

MR-Linac: Challenges and Opportunities

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Making Cancer History[®]

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- MD Anderson is part of a MR-Linac Consortium and has MRA with Elekta, Varian

The Evolution of Radiation Therapy: Imaging has always played a critical role in RT

1980's





Standard Collimator

Linac reduced complications compared to Co60

1970' s





Cerrobend Blocking Electron Blocking

Blocks were used to reduce the dose to normal tissues

MLC leads to 3D conformal therapy which allows the first dose escalation trials.

Multileaf Collimator

Computerized 3D CT Treatment Planning







Dynamic MLC and IMRT

Computerized IMRT introduced which allowed escalation of dose and reduced compilations

2000's



1990's



Functional Imaging

High resolution IMRT

IMRT Evolution evolves to smaller and smaller subfields and high resolution IMRT along with the introduction of new imaging technologies

Courtesy of Dave Fuller

Adoption of IGRT (including MRI) By US Radiation Oncologists is Growing



Simpson et al, J Am Coll Radiology 2009

Role of Imaging in Radiation Therapy Three Distinct Applications

1) Treatment Planning

- 1) Accurate target delineation (typically GTV or tumor bed)
- 2) Functional imaging (if available)help to define high risk volume
- Treatment Response Assessment
 During, post-treatment
- 3) Treatment localization & delivery
 - 1) Motion management using On Board Imaging and/or markers

1) Treatment Planning: Superb Soft Tissue Contrast Accurate Delineation





2) Treatment Response Assessment: Functional Imaging (DWI, DCE, MRS etc.) Enables Personalized/Adaptive Therapy



More Frequent Response Assessment and Intra fractional and enable Adaptive Treatment

Olsen et al, ASTRO 2011

3) Treatment Delivery: Accurate target tracking/gating in treatment



Can we get a system that integrates all these goals together?

Integrated MRI-Radiotherapy Systems: MRI Guided Localization & Delivery







Current Integrated/Hybrid MRI-Radiotherapy Systems

Viewray (Co-60 source)
Bi-planar Linac-MR
MRI-Linac at 1.5T

The ViewRayTM System

- Washington University in Saint Louis
- UW Madison



The ViewRayTM System

- 0.35T MRI scanner + ⁶⁰Co radiotherapy system
 - Split magnet design to allow beam penetration and reduce scatter radiation.
 - Radiation produced by ⁶⁰Co is not affected by magnetic field.
 - At low magnetic field strength, effect of magnetic field on dose distribution is negligible.
 - At low magnetic field strength, spatial integrity is good (~2mm).
 - Three symmetrically located ⁶⁰Co sources reduce the effect of gantry rotation on magnetic field.

Bi-Planar Linac MR

• Cross Cancer Institute (Dr. Fallone)



Courtesy of Dr. Gino Fallone

Bi-Planar Linac MR

- 0.5T Bi-polar MRI imager + 6 MV LINAC
 - Bi-polar MRI provides tunnel for radiation beam
 - Either passive or active magnet shielding to minimize the effect of magnetic field on LINAC.
 - Bi-polar MRI allows parallel orientation of magnetic field to LINAC axis to reduce electron return effect.

MRI-Linac at 1.5T

Invented in UMC Utrecht and being commercialized by Elekta/Philips



MRI-RT at 1.5T: Key Features

- 1.5T MRI scanner + 6 MV LINAC
 - Active magnetic shielding creates B=0 at accelerator gun and minimal magnetic field at accelerator tube.
 - The superconducting coils are put aside and the gradient coil is split to allow beam passage.
 - Closed cryogen bore increases scatter.
 - Additional magnetic sources are added to the rotating LINAC structure to create a combined magnetic effect independent of LINAC position.
 - Correction schemas for gradient nonlinearity and B₀ inhomogeneity to improve spatial integrity.

MR-Linac

- 1. Linac mounted on a rotatable gantry around the MRI magnet
 - The radiation isocentre is at the centre of the MRI imaging volume



- 2. Modify the linac to make it compatible with the MRI
- 3. Modify the MRI system to
 - Minimise material in the beam path and ensure it is homogeneous
 - > Minimise magnetic field at the Linac







MRI with Outside Ring Gantry





Courtesy of Dr. Jan Lagendijk & Bas Raaymakers

First generation high field MR Linac Example Images (courtesy of Philips)



High resolution (0.7mm x 0.7mm x 1mm), 3D acquisition with exquisite image quality in all planes

High frame-rate, multi-planar acquisition for motion monitoring



PHILIPS

Successful Test of Clinical MRL System





Clinical MRI linac system test on 10-10-2014 Simultaneously deliver Radiation and make MRI.

No explosion or magnet quench!



Minimal Interference Between MRI and Linac !!!





Prototype MRI accelerator



1.5 T diagnostic MRI quality

No impact of beam on MRI

Low Geometric Distortion



e Mode S (x): -0.05 🗘 T (y): -15.88 🗘 C (z): 5.55 😂 cm

Real-time Imaging: Enables motion tracking or gating



Real-time visualization of structures while beam-on!



MR-Linac Clinical Consortium

- UMC Utrecht* (Utrecht)
- MD Anderson (Houston)
- NKI-AvL (Amsterdam)
- MCW (Milwaukee)
- Sunnybrook (Toronto)
- Royal Marsden-ICR (London)
- Christie (Manchester)



What clinical benefits could MR bring to IGRT?

Soft-tissue visualization

- Difficult-to-image targets and critical structures become 'easy'
- Improved ability to adapt treatment
- Ability to see the tumour not just the organ GTV boost

Real-time 2D and 3D imaging

- Imaging simultaneous with irradiation
- Gating and tracking without surrogates

No imaging dose

More frequent imaging assessment to monitor anatomical response

Quantitative imaging

 Frequent tumour treatment response assessment (inter-& intra-fractions)

Courtesy of Elekta/Philips

Advantages of MRI Guided RT (MR-IGRT)

- Incorporating MR for simulation & treatment planning allows reproducible millimeter accuracy in soft tissue definition
- Functional imaging (DCE/DWI) allows dose painting to high risk tumor volume for greater tumor control
- MR OBI (on board imaging) allows target and critical structure localization & tracking based on gold-standard anatomy rather than fiducial markers, bony anatomy or other surrogate as in CT
- Intra-fraction anatomic and functional imaging allows early evaluation of tumor response and adaptive treatment escalation or de-escalation to improve tumor control or treatment toxicity

The technical capabilities promised by integrated MRI-guided therapy systems present tremendous opportunities for paradigm changes in oncology.

Possibilities for current clinical practice?

• Decreased morbidity (in theory)

Safely deliver a higher dose to GTV, if needed

Better intra-fraction control (for adaptive Tx)

Movement of tumor and normal tissue, tumor deformation, intratreatment shrinkage

 But, this will depend on many future developments and studies: RF coils, 2D or 3D tracking, table steering, intrafraction automated contouring, intrafractional re-planning, questions about who will decide when it is safe to irradiate, # of fractions and the scheme of fractions might be reduced for some sites (just like lung stereotaxy), or even skip a fraction based on functional assessement?

 All the above questions may be answered by biology research with these new systems!!!

What future radiation treatment may look like?

- Pre-treatment
 - Optimal information on anatomy, biology, movement
 - Planning which deals with patient specific uncertainties
- Treatment
 - Look with optimal soft-tissue contrast
 - Adapt for movement of tumour
 - Dose accumulation / Anatomy of the day important:
 - If normal tissue is too close: stop treatment at safe level and come back another day, based on functional imaging of tumour and normal tissues
 - If not, treat until maximum time has elapsed. Maximum dose less important if safe (e.g. 40Gy)
- Post-treatment
 - Optimal information on biology to check response
 - Re-treatment if required

New Issues/Challenges For Integrating MRI into Radiation Therapy

- Facility planning: New considerations
- New QC Procedures
- MRI system → Radiotherapy system
 - Beam generation
 - Beam penetration
 - Scatter caused by beam penetration through MRI system
 - Impact of Lorentz force on secondary electrons
- Radiotherapy system → MRI system
 - Magnetic field homogeneity
 - Radiofrequency interference
- New Safety Issues: Radiation AND MRI safty





Some Technical Challenges

- QA/QC tools and procedures:
 - Machine QA
 - Patient QA
 - New Phantoms
- MRI:
 - Geometric distortions
 - Lack of electron density information
 - Optimized imaging sequences
 - Auto segmentation
 - Coils
- Safety:
 - Implant, contrast agents, claustrophobia, etc.
- Tools and procedures for adaptive therapy
 - fMRI and radiobiology based adaptive radiotherapy
 - Dose painting
 - Accumulated dose mapping

Driving Forces for MRL Adaptation

- What are the main motivations that drive users to use MRL instead of the current model of CT, MRI, Linac?
- Why would anybody pay \$€¥£€¥£ for such an integrated system?
- Where MRL may provide the most value to the clinical care and research in radiation therapy?
- List of the obvious advantages of using MRL
 - Superior target delineation and precision,
 - Capable of real time tracking
 - Early (intra-treatment) response assessment and normal tissue toxicity!
 - Adaptive treatment throughout treatment
 - No ionizing radiation for imaging
 - What else??? Are the enough?
- But what are MRL's true "killer-apps" ???

fMRI capability may be the key!

- Early, intra-treatment, frequent functional imaging assessment of tumor response and normal tissue toxicity may be the key to success and a major selling point for an integrated MRI-radiation treatment system
- Tumors' heterogeneity are both spatially and temporally dependent → differences in response to radiation treatment both spatially and temporally, and they vary from patient to patient
- MRL with fMRI capability on MRL enables true individualized, adaptive treatment strategy
- With on-board fMRI capability, MRL may also enable future large scale clinical trials and basic radiobiology researches of tumor and normal tissue's early response to radiation and their correlation to late effects/complications
- All these need to be proven by carefully designed outcome studies on MRL!

Conclusions



- MR Image-guided radiation therapy are gaining great interests and is one of the fast growing areas in radiation therapy today
- Integrated MRI-radiotherapy systems are bringing in exciting new opportunities and are still in the early development stage. Much more to come.
- MR-IGRT is a major part of the future for radiotherapy
- Radiotherapy may be at the brinks of a major paradigm change.

Radiotherapy is changing and we have always been doing "precision medicine"

From X-ray based planning $\rightarrow \rightarrow$ MRI-based planning From no movement correction $\rightarrow \rightarrow$ weekly or even daily adaptation Today's Radiotherapy $\rightarrow \rightarrow$ high precision



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What are the main challenges for MRI-only treatment planning in today's radiation therapy?

- A. Geometric distortion in MRI
- B. Lack of electron density information for TPS
- C. Interference of magnetic field on secondary electrons
- D. RF interference of MRI to radiation therapy

E. A & B



87%

Correct Answer: E

Reference:

MR in radiotherapy-an important step towards personalized treatments? Report from SSM's scientific council on ionizing radiation within oncology, 10-2014 What are the main considerations in facility planning for MRI-Linac?

- A. RF shielding for the MRI
- B. Radiation shielding for the linac
- C. Acoustic noise
- D. Screening of non-MRI compatible implanted devices in patients
- E. A&B&D
- F. All of the above



Correct Answer: E

Reference:

MR in radiotherapy-an important step towards personalized treatments? Report from SSM's scientific council on ionizing radiation within oncology, 10-2014