Cross Cancer Institute
MR-Linac:
Rotating the Magnet-linac Combo

Real-time MR Guided RT

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Rotating Bi-Planar linac –MR
Cross Cancer Institute

- 6 MV medical linear accelerator (linac).
- Low-field (0.56 T) biplanar MR imager.
RF Shielding

K-space data of the first (left) and second (right) phantoms taken during linac pulsing while the RF shielding was insufficient. The data illustrate clear 'lines' in the k-space from the RF interference picked up by the MRI coil.


RIC in RF COILs

Isolation of copper winding as the source RIC. Magnitude of the RIC pulse is larger when the entire coil length is irradiated compared to only 2.5 cm width.
Linac-MR images

- Linac not producing radiation (left) and with linac producing radiation at 250 MU/min (right).
- RIC not apparent through visual inspection alone

Post-Processing RIC removal
Post-Processing RIC removal


Rotating Biplanar Options

Advantage of bi-planar MRI

- Allows PARALLEL in addition to PERPENDICULAR
- PARALLEL
  - Simplifies Magnetic Shielding Design
  - NO ELECTRON RETURN EFFECT
  - NO INCREASE in EXIT SURFACE DOSE
- Avoids radiation traversing through MR magnet
- Avoids production of Eddy currents created by linac rotating wrt MRI in cylindrical design

Magnetic shielding

- For 20% beam loss
  - **Perpendicular ~ 4 G**
  - **Parallel ~ 120 G**

- Parallel at 0.5 T
  - NO shielding required

Perpendicular vs. Parallel

- In the parallel configuration, the effect of the magnetic field is to somewhat collimate the shower of secondary electrons, thereby reducing the beam penumbra and focusing the dose depositing by a given beam.

5 field Lung Plan
Eclipse TPS
Patient Dosimetry

0.5 T

Parallel Configuration: Lower penumbra


SURFACE DOSE
**OUR CURRENT SYSTEMS**

- biplanar magnet assembly
- treatment assembly
- superconducting coil
- gantry support link

**Entrance**

**Surface Dose: Longitudinal**

Schematic diagram of the longitudinal linac-MR system with the isocenter at 126 cm.

The CAX magnetic field maps of our realistic 3-D models versus a 1-D model.
ENTRANCE SURFACE SKIN DOSE

Longitudinal

NO SIGNIFICANT INCREASE

EXIT SURFACE DOSE

Perpendicular

SIGNIFICANT INCREASE

10 x10 cm² photon beam; phantom surface at 136 cm from source
SUMMARY SURFACE DOSE

PERPENDICULAR

ENTRY
DECREASE BY < 1/2

EXIT
INCREASE BY > 1/2

PARALLEL

ENTRY
INSIGNICANT INCREASE

EXIT
SAME as Bo=0

Calibration: Ion chamber

Arrow: Magnetic field; cylinder: long axis-central
Transparent prism: radiation field

Parallel/longitudinal

Perpendicular/transverse

Ion chamber response

Real-time Tumour-Tracked Irradiation

- Minimize PTV margin in dynamic target

Current State of the art

Real-time MR guided Tumour-Tracked RT

Tumor-Tracked Irradiation: Cross Cancer Institute

Real-time tumour tracking scheme

Motion phantom in linac-MR

Repeat for each image

4 fps

Auto-contouring

On-line MLC controlling

MR image

Target shape & centroid

MLC conformation

Our Tumour Tracking (Auto contour):
Evaluation Experiment

• Lung Phantom is driven in by programmable 1-D motor.
• Optical Encoder independently records position of tumour for comparison.
• Realistic tumour movement (inf-sup) as determined through Cyberknife patient data.
Auto-contouring (3 T images)

Original image

Auto-contoured image
Auto-contouring (Est. 0.5 T images)

Original image | Auto-contoured image

Auto-contouring (Est. 0.2 T images)

Original image | Auto-contoured image
PREDICTION

Total time delay from imaging to MLC motion completion

241~269 msec
Solution to tracking failures

- Multiple ANNs & predictions
  - More frequent MLC motion triggering
    (ex. 1 ANN vs. 7 ANN, imaging at 3.6 fps (every 280 ms))

Motion prediction

Our Algorithm’s Prediction-- 1D sup-inf tumour position in 280 ms advance
Tested on 3D tumour motion by Cyberknife: (Suh et al. PMB, 53, 3623-40(2008)

- Original data
- Prediction
- Error (mm)

Demonstration

Tumour-Trackered (2 D imaged) Irradiation

CCI linac-MR Prototype


Demonstration of intra-fractional tracking
Phantom motion follows pre-defined 1-D motion pattern during tracking.

To register films to each other, the edges of the phantom (indicated by red dots) are manually marked.

- For each motion pattern, moving target was irradiated for 2 minutes as follow:

  1. Without tracking (MLC conformed to initial target position during irradiation)
  2. With tracking + without motion prediction
  3. With tracking + with motion prediction
Demonstration of intra-fractional tracking

<table>
<thead>
<tr>
<th>Phantom motion</th>
<th>Film results</th>
<th>Profile along white line</th>
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<td>None</td>
<td>S0 Motion (x) Margin (x) Track (x) Predict (x)</td>
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<td></td>
<td>S1 Motion (x) Margin (x) Track (x) Predict (x)</td>
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<td>S0</td>
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<td>S0 Motion (x) Margin (x) Track (x) Predict (x)</td>
<td><img src="image7" alt="Graph" /></td>
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Potential Advantages

Bi-planar MR Perpendicular

- Bi-planar MR perpendicular
  - Lorentz Force in same direction irrespective of rotation...
    - Potential to preferentially deliver dose towards a region irrespective of rotation angle
  - May have some advantages for some clinical sites
Advantages of Real-time MRI-linac

- Margin-reduction, normal-tissue avoidance, decreased morbidity
- Eliminate set-up & motion uncertainties
- Daily targeting of volume changes & rep. motion
- Monitor tumour-regression
- Tumour-tracking … Tumour-tracked irradiation
- Etc.

Clinical Applications Real-time MRI-linac

- Non-small cell lung cancer (NSCLC)
- Hepatobiliary Carcinoma
- Breast Cancer
- Non-Hodgkin’s lymphoma of the stomach
- Colorectal Cancer
- Cervical Cancer
- Pediatrics, etc
Patient flow

- MR-Simulation & Treatment Planning
- Monitor, verify and treat on MRI-linac hybrid for all fractions

PRESENT INSTALLATION
Cross Cancer Institute
University of Alberta
Edmonton
System Layout at our Hospital

Room size:
Depth: 19.4 feet
Width: 19.8 feet
Height: 12.0 feet

Install Without Need to Remove Wall or Ceiling
No cryogens (helium, nitrogen), no cryogen vent required.

DETERMINE BEST CONFIGURATION FOR EACH DISEASE SITE

The TEAM

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