td>
<td>3D conformal radiation therapy</td>
</tr>
</tbody>
</table>

## Imaging study

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

![Figure 1](siemens.com/magnetom-world-rt)

**Figure 1:**  
Adjustable RF coil bridges and RF coil positioning.
Imaging protocol

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

Download the .exar1 file at www.siemens.com/magnetom-world-rt

Special considerations

Acquisition

- Respiratory gating performed for tumors close to gastroesophageal junction (GEJ).
- Cardiac gating performed for tumors close to heart.
- Contrast injection performed using bolus tracking technique.
- Readout bandwidths adjusted to ensure WFS < 1 pixel.

Preparing images for treatment planning

- Apply 3D distortion correction to all images.
- Apply image standardization to non-DWI images.
- Perform local rigid registration over gross tumor volume to align reference MR image with planning CT images.

Example images

Figure 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
- Spine 32, 32-channel spine coil
- 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
- Index patient-specific immobilization devices to flat table overlay.
- Patient to be positioned as per CT Simulation. Head first supine.
- Straighten the patient to AP and rotation tattoos with the external laser system.
- Secure coil bridges to table and strap 18-channel surface coil to the bridges.
- Lower the bridges so that it is close to the patient’s torso but not deforming the external contours.
- Ensure that the coil covers the top of lung apices to lower costophrenic angles.
- Landmark over the cross hair of the coil (center of the thorax).

Figure 1:
Patient positioned as per CT Simulation (straightened on tattoos with the external laser system). Coil bridges secured to the table and Body 18 coil strapped to the bridges.

Figure 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).
**Imaging protocol**

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

**Special considerations**

**Tips and tricks**

- Use phase navigation for T2 HASTE for optimal image quality.
- 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.
- 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.
- 3–4 mm slice thickness to encompass entire thorax in an ideal acquisition time to maintain image quality.
**Breast prone unilateral**

Adam Currey, M.D.; Colette Gage, BS RTR(MR); Eric Paulson, Ph.D.

Medical College of Wisconsin, Milwaukee, WI, USA

### Patient

**Patient presentation**

Breast cancer with the following indications:

- Patients requiring surgical bed boost
- Dense breast tissue
- Small lumpectomy cavities
- Long delays between surgery and start of RT
- Inadequate surgical clips

**Treatment prescribed**

3D conformal radiotherapy

### Imaging study

**Scanner**

MAGNETOM Verio 3T

**Equipment required**

- Sentinelle breast coil with base and all pads removed
- Custom styrofoam arm support
- Custom styrofoam body support
- G9 fiberglass breast bridge

**Patient prep needed**

- Change into gown and robe (open to the front).
- Place 22 gauge intravenous cannula into antecubital vein.

**Setup and landmark**

- Remove spine array and all other pads from MRI table.
- Set Sentinelle breast coil (with base removed) onto MRI table.
- Arrange styrofoam arm support to fit into MRI table and sit flush with breast coil.
- Arrange styrofoam body support to fit onto the incline of the breast coil.
- Arrange G9 fiberglass breast bridge to lay flat across the two styrofoam supports.
- Use a blanket or pad for patient to rest their head.
- Setup patient head-first prone. Secure upper extremities using padding or blankets.
- Use external LAP lasers* to verify breast position.
- Landmark over center of diseased breast.

* The information shown herein refers to products of 3rd party manufacturers and thus are in their regulatory responsibility. Please contact the 3rd party manufacturer for further information.

---

**Figure 1:**

Sentinelle breast coil (base removed) with pink styrofoam body support, white styrofoam arm support, and G9 fiberglass breast bridge.
Imaging protocol

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Scan time</th>
<th>Utility for RT</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Localizer</td>
<td>0:30 min</td>
<td>Delineation of seroma</td>
<td>Rotate axial field of view</td>
</tr>
<tr>
<td>Ax 3D T2(f)</td>
<td>6:00 min</td>
<td>Registration reference</td>
<td>Rotate axial field of view</td>
</tr>
<tr>
<td>Ax 3D T1</td>
<td>3:30 min</td>
<td>Localization of gross tumor volume</td>
<td></td>
</tr>
<tr>
<td>Ax DWI RESOLVE</td>
<td>5:00 min</td>
<td>Localization of gross tumor volume</td>
<td></td>
</tr>
<tr>
<td>Ax DCE</td>
<td>8:00 min</td>
<td>Delineation of gross tumor volume</td>
<td></td>
</tr>
</tbody>
</table>

Special considerations

Acquisition
- Prescribe axial 3D T1 and 3D fat-suppressed T2 volumes with field-of-view slightly rotated tangentially to minimize cardiac motion effects over axilla.
- Confirm L/R phase encode direction.
- Prescribe high order shim volume over breast.
- Readout bandwidths adjusted to ensure WFS < 1 pixel.

Preparing images for treatment planning
- Apply 3D Distortion Correction to all images.
- Perform local rigid registration over breast.

Example images

Figure 2: Ax 3D fat-suppressed T2 (2A), Ax 3D T1 (2B), Ax DWI and apparent diffusion coefficient (2C), and Ax DCE (2D) images used for target and OAR localization and delineation.
# Breast supine unilateral

Adam Currey, M.D.; Colette Gage, BS RTR(MR); Eric Paulson, Ph.D.
Medical College of Wisconsin, Milwaukee, WI, USA

## Patient

<table>
<thead>
<tr>
<th>Patient presentation</th>
<th>Breast cancer with the following indications:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Patients requiring surgical bed boost</td>
</tr>
<tr>
<td></td>
<td>• Dense breast tissue</td>
</tr>
<tr>
<td></td>
<td>• Small lumpectomy cavities</td>
</tr>
<tr>
<td></td>
<td>• Long delays between surgery and start of RT</td>
</tr>
<tr>
<td></td>
<td>• Inadequate surgical clips</td>
</tr>
</tbody>
</table>

| Treatment prescribed | 3D conformal radiotherapy |

## Imaging study

<table>
<thead>
<tr>
<th>Scanner</th>
<th>MAGNETOM Verio 3T</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Equipment required</th>
<th>Two Large flex surface coils</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Two Coil bridges</td>
</tr>
<tr>
<td></td>
<td>Two Nylon locking straps</td>
</tr>
<tr>
<td></td>
<td>MR-compatible CQUAL board</td>
</tr>
<tr>
<td></td>
<td>Headphones</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Patient prep needed</th>
<th>Change into gown and robe.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Place 22 gauge intravenous cannula into antecubital vein.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Setup and landmark</th>
<th>Remove spine array and all other pads from MRI table.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Position MR-compatible CQUAL board on couch, typically at 5 degree incline.</td>
</tr>
<tr>
<td></td>
<td>Setup patient head-first supine with upper extremities in arm and wrist supports.</td>
</tr>
<tr>
<td></td>
<td>Place RF coil bridges over chest and adjust to conform patient surface anatomy.</td>
</tr>
<tr>
<td></td>
<td>Arrange both large flex coils circumferentially over RF coil bridges and secure with two nylon straps. Position coils as superior as possible without hitting arms. Confirm breasts are not deformed.</td>
</tr>
<tr>
<td></td>
<td>Place headphones on patient.</td>
</tr>
<tr>
<td></td>
<td>Landmark over center of breasts.</td>
</tr>
</tbody>
</table>
Imaging protocol

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Scan Time</th>
<th>Utility for RT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Localizer (free breathing)</td>
<td>0:30 min</td>
<td></td>
</tr>
<tr>
<td>Ax PACE T2 STIR HASTE</td>
<td>5:00 min</td>
<td>Delineation of seroma</td>
</tr>
<tr>
<td>Ax Lymphography</td>
<td>2:00 min</td>
<td>Visualization of lymph nodes</td>
</tr>
<tr>
<td>Ax PACE DWI</td>
<td>5:00 min</td>
<td>Localization of gross tumor volume</td>
</tr>
<tr>
<td>DCE</td>
<td>8:00 min</td>
<td>Delineation of gross tumor volume</td>
</tr>
</tbody>
</table>

Special considerations

Acquisition
- Prescribe axial volume to cover superiorly through larynx and inferiorly through diaphragm.
- Prescribe Ax Lymphography volume centered to cover super-clavicular and axillary lymph nodes.
- Adjust concatenations in respiratory triggered acquisitions to patient respiratory rate, ensuring all slices are acquired at specific respiratory state (e.g., end expiration).

Preparing images for treatment planning
- Apply 3D Distortion Correction to all images.
- Calculate thin-slice maximum intensity projection of lymphography images.
- Perform local rigid registration over breast.
### Pancreas

Beth Erickson, M.D.; Paul Knechtges, M.D.; Eric Paulson, Ph.D.

Medical College of Wisconsin, Milwaukee, WI, USA

### Patient

<table>
<thead>
<tr>
<th>Patient presentation</th>
<th>Locally advanced unresectable pancreatic adenocarcinoma</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment prescribed</td>
<td>Respiratory-gated intensity modulated radiation therapy</td>
</tr>
</tbody>
</table>

### Imaging study

<table>
<thead>
<tr>
<th>Scanner</th>
<th>MAGNETOM Verio 3T</th>
</tr>
</thead>
</table>
| Equipment required | • Two 6-channel Body Matrix coils  
|                  | • Spine array coil  
|                  | • Two adjustable coil bridges  
|                  | • Two Nylon straps  
|                  | • Flat table overlay  
|                  | • Headphones  
|                  | • Patient-specific immobilization device/s |

| Patient prep needed | • Change into gown and robe.  
|                     | • Place 22-gauge intravenous cannula into antecubital vein. |

| Setup and landmark | • Position flat table overlay over spine array.  
|                    | • Index patient-specific immobilization devices to flat table overlay.  
|                    | • Setup patient head-first supine, using external lasers to align and straighten, and confirm pelvic crest is above S9 on spine array coil.  
|                    | • Place RF coil bridges over abdomen and conform to patient surface anatomy.  
|                    | • Wrap two 6-channel Body Matrix coils circumferentially over RF coil bridges and secure with two Nylon straps.  
|                    | • Place headphones on patient.  
|                    | • Landmark over diaphragm. |

![Figure 1: Adjustable RF coil bridges and RF coil positioning.](siemens.com/magnetom-world-rt)
Imaging protocol

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

Special considerations

Acquisition
- Contrast injection performed using bolus tracking technique.
- Administer 1 mg Glucagon IV (1/2 at start of exam, 1/2 midway through exam) to suppress peristalsis.
- Respiratory gating and breath-holds performed at end expiration to match phase of gating window used for treatment delivery.
- Readout bandwidths adjusted to ensure WFS < 1 pixel.

Preparing images for treatment planning
- Apply 3D distortion correction to all images.
- Apply image standardization to non-DWI images.
- Identify a reference MR image and perform local MR-MR rigid registration over gross tumor volume to correct for inter-sequence motion.
- Perform local rigid registration over gross tumor volume to align reference.
- MR image with planning CT images.

Example images

Figure 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.; Allen Li, Ph.D.

Medical College of Wisconsin, Milwaukee, WI, USA

## Patient

<table>
<thead>
<tr>
<th>Patient presentation</th>
<th>Intrahepatic cholangiocarcinoma</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment prescribed</td>
<td>Liver stereotactic body radiation therapy</td>
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</tbody>
</table>

## Imaging study

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

![Figure 1](siemens.com/magnetom-world-rt)

Adjustable RF coil bridges and RF coil positioning.
### Imaging protocol

**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** |  |  |  
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 | Localization of gross tumor volume |  
Ax BH T1 Dixon CAIPI 30 min delay | 0:12 min | Localization of gross tumor volume |  

**Injection Rate**
2 cc/sec

**Agent Vol**
10 mL (Gadoxetate disodium)

### Special considerations

**Acquisition**
- Contrast injection performed using bolus tracking technique.
- Administer 1 mg Glucagon IV (1/2 at start of exam, 1/2 midway through exam) to suppress peristalsis.
- Respiratory gating and breath-holds performed at end expiration to match phase of gating window used for treatment delivery.
- Readout bandwidths adjusted to ensure WFS < 1 pixel.

**Preparing images for treatment planning**
- Apply 3D distortion correction to all images.
- Apply image standardization to non-DWI images.
- Identify a reference MR image and perform local MR-MR rigid registration over gross tumor volume to correct for inter-sequence motion.
- Perform local rigid registration over gross tumor volume to align reference MR image with planning CT images.

### Example images

*Figure 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 1

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

**Patient**

<table>
<thead>
<tr>
<th>Patient presentation</th>
<th>58-year-old man presenting with metastatic liver lesions from a primary colon cancer.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment prescribed</td>
<td>Stereotactic Body Radiation Therapy (SBRT) 45 Gy in 3 fractions</td>
</tr>
</tbody>
</table>

**Imaging study**

<table>
<thead>
<tr>
<th>Scanner</th>
<th>MAGNETOM Aera 1.5T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment required</td>
<td>Spine 32 surface coil  &lt;br&gt; Body 18 surface coil  &lt;br&gt; Wireless respiratory monitoring system</td>
</tr>
<tr>
<td>Patient prep needed</td>
<td>Immobilization device: Full-body vacuum cushion (BodyFIX, Elekta Instruments, Crawley, UK) + abdominal compression belt (Aktina Medical, Congers, NY, USA)</td>
</tr>
<tr>
<td>Setup and landmark</td>
<td>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 MRI built in lasers.</td>
</tr>
</tbody>
</table>

Figure 1:  
Patient immobilization setup.
Imaging protocol

All the sequences, except the 2D cine, are corrected for geometry distortion using the built in Siemens 3D correction algorithm.

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

Download the .exar1 file at [www.siemens.com/magnetom-world-rt](http://www.siemens.com/magnetom-world-rt)
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.
Example images

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

Figure 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).
Liver 2
Leah Best; Jameen Arm; Nick Marks; Laura O’Connor; Narelle Grabham; Ben Ling; Melissa Lovell
Calvary Mater Hospital Newcastle, Newcastle, NSW, Australia

Patient

Patient presentation
60-year-old male, Hepatitis C positive with HCC in segment 6 of the liver. Previously treated twice with Trans Arterial Chemoembolization (TACE).

Treatment prescribed
Stereotactic Body Radiation Therapy (SBRT) – 50 Gy in 5 fractions to the PTV which is a 5 mm expansion on the Gross tumor volume. Treated on non-consecutive days. VMAT technique used.

Imaging study

Scanner
MAGNETOM Skyra 3T

Equipment required
- CIVCO flat table overlay
- Spine array 32-channel surface coil
- Body 18-channel long surface coil
- CIVCO Vac-Loc cushion – patient specific
- Wing Board
- Knee Rest
- Contrast Injector

Patient preparation
- Fasting for 2 hours prior to CT scan, MRI after.
- No carbonated beverages on the day of examination same as treatment.

Setup and landmark
- Position flat table overlay on spine array coil.
- Patient to be positioned head first supine.
- Position patient specific Vac-Loc cushion on table.
- Consider positioning patient closer to the foot end of table to enable the emergency buzzer to reach when arms above head.
- Consideration should be made when making Vac-Loc cushion to enable it to fit in the bore of scanner without movement.
- Patients unable to use the Vac-loc cushion use wing board only.
- Patient positioned as per positioning for CT simulation.
- Patient aligned using rotation tattoos and external laser bridge.
- Body matrix coil positioned over liver region and stabilized with Velcro straps.
- Patient coached on breathing instruction for examination. All images taken on exhalation.

* The information shown herein refers to products of 3rd party manufacturers and thus are in their regulatory responsibility. Please contact the 3rd party manufacturer for further information.
### Imaging protocol

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Scan time</th>
<th>Utility for RT</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Localizer_bh expiration</td>
<td>0:19 min</td>
<td>All scanning on expiration</td>
<td></td>
</tr>
<tr>
<td>t1 vibe Dixon tra caipi pre</td>
<td>0:14 min</td>
<td>Base line for contrast</td>
<td></td>
</tr>
<tr>
<td>t2 haste cor fs mbh</td>
<td>1:10 min</td>
<td>Organ contouring</td>
<td></td>
</tr>
<tr>
<td>Care Bolus</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Position trigger ROI on descending</td>
<td></td>
<td></td>
<td>Injection Rate</td>
</tr>
<tr>
<td>aorta 1 cm above diaphragm)</td>
<td></td>
<td></td>
<td>1 ml/s contrast media</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1 ml/s Saline 10 ml</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3 ml/s Saline 30 ml</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Gad Vol</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.1 mmol/kg (disodium gadoxetate)</td>
</tr>
<tr>
<td>t1 vibe dixon tra arterial</td>
<td>0:14 min</td>
<td>Tumor delineation</td>
<td>Gadobutrol 0.1 mmol/kg</td>
</tr>
<tr>
<td>t1 vibe dixon tra pv</td>
<td>0:14 min</td>
<td>Tumor delineation / Organ contouring</td>
<td></td>
</tr>
<tr>
<td>t1 vibe dixon tra delayed</td>
<td>0:16 min</td>
<td>Tumor delineation</td>
<td></td>
</tr>
<tr>
<td>t1 vibe dixon cor delayed</td>
<td>0:16 min</td>
<td>Tumor delineation</td>
<td></td>
</tr>
<tr>
<td>localizer non bh free breathing</td>
<td>0:16 min</td>
<td>Tumor delineation</td>
<td></td>
</tr>
<tr>
<td>t2 blade spair tra mbh</td>
<td>2:49 min</td>
<td>Tumor delineation / Organ contouring</td>
<td></td>
</tr>
<tr>
<td>ep2d diff b50-800 free breathing</td>
<td>3:35 min</td>
<td>Tumor delineation</td>
<td></td>
</tr>
<tr>
<td>t1 vibe dixon tra 15 min delayed</td>
<td>0:15 min</td>
<td>Delineation of non-functioning liver tissue</td>
<td></td>
</tr>
<tr>
<td>t1 vibe dixon cor 15 min delayed</td>
<td>0:16 min</td>
<td>Delineation of non-functioning liver tissue</td>
<td></td>
</tr>
</tbody>
</table>

Download the .exar1 file at [www.siemens.com/magnetom-world-rt](http://www.siemens.com/magnetom-world-rt)
Special considerations

Tips & tricks
• Vac-loc bag sits on wing board. If the Vac-loc bag is too wide to fit into the bore, wing board only used – position as normal using tattoos and external lasers.
• Subtract images of the arterial phase, allows better delineation of tumor enhancement. Inline subtraction can be set up as part of routine Liver Dot Engine.
• Contrast choice dependent on lesion type as determined by radiation oncologist.
• T1 Post contrast imaging most useful for tumor contouring.

Preparing images for planning
• No specific changes made. Images exported as is to RT treatment planning software.

RTP requirements
• 3D distortion correction selected
• Bandwidth selection shift < 1 hz/pixel

Example images

Figure 2:
T1 pre-contrast, T1 arterial phase, T1 arterial subtracted, T1 portal venous phase, T1 delayed, b-value 1400 s/mm², ADC, T2 BLADE SPAIR, T1 delayed 15 min. HCC lesion not well seen in these images post TACE. Post-contrast T1 imaging most useful for tumor delineation.

Figure 3:
Dose distribution superimposed on T1 post-contrast images.
From technology to tips and tricks, you will find the news on all aspects of MRI in Radiation Therapy at: www.siemens.com/magnetom-world-rt

Just a mouse click away you will find application tips and How-I-do-it articles allowing you to optimize your daily work and exploit the full potential of your MAGNETOM system.

**Machine-specific MRI quality control procedures for stereotactic radiosurgery treatment planning**

Ali Fatemi, Ph.D. et al.
Mississippi Medical Center, Jackson, MS, USA

The centerpiece of the MAGNETOM World Internet platform consists of our users’ clinical results. Here renowned experts share their optimized MR protocols for various body regions.

**Head & neck**

Eric Paulson, Ph.D. et al.
Medical College of Wisconsin, Milwaukee, WI, USA

With the wealth of articles available at the MAGNETOM World we aim to increase peer-to-peer exchange of practices and to demonstrate how MAGNETOM users around the world are tackling the challenges posed by the introduction of MRI in the radiotherapy routine.

**MR-simulation for radiotherapy treatment planning of head and neck cancer using 3T MAGNETOM Vida**

Daniela Thorwart, Ph.D. et al.
University of Tübingen, Germany
Prostate 1

Cynthia Ménard1; Jean-Charles Côté2; Guila Delouya1; Maroie Barkati1; Karim Boudam1; Carole Lambert1; Gary Liney2

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
• Body 18 long surface coil
• 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.
• Patients are instructed to empty their bladder before simulation. Bowel prep includes a fleet enema before imaging.
• 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.

Figure 1: Patient positioned on the spine coil with the Body 18 long surface coil on top, and with a foot rest.
Imaging protocol

Download the .exar1 file at www.siemens.com/magnetom-world-rt

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

- 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 (see Figure 2).

• 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.

Figure 2:
Workflow for registering MR images to planning CT.
Example images

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

Figure 4:
Slice corresponding to tumor at right anterior apex best visualized on calculated b=1600 DWI (4C).
Prostate 2

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

Reproduced with permission from the "Method book for the use of MRI in radiotherapy" (Version 3) of the Swedish Vinova project.

Imaging study

**Scanner**
- MAGNETOM Aera 1.5T

**Equipment required**
- Body 18 Long coil
- Coil holders
- Flat table overlay (Civco Medical Solutions, Kalona, IA, USA)*
- 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.

- 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 taking hold of it and rotating.

- 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:

![Figure 1](image_url)

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

* The information shown herein refers to products of 3rd party manufacturers and thus are in their regulatory responsibility. Please contact the 3rd party manufacturer for further information.
• 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 (see Figure 2).

![Figure 2: Separation of the buttocks on (2A) CT image, and (2B) MR image.](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.

![Figure 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.](image)
### Imaging protocol

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Scan time</th>
<th>Utility for RT</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sag T2</td>
<td></td>
<td>Delineating of rectum and bladder</td>
<td></td>
</tr>
<tr>
<td>Axial T2</td>
<td>6.17 min</td>
<td>Delineating of prostate and extracapsular disease (dark)</td>
<td>Potential post-biopsy hemorrhage, difficult to see the marker</td>
</tr>
<tr>
<td>Axial fat suppressed T2</td>
<td></td>
<td>Delineating of extracapsular disease (dark), lymph nodes (bright)</td>
<td>Potential post-biopsy hemorrhage</td>
</tr>
<tr>
<td>Axial T1</td>
<td>3.38 min</td>
<td>Detection of post-biopsy haemorrhaging (bright), visualization of markers</td>
<td></td>
</tr>
<tr>
<td>Axial Diffusion ADC</td>
<td></td>
<td>Delineating of tumor (dark)</td>
<td></td>
</tr>
</tbody>
</table>

### 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 prostheses¹, 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 Healthcare.
• 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.

Figure 3:
(3A) T1 VIBE tra 2 mm (3:38 min), (3B) 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

<table>
<thead>
<tr>
<th>Patient presentation</th>
<th>Prostate adenocarcinoma</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment prescribed</td>
<td>Volumetric modulated arc therapy</td>
</tr>
</tbody>
</table>

## Imaging study

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

---

### Figure 1:
Adjustable RF coil bridges and RF coil positioning.
Imaging protocol

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Scan time</th>
<th>Utility for RT</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Localizer</td>
<td>0:30 min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sag Restore T2 TSE</td>
<td>3:00 min</td>
<td>Delineation of gland and rectum / gland interface</td>
<td></td>
</tr>
<tr>
<td>Ax Restore T2 TSE</td>
<td>5:00 min</td>
<td>Delineation of gland</td>
<td></td>
</tr>
<tr>
<td>Cor Restore T2 TSE</td>
<td>3:00 min</td>
<td>Delineation of gland and localization of urethra</td>
<td></td>
</tr>
<tr>
<td>Ax DWI</td>
<td>5:00 min</td>
<td>Localization of gross tumor volume</td>
<td>Acquired b-values: 200, 600, 1000 s/mm²; calculated b-value: 1400 s/mm²</td>
</tr>
</tbody>
</table>

Special considerations

Acquisition
• Readout bandwidths adjusted to ensure WFS < 1 pixel.

Preparing images for treatment planning
• Apply 3D distortion correction to all images.
• Apply image standardization to non-DWI images.
• Perform local rigid registration over prostate gland to align reference MR image with planning CT images.

Example images

Figure 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).
Prostate 4

Leah Best; Jameen Arm; Nick Marks; Laura O’Connor; Narelle Grabham; Ben Ling; Melissa Lovell
Calvary Mater Hospital Newcastle, Newcastle, NSW, Australia

Patient

<table>
<thead>
<tr>
<th>Patient presentation</th>
<th>80-year-old male presenting with prostate cancer.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment prescribed</td>
<td>39-day treatment – VMAT (volumetric moderated arc therapy) glandular prostate 78 Gy, prostate with 7 mm margin 74.1 Gy, seminal vesicles with 8 mm margin 65 Gy, pelvis lymph nodes 55 Gy simultaneous integrated boost</td>
</tr>
</tbody>
</table>

Imaging study

<table>
<thead>
<tr>
<th>Scanner</th>
<th>MAGNETOM Skyra 3T system</th>
</tr>
</thead>
</table>
| Equipment required | • Spine array 32-channel surface coil  
• Body matrix 18-channel long surface coil  
• Knee rest  
• Foot rest  
• Plastic ring |
| Immobilization | • Patient lays on table with knees over knee rest and feet in foot rest.  
• Patient holds plastic ring on chest. |
| Patient prep needed: | • Low fibre diet  
• Empty bladder 30 minutes prior to appointment time, drink 1 glass of water (250 ml) and do not empty bladder until examination complete. |
| Setup and landmark | • Patient can either be positioned feet first or head first.  
• We position the patient feet first for comfort.  
• Ensure patient is aligned so prostate is central to a spinal coil element.  
• Body matrix coil centered over prostate.  
• Centre over prostate. Prostate to isocentre. |

Figure 1: Patient positioning for routine RT prostate planning.
Figure 2: Coverage for T2 TSE tra and T1 FLASH tra.
Imaging protocol

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Scan time</th>
<th>Utility for RT</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Localizer</td>
<td>0:17 min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Haste Localizer</td>
<td>0:29 min</td>
<td>Positioning and review bladder size, rectal filling</td>
<td></td>
</tr>
<tr>
<td>T2 tse tra 2D</td>
<td>4:35 min</td>
<td>Prostate anatomy and tumor delineation. Organ contouring.</td>
<td></td>
</tr>
<tr>
<td>T1 FLASH tra 2D</td>
<td>3:06 min</td>
<td>Gold seed identification</td>
<td>T1 useful to see blood products</td>
</tr>
<tr>
<td>Options</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T2 BLADE sag</td>
<td>3:23 min</td>
<td>Review Rectafix position</td>
<td>To review depression of Rectafix rod</td>
</tr>
<tr>
<td>Diffusion</td>
<td>3:46 min</td>
<td>Assess aggressiveness of tumor</td>
<td>Use high b-value (&gt; 1500 s/mm²)</td>
</tr>
</tbody>
</table>

Special considerations

Tips & tricks
- Use high flip angle (80°) for T1 FLASH to delineate blood products.
- T1 FLASH is used to delineate the gold seeds in the prostate for IGRT.
- Assess bladder filling and rectal gas on haste localizer. May require additional prep as per radiation therapists.
- Rectafix (Scanflex Medical AB, Täby, Sweden) is a rectal positioning device used for SBRT prostate treatments to depress the rectum away from the prostate for treatment.
- CIVCO flat table overlay used for patients with Rectafix rod*.

Preparing images for planning
- No specific changes made. Images exported as is to RT treatment planning software.

RTP requirements
- Patients scanned feet first images flipped to match planning CT at planning stage.
- Patient positioned as per positioning for CT simulation.
- Patient aligned using rotation tattoos and external laser bridge.

Example images

Figure 3:
(3A) T2 transverse lesion, (3B) T1 gradient lesion, lesion seen in the right peripheral zone. T2 seed, T1 gradient seed. (3D) Arrow shows gold seed surrounded by increased signal intensity associated with blood products.

Figure 4:
Final dose distribution.

* The information shown herein refers to products of 3rd party manufacturers and thus are in their regulatory responsibility. Please contact the 3rd party manufacturer for further information.
Cervix

Beth Erickson M.D.; Colette Gage, BS RTT(MR); Allen Li, Ph.D.

Medical College of Wisconsin, Milwaukee, WI, USA

Patient

<table>
<thead>
<tr>
<th>Patient presentation</th>
<th>Cervix cancer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment prescribed</td>
<td>3D conformal radiotherapy</td>
</tr>
</tbody>
</table>

Imaging study

<table>
<thead>
<tr>
<th>Scanner</th>
<th>MAGNETOM 3T Verio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment required</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Two 6-channel body matrix coils</td>
</tr>
<tr>
<td></td>
<td>Spine array coil</td>
</tr>
<tr>
<td></td>
<td>Two Adjustable coil bridges</td>
</tr>
<tr>
<td></td>
<td>Two Nylon straps</td>
</tr>
<tr>
<td></td>
<td>Flat table overlay</td>
</tr>
<tr>
<td></td>
<td>Patient-specific immobilization device(s)</td>
</tr>
<tr>
<td></td>
<td>Ultrasound gel</td>
</tr>
<tr>
<td></td>
<td>60 cc syringe</td>
</tr>
<tr>
<td>Patient prep needed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Change into gown and robe.</td>
</tr>
<tr>
<td></td>
<td>Have patient empty bladder.</td>
</tr>
<tr>
<td></td>
<td>Place 22 gauge intravenous cannula into antecubital vein.</td>
</tr>
<tr>
<td>Setup and landmark</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Position flat table overlay over spine array.</td>
</tr>
<tr>
<td></td>
<td>Index patient-specific immobilization devices to flat table overlay.</td>
</tr>
<tr>
<td></td>
<td>Setup patient head-first supine, using external lasers to align and straighten, and confirm pelvic crest is above S9 on spine array coil.</td>
</tr>
<tr>
<td></td>
<td>Place RF coil bridges over pelvis and conform to patient surface anatomy.</td>
</tr>
<tr>
<td></td>
<td>Wrap two 6-channel body matrix coils circumferentially over RF coil bridges and secure with two Nylon straps.</td>
</tr>
<tr>
<td></td>
<td>Landmark over diaphragm.</td>
</tr>
</tbody>
</table>
**Imaging protocol**

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Scan time</th>
<th>Utility for RT</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Localizer</td>
<td>0:30 min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sag Driven Equilibrium T2 TSE</td>
<td>3:00 min</td>
<td>Delineation of gross tumor volume</td>
<td></td>
</tr>
<tr>
<td>Ax Driven Equilibrium T2 TSE</td>
<td>5:00 min</td>
<td>Delineation of gross tumor volume</td>
<td></td>
</tr>
<tr>
<td>Ax DWI</td>
<td>5:00 min</td>
<td>Localization of gross tumor volume</td>
<td>Acquired b-values: 200, 600, 1000 s/mm²; calculated b-value: 1400 s/mm²</td>
</tr>
<tr>
<td>Ax Fat-Suppressed T1 TSE + Gad</td>
<td>5:30 min</td>
<td>Delineation of gross tumor volume</td>
<td>Injection Rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Hand bolus</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Gad Vol 0.1 mmol/kg (Multihance)</td>
</tr>
</tbody>
</table>

**Special considerations**

**Acquisition**
- Inject vaginal gel at start of exam.
- Administer 1 mg Glucagon IV (1/2 at start of exam, 1/2 midway through exam) to suppress peristalsis.
- Contrast injection performed using bolus tracking technique.
- Readout bandwidths adjusted to ensure WFS < 1 pixel.

**Preparing images for treatment planning**
- Apply 3D Distortion Correction to all images.
- Apply image standardization to non-DWI images.
- Perform local rigid registration over cervix to align with planning CT images.

**Figure 1:**
Adjustable RF coil bridges and RF coil positioning.

Download the .edx file at [www.siemens.com/magnetom-world-rt](http://www.siemens.com/magnetom-world-rt)
# Cervix – Brachytherapy

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

## Patient

<table>
<thead>
<tr>
<th>Patient presentation</th>
<th>Cervix cancer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment prescribed</td>
<td>High dose rate brachytherapy boost</td>
</tr>
</tbody>
</table>

## Imaging study

<table>
<thead>
<tr>
<th>Scanner</th>
<th>MAGNETOM 3T Verio</th>
</tr>
</thead>
</table>
| Equipment required       | • Two 6-channel Body Matrix coils  
                          | • Spine array coil  
                          | • Two adjustable coil bridges  
                          | • Two Nylon straps  
                          | • Flat table overlay  
                          | • MR-compatible physiological monitoring equipment |
| Patient prep needed      | • Brachytherapy preparation (including anesthesia) |
| Setup and landmark       | • Position flat table overlay over spine array.  
                          | • 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.  
                          | • Attached physiological monitoring devices.  
                          | • Place RF coil bridges over pelvis and conform to patient surface anatomy.  
                          | • Wrap two 6-channel Body Matrix coils circumferentially over RF coil bridges and secure with two Nylon straps.  
                          | • Landmark over diaphragm. |

---

**Figure 1:**
Adjustable RF coil bridges and RF coil positioning.
### Imaging protocol

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Scan time</th>
<th>Utility for RT</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Localizer</td>
<td>0:30 min</td>
<td>Confirmation of applicator positioning and absence of perforation</td>
<td>Aligned to applicator in three planes</td>
</tr>
<tr>
<td>3PL T2 HASTE</td>
<td>0:59 min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ax 3D T2 SPACE</td>
<td>12:00 min</td>
<td>Planning MR image, delineation of targets and OAR</td>
<td>1 x 1 x 1.5 mm³ voxels</td>
</tr>
<tr>
<td>Ax T2 TSE</td>
<td>4:00 min</td>
<td>Delineation of gross tumor volume and high risk clinical target volume</td>
<td>Para-axial, parallel to ring</td>
</tr>
<tr>
<td>Sag T2 TSE</td>
<td>3:00 min</td>
<td>Delineation of gross tumor volume and high risk clinical target volume</td>
<td>Para-sagittal, parallel to tandem</td>
</tr>
<tr>
<td>Cor T2 TSE</td>
<td>3:00 min</td>
<td>Delineation of gross tumor volume and high risk clinical target volume</td>
<td>Para-coronal, parallel to tandem</td>
</tr>
</tbody>
</table>

### Special considerations

**Acquisition**

- Administer 1 mg Glucagon IV (1/2 at start of exam, 1/2 midway through exam) to suppress peristalsis.
- Readout bandwidths adjusted to ensure WFS < 1 pixel.

**Preparing images for treatment planning**

- Apply 3D distortion correction to all images.
- Apply image standardization to all images.

### Example images

*Figure 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.
**Cervix – Brachytherapy**

**Maja Sohlin; Karin Petruson; Karin Bergmark; Mona Riström Waite**

Sahlgrenska University Hospital, Gothenburg, Sweden

---

**Patient**

<table>
<thead>
<tr>
<th>Patient presentation</th>
<th>Cervical cancer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment prescribed</td>
<td>MRI-guided high dose rate brachytherapy</td>
</tr>
</tbody>
</table>

**Imaging study**

<table>
<thead>
<tr>
<th>Scanner</th>
<th>MAGNETOM Aera 1.5T</th>
</tr>
</thead>
</table>
| Equipment required | • Body 18 Long coil  
• Spine array coil  
• Knee support  
• Velcro straps  
• Sand bags  
• MR-compatible physiological monitoring equipment |
| Patient prep needed | • Brachytherapy preparation (including anesthesia)  
• Insertion of MR marker into applicator ring and tandem  
• Clamp urinary catheter right before MRI |
| Setup and landmark | • Prepare table without flat table overlay and with mattress.  
• Undock table and remove outside examination room for patient transfer.  
• Transfer patient from brachytherapy suite to MR table, setting up patient head-first supine using pillow and customized knee support.  
• Attach physiological monitoring devices.  
• Dock table and place the 18-channel Body Matrix coil over the patient’s pelvis without using RF coil bridges and attach coil firmly using velcro straps.  
• Support outer side of patient’s feet using sand bags.  
• Landmark over pubic symphysis. |

![Figure 1: Patient setup using Body 18 Long coil and knee support.](siemens.com/magnetom-world-rt)
Imaging protocol

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Scan Time</th>
<th>Utility for RT</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Localizer</td>
<td>0:08 min</td>
<td>Positioning of applicator ring in magnet iso-center</td>
<td>The transversal stack is planned with its center in the ring plane</td>
</tr>
<tr>
<td>Localizer ISO positioning</td>
<td>0:44 min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T2 TSE sag</td>
<td>3:06 min</td>
<td>Planning MR image, delineation of targets and OAR</td>
<td>0.9 x 0.9 x 3 mm³ voxels Parallel to tandem if visible in localizer_ISOpos</td>
</tr>
<tr>
<td>T2 TSE para-cor</td>
<td>3:25 min</td>
<td>Planning MR image, delineation of targets and OAR</td>
<td>Para-coronal, parallel to tandem 0.9 x 0.9 x 3 mm³ voxels</td>
</tr>
<tr>
<td>T2 TSE para-tra</td>
<td>5:07 min</td>
<td>Delineation of targets and OAR</td>
<td>Para-axial, parallel to ring 0.9 x 0.9 x 3 mm³ voxels</td>
</tr>
<tr>
<td>T2 SPACE para-tra</td>
<td>7:35 min</td>
<td>Reconstruction of applicator and needles</td>
<td>Para-axial, parallel to ring 0.9 x 0.9 x 1 mm³ voxels</td>
</tr>
</tbody>
</table>

Special considerations

Coverage
- t2_tse_sag: Obturator muscle
- t2_tse_para-cor: Uterus – Cervix – Vagina – Tumor
- t2_tse_para-tra: Above uterus – 3 cm below applicator/full vagina

Preparing images for planning
- Apply 3D distortion correction (automatic)

RTP requirements
- Readout bandwidths adjusted to ensure WFS < 1 pixel
- 0 mm inter-slice gap for 2D acquisitions to eliminate interpolation in the RTP system

Example images

Figure 2: Coverage areas.

(3A) Sagittal 2D T2 TSE
(3B) Para-coronal 2D T2 TSE
(3C) Para-transversal 2D T2 TSE
(3D) Para-sagittal reformat of transversal 3D T2 SPACE
(3E) Para-coronal reformat of 3D T2 SPACE
(3F) Para-transversal reformat of 3D T2 SPACE
Rectum

Cynthia Eccles; Helen McNair; Trina Herbert; Shree Bhide
The Royal Marsden NHS Foundation Trust, Sutton, UK

Patient

Patient presentation
Increased bowel frequency, redness in stool, transient episodes of fatigue and mild rectal discomfort; biopsy confirmed moderately differentiated carcinoma 7 cm from anal verge from approximately 10 o’clock to 12 o’clock; Diagnosis T3C

Treatment prescribed
Radical RT 52.5 Gy/25 simultaneous integrated boost; 6 MV VMAT

Imaging study

Scanner
MAGNETOM Aera 1.5T

Equipment required
- Body 18 1.5T Tim coil
- In-house (custom) coil bridge
- In-house (custom) flat table top
- CombiFix™ with knee pad
- Head rest
- Beekley Dots on anterior and lateral tattoos

Patient prep needed
- 700 ml water drunk after emptying 1 hour prior to RT.
- 700 ml water drunk after emptying 30 minutes prior to MRI.
- Change into hospital gown, underwear removed.

Setup and landmark
- Index immobilization equipment according to patient treatment setup.
- Setup patient head-first supine.
- Use external lasers to align and straighten with reference to RT planning tattoos.
- Place coil and bridge over pelvis area, ensuring patient contour preserved.
- Give patient ear plugs and headphones.
- Landmark at level of tattoos.

Figure 1:
Hard table top.

Figure 2:
CombiFix™ and head rest.

Figure 3:
Coil in bridge.
**Imaging protocol**

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Scan time</th>
<th>Utility for RT</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Localizer</td>
<td></td>
<td>Planning of sequences</td>
<td></td>
</tr>
<tr>
<td>mDixon¹</td>
<td>4:48 min</td>
<td>Research – for workup of synthetic CT and delineation of normal tissues including nodes</td>
<td>Include external contour; cover from L3 to mid-femur</td>
</tr>
<tr>
<td>T2 SPACE</td>
<td>14:00 min</td>
<td>Target delineation; OAR delineation</td>
<td></td>
</tr>
<tr>
<td>T2 TSE</td>
<td>12:57 min</td>
<td>Nodal delineation</td>
<td></td>
</tr>
</tbody>
</table>

Download the .exar1 file at [www.siemens.com/magnetom-world-rt](http://www.siemens.com/magnetom-world-rt)

**Example images**

**Figure 4:**
mdixon¹.

**Figure 5:**
T2 SPACE, acquired axially.

**Figure 6:**
T2 TSE.

**Figure 7:**
Patient image showing the coverage.

¹ WIP, the product is currently under development and is not for sale in the US and in other countries. Its future availability cannot be ensured.
# Musculoskeletal

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

## 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  
|• Sarcoma  
|• Osteosarcoma  
|• Metastatic disease |
| Treatment prescribed | Dependent on location and disease extent |

## Imaging study

| Scanner | MAGNETOM Skyra 3T |
| Equipment required | • Flex 4 Large and Small (Site dependent)  
|• Body 18 surface coil (Site dependent)  
|• Flat table overlay (CIVCO)*  
|• Velcro straps  
|• 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.  
|• Patient to be positioned as per CT Simulation.  
|• Straighten the patient’s anatomy of interest using the rotation tattoos with the external laser system.  
|• Depending on the region of interest. |

* The information shown herein refers to products of 3rd party manufacturers and thus are in their regulatory responsibility. Please contact the 3rd party manufacturer for further information.

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**Figure 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.
Imaging protocol

Small region of interest

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

Long bones and larger regions of interest (TimCT)

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Scan time</th>
<th>Utility for RT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Localizer</td>
<td>0:09 min</td>
<td></td>
</tr>
<tr>
<td>T1 FLASH TimCT</td>
<td>4:48 min</td>
<td>Bone registration to CT</td>
</tr>
<tr>
<td>T2 HASTE FS TimCT</td>
<td>6:43 min</td>
<td>Delineation of gross tumor volume and nodes</td>
</tr>
<tr>
<td>T2 HASTE TimCT</td>
<td>6:43 min</td>
<td>Delineation of gross tumor volume and associated edema</td>
</tr>
</tbody>
</table>
**Special considerations**

**Tips and 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**

![Example images](siemens.com/magnetom-world-rt)

**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.
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).

Metastatic disease in femur using TimCT for a 60 cm scan length
Figure 6:
Reconstructed T2 HASTE with SPAIR showing hyperintense metastatic 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.

Thank you!

The entire staff at Centre hospitalier de l’Université de Montréal, Canada, and at Siemens Healthineers extends their appreciation to all the radiation oncologists, technologists, physicists, experts and scholars who donate their time and energy – without payment – in order to share their expertise.
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