MR-only based simulation with pseudoCT generated data in prostate radiation therapy planning

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January 15, 2016

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Challenges in radiation therapy accuracy

Tumor delineation: The weakest link in the search for accuracy in radiotherapy

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Abstract

Target definition is a major source of errors in both prostate and head and neck external-beam radiation treatment. Delineation errors remain constant during the course of radiation and therefore have a large impact on the dose to the tumor. Major sources of delineation variation are visibility of the target including its extensions, disagreement on the target extension, and interpretation or lack of delineation protocols. The visibility of the target can be greatly improved with the use of multimodality imaging. Both in the head and neck and the prostate, computed tomography (CT)-magnetic resonance imaging coregistration decreases the target volume and its variability. CT-positron emission tomography delineation is promising for delineation in head and neck cancer. Despite the better visibility, a different interpretation of the target extension remains a major source of error. The use of coregistration of CT with a second modality, together with improved guidelines for delineation and an online anatomical atlas, increases agreement between observers in prostate, lung, and nasopharynx tumors. Delineation errors should not be treated differently from other geometrical errors. Similar margin recipes for the correction of setup errors and organ motion should be adapted to incorporate the effect of delineation errors. A calculation of a 3-dimensional clinical target volume-planning target volume margin incorporating delineation errors for the head and neck is around 6.1 to 9.7 mm. Given the good local control of IMRT with smaller margins and smaller pathological specimens, it is likely that the delineated CTV frequently overestimates the actual volume.
Advantage of MRI
In soft tissue contrast
MRI in Radiation Oncology

Historical overview

Number of publications on MRI in International Journal of Radiation Oncology, Biology, Physics

- rectum
- head neck
- cervical
- prostate
- brain

MR RT of prostate: the greatest contributor
Use of MRI for brachytherapy planning

MR imaging for dose planning in HDR prostate brachytherapy

- Reconstruction of catheters on MRI
- Contouring: Prostate (ctv1), Urethra, Rectum, Bladder, ctv0

Tx: Afterloader
Challenges in the use of MR for RT

- Imaging in the radiation therapy treatment position
- High geometric fidelity and QA tools for evaluation
  - Sensitivity to metal artifacts
- MR protocols optimized for RT planning
- Simplification and fit into the existing RT workflow
- Pathway into MR guidance for dose delivery

Courtesy of William Beaumont, Detroit, USA
Dedicated RT accessories
Imaging in the treatment position

MR-RT CouchTop, 2.5 cm thinner than overlay
- Improved SNR
- Free up in-bore space for patient positioning
- Less mechanical play
- Complete with indexing, and compatible with immobilization accessories from main vendors in RT (ex. CIVCO, Orfit, Qfix)

Anterior coil support
- Bring the Anterior coil close to each patient to improve SNR, without touching body’s contours
- Easy tilt and adjustment in height by a single operator
- Support follows the wide bore dimensions providing maximum space for the patient

External laser positioning system
- Connectivity with MRI for one-click travel-to-scan: move patients directly from ELPS localization position to imaging isocenter
Geometric accuracy and quality assurance

Dedicated QA package for volumetric accuracy evaluation

- An industry-leading gradient linearity for geometric accuracy
- 3D gradient distortion correction functionality
- Geometric imaging accuracy:
  \[ \leq 1 \text{ mm} \quad \text{Ø} \quad 32 \text{ cm volume (typical)} \]
- Ready-to-use QA package for routine evaluation

![Contour map of geometric accuracy](image)

Dedicated phantom – automated procedure

Contour map of geometric accuracy

PHILIPS
Let ScanWise Implant guide you
Simplifying scanning patients with MR Conditional implants

• The implant manufacturer’s specified MR condition values are entered only once
• ScanWise Implant automatically adjusts all scan parameters to meet the implant Conditional values entered by the operator
• The MR scanner will adhere to the conditions throughout the whole examination

Initial availability on 1.5T systems
O-MAR XD for radiotherapy planning

Imaging protocols designed for MR simulation

**Regular T2W without O-MAR**
T2W 3D TSE, 7:22 min, 250 slices

**O-MAR**
3D T2W TSE-SEMAC, 5:40 min, 47 slices

The signal void extends partly on top of the seminal vesicles

O-MAR: Metal artifact reduction

**Ingenia MR-RT 1.5T**
Cobalt-chrome implant
MR protocols optimized for RT planning
Coil arrangements work together with customized scan protocols

For main RT applications:
- Brain
- Head & neck
- Prostate
- Female pelvis
- Spine

Dedicated coil solutions
Digital coil architecture for enhanced SNR in all RT applications

Customized ExamCards provide:
- High contrast (tumor, OAR)
- Optimized for geometric fidelity
- Fast imaging
Current use of MR in radiation therapy

Excellent soft-tissue contrast added to CT-based planning

- MR sim
- CT sim
- MR-CT registration
- Density information (Hounsfield Units)
- Soft-tissue contrast
- Delineation
- Dose calculation
- Treatment plan and delivery
Bringing the real power of MR simulation

MR-only simulation: adopt a single-modality approach

- Soft-tissue contrast
- Treatment plan and delivery
- Density information (Hounsfield Units)
- Dose calculation

**MR sim**

**CT sim**

**MR-CT registration**

**Delineation**

**PHILIPS**
MR-only simulation at a glance

**Imaging**
- Dedicated scan sequence for MR-only sim. MRCAT source imaging: fast and robust image acquisition in a few minutes.

**MRCAT generation**
- Embedded MRCAT generation
- Fully automated generation of MRCAT images parallel to image acquisition – adding no extra time to the imaging session.

**Export to TPS**
- Export to treatment planning systems
- DICOM-CT conform output for export to main treatment planning systems.
Embedded post-processing for pseudoCT generation

- Hybrid imaging and atlas-based classification of tissue types: Air, fat, water, spongy bone and cortical bone
- Assignment of HU values Based on bulk density assignment
Classification & Density Value Assignment

- Philips 3T Ingenia TX System
- 12-element posterior / 16-element anterior receive coil
- 3D cartesian FFE acquisition
- $TE_1/TE_2 = 1.1\text{ms}/2.1\text{ms}$, $TR = 3.3\text{ms}$, $\alpha = 10^\circ$ (-> Dixon reconstruction)
- $1.7\times1.7\times2.5 \text{ mm}^3$ voxels, $400\times300\times400 \text{ mm}^3$ FOV, imaging time 1:49 min
- Conventional mDixon reconstruction used to generate the following images:
  1. In-phase; 2. Water-only; 3. Fat-only
MRCAT Algorithm Overview

Background processes

1. Calculate body mask
2. Soft tissue classification
3. Segment bone mask
4. Classify compact and spongy bone
5. Assign HU values

MRCAT source water image

MRCAT source in-phase image

MRCAT image
DVH: equivalence in dose plans
MRCAT-based versus CT-based dose plans

Images courtesy of Docrates Cancer Center, Helsinki, Finland (Ingenia 1.5T)

DVH comparison MRCAT-based (___) versus CT-based (+++++) plans. PTV78, PTV50, rectum and bladder
Patient positioning and verification

Fusion of MRCAT image and seed scan (b-FFE) showing prostate gold seeds that are contoured in the prostate.

Patient alignment at the scanner using external laser system.

Position verification at linac with either:
- cone beam computed tomography
- plain radiographs using DRRs
- graphically or numerically recorded location of gold seeds.

Images courtesy of Docrates Cancer Center, Helsinki, Finland (Ingenia 1.5T)
QA of MR only workflow in Radiotherapy

EPI D dosimetry as routine QA tool

- In a MR only workflow in Radiotherapy, dose is calculated on a CT equivalent scan derived from MR sequences
- Since these simulated CTs may not be as robust as a standard CT, QA becomes necessary for each patient
- Routine QA of an MR only workflow with in-vivo EPI D dosimetry was evaluated

Methods
- 25 pelvic patients, 19 prostate and 6 rectum
- Scanned on 3T Philips Achieva with flat table top
- MRCAT tissue classification based on DIXON sequences
- All patients treated with CT based workflow, dose measured on EPI D for first three treatment fractions
- RT dose re-calculation on MRCAT scans
- Back-projection of measured in-vivo EPI D dose on MRCAT scans
- 3%, 3mm gamma evaluation for dose comparison

Conclusion: EPI D dosimetry can be used as routine QA of a MR only workflow

Courtesy: Marloes Frantzen-Steneker, NKI-AVL, Amsterdam, The Netherlands
4D MRI: Motivation

4D image data are used in radiation therapy planning to estimate typical motion of the tumor or organs at risk. Today 4D CT is commonly used for this purpose.

**MRI offers important advantages:**
Better soft tissue contrast $\rightarrow$ Direct visualization of structures of interest.
No ionizing radiation $\rightarrow$ Imaging can be performed as often as required.
4D MRI Example: belt triggered acquisition

**3T Ingenia:**
8 respiratory phases, 32 slices
Resolution: 1.5 x 1.5 x 5 mm
Echo time 76 ms

*bands show trigger levels for the different respiratory phases*

*red dots mark data acquisition*

*Courtesy: Tim Nielsen, Sascha Krüger, Philips Research Hamburg*
4D MRI: Volunteer @1.5T: navigator triggered

axial

Reformats: coronal

sagittal

Courtesy: Tim Nielsen, Sascha Krüger, Philips Research Hamburg
4D-MRI: @1.5T using respiratory belt

Courtesy: T. van de Lindt, the Netherlands Cancer Institute, Amsterdam, the Netherlands
High field MRI-g radiation therapy system

Example volunteer images

*MR-Linac is a research program. It is not available for sale and its future availability cannot be guaranteed.
A vision towards greater MR integration

MRI has a bright future in radiation oncology

*MR-Linac is a research program. It is not available for sale and its future availability cannot be guaranteed.