UMC Utrecht

On-line planning for the MRI-accelerator: Virtual Couch shift and On-line re-planning

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ELEKTA

PHILIPS sense and simplicity

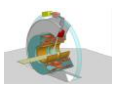
stw

KWF KANKER BESTRIJDING

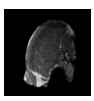
SUN NUCLEAR corporation

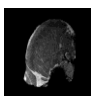
PTW

1.5 T MRI accelerator: Simultaneous irradiation and MRI

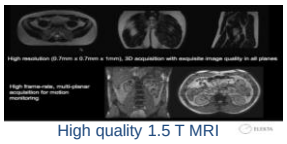


Evolution of the MRI accelerator





No impact of “beam on” for MRI



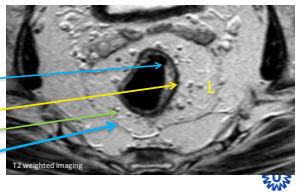
High quality 1.5 T MRI

T2 weighted MRI Rectum

The rectum, anatomy on MRI, from inside to outside:

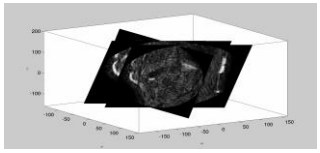
Lumen
Three rectal wall layers:
- Mucosal layer
- Submucosal Layer
- Muscle layer

Mesorectal fat
Mesorectal fascie



Courtesy of Martijn Intven

Multi-slice imaging example

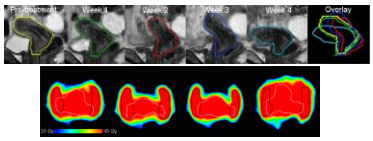


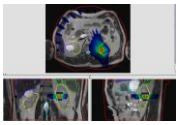
bSSFP sequence with radial read-out (25% sampled)
3 planes each updated at 4Hz

Courtesy of Bjorn Stemkens

Plan adaptation enabled by MRI guided Radiotherapy

Improved conventional RT
e.g. MRI based position verification cervix
From Kerkhof et al. 2008



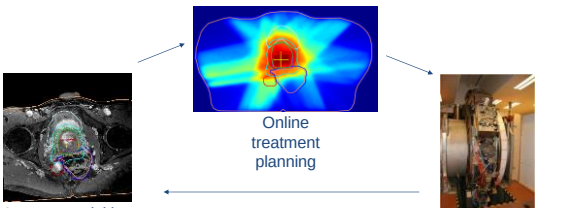


Body stereotactic approaches
e.g. single fraction RT
Kidney tumours
From Kerkhof et al. 2010

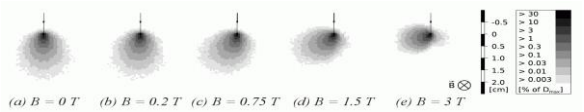
Virtual couch shift (VCS) and re-planning

- MRL table motion in CC only
  - On-line plan adaptation
    - Translations
    - Rotations
    - Deformations
  - Virtual couch shift, move the pre-treatment dose distribution
    - Aperture shift
    - Aperture morphing (Ahunbay et al.)
    - Re-planning
  - Re-planning for new anatomy

MRL treatment cycle

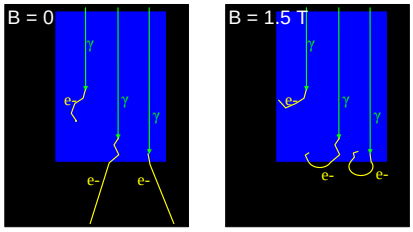


Point spread kernels as function of magnetic field



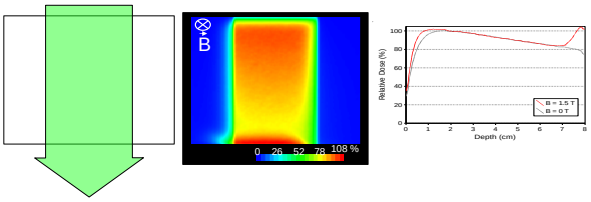
Courtesy of Alexander Raaijmakers

Dose deposition in a magnetic field
The Electron Return Effect (ERE)



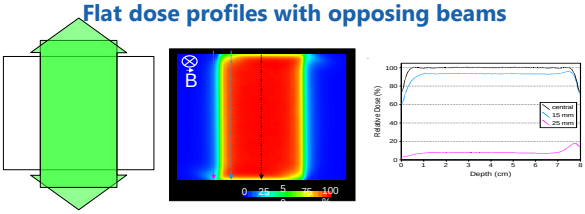
Courtesy of Alexander Raaijmakers

ERE (Electron Return Effect)
Dose increase at all tissue-air boundaries



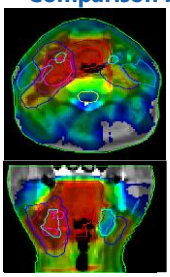
From Raaijmakers et al. PMB 2005

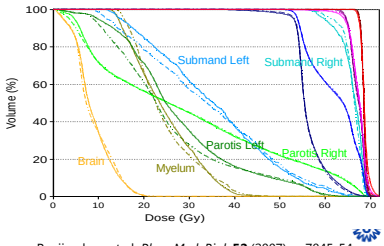
ERE (Electron Return Effect)
Flat dose profiles with opposing beams



Raaijmakers et al. *Phys. Med. Biol.* **50** (2005) p. 1363-76

DVH for optimized dose distribution oropharynx Comparison between B = 0 T and B = 1.5 T



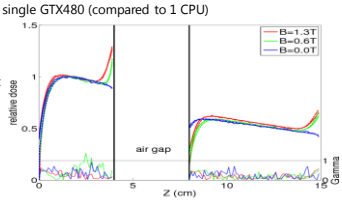


Raaijmakers et al. *Phys. Med. Biol.* **52** (2007) p. 7045-54

GPUMCD
Transport in magnetic fields

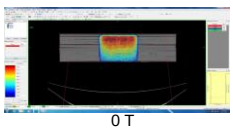
- Monte Carlo code designed to run on GPU's (Hissoiny et al 2011)
- Benchmarked against EGSnrc and DPM
  - Within 2%/2mm
  - 900, resp 200 times faster using single GTX480 (compared to 1 CPU)

- Validated as done for Geant4 by (Raaijmakers et al 2007)
- Large magnetic field induced impact
- Within 2%/2mm ("Old" GPUMCD) (Hissoiny et al PMB 2011)

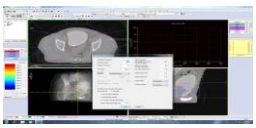


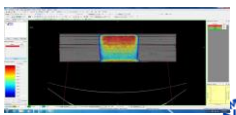
IMRT for the MRL: Monaco

- GPUMCD integrated in CMS Monaco
- Clinical work flow (incl sequencing)
- Virtual Couch shift by aperture adaptation



0 T





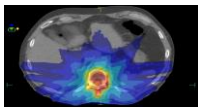
1.5 T

Virtual couch shift (VCS) by Monaco

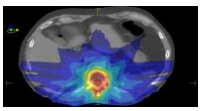
- VCS to Account for translations
  - in Monaco -> aperture shift
- VCS vs. on-line re-planning
- Bone metastases
- 10 days → 10 VCS's
- No magnetic field
- Calculation time:
  - Approx. 25 min for re-plan
  - Approx. 3 min for VCS

Courtesy Stan Hoogcarspel and Mariska Damen

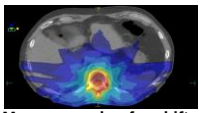
SBRT for spinal bone metastasis



Original IMRT plan



Monaco VCS for shift
X; 0.9 mm Y; 7.0 mm Z; 1.9 mm



Monaco re-plan for shift
X; 0.9 mm Y; 7.0 mm Z; 1.9 mm

Courtesy Stan Hoogcarspel and Mariska Damen

Mean percentage difference within regions / organs

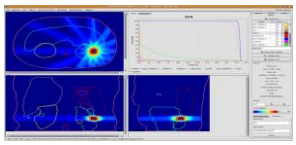
% difference	Re-planning		Virtual couch shift
Region (mean dose original plan)	Mean	Region (mean dose original plan)	Mean
Myelum (24 Gy)	4.89 % (1.17 Gy)	Myelum (24 Gy)	2.34 % (0.56 Gy)
Right kidney (3.2 Gy)	4.30 % (0.14 Gy)	Right kidney (3.2 Gy)	2.16 % (0.07 Gy)
Target (36 Gy)	0.12 % (0.04 Gy)	Target (36 Gy)	0.61 % (0.22 Gy)

- VCS in on-line time regime!
  - Start delivery right after VCS
- VCS result depends on MLC orientation
- Hypothesis, joint aperture adaptation instead of aperture by aperture adaptation

Courtesy Stan Hoogcarspel and Mariska Damen

MRL treatment planning (MRLTP)

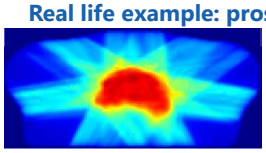
- Dose engine for beamlets
  - GPUMCD (Hissoiny et al. 2011)
- Inverse optimisation:
  - FIDO (Goldman et al. 2009) for inverse optimization
  - AIDO, (based onZiegenhein et al. (2013)
- Sequencing
  - Segment-by-segment optimisation (Kontaxis et al. 2014)

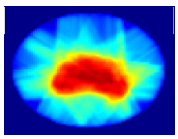


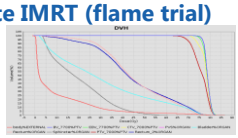
Kidney IMRT plan in 15 sec. fluence (1 GTX480 per beam)

Bol et al., 2012

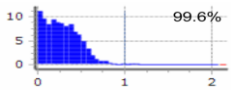
Real life example: prostate IMRT (flame trial)







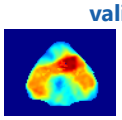
GTV boost to 94 Gy
All constraints met



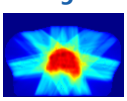
Experimental validation by Delta4
99.6% gamma passage: clinically acceptable

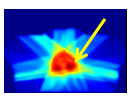
Courtesy Charis Kontaxis

Examples of "clinical grade", experimentally validated plans using Delta4 (0T)

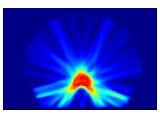


Head and Neck

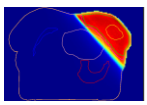




Flame prostate, with and without GTV boost



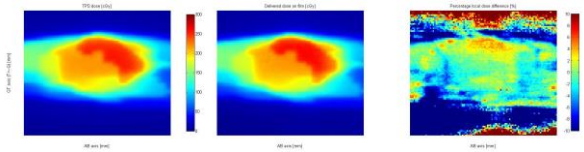
Stereotactic spinal bone



Mamma, 2 tangential beam IMRT

Courtesy Charis Kontaxis

IMRT plan at MRL (at 1.5T)
Validated by film dosimetry in solid water phantom



Calculated IMRT Dose distribution

Measured IMRT Dose distribution

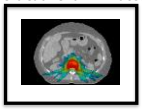
Difference <4% for high dose area

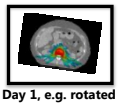
Courtesy Jochem Wolthaus

MRLTP for adapting IMRT to the actual anatomy: Virtual Couch Shift (VCS)

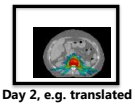
- **VCS:** On-line plan adaptation to **move dose instead of couch**
  - Maintain pre-treatment, patient specific considerations
  - Re-generate pre-treatment plan for new position/orientation

Pre-treatment IMRT dose

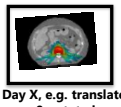




Day 1, e.g. rotated

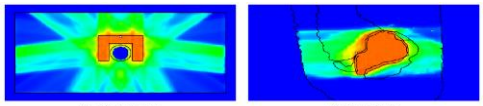


Day 2, e.g. translated



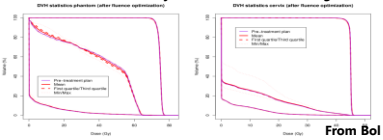
Day X, e.g. translated & rotated

VCS of phantom and cervix case



(a) Phantom case (b) Cervix case

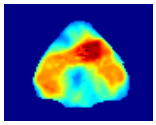
48 translations in x,y,z direction: 1,2,3,5,8,13,21,34 mm
42 rotations around x,y,z axis: 1,2,3,5,8,13,21 degrees



From Bol et al. PMB (2013)

Segment by segment optimisation: towards intra-fraction plan adaptation

- Fluence optimisation
- Simple segmentation
- Pick "most efficient" segment
- Calculate dose from segment
  - Monaco
- Subtract segment from ideal fluence
- Loop to fluence optimisation



Head and Neck IMRT
For inter-fraction variation

- Open for on-the-fly anatomical changes

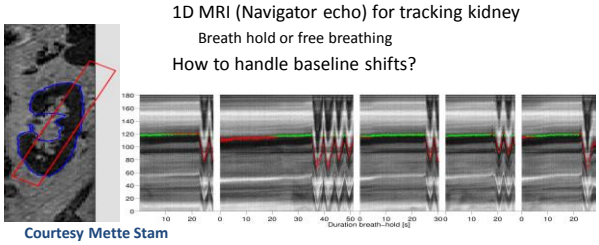
Courtesy Charis Kontaxis

Example of MRI based gated radiotherapy for kidney

1D MRI (Navigator echo) for tracking kidney

Breath hold or free breathing

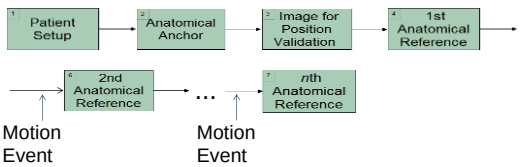
How to handle baseline shifts?



Courtesy Mette Stam

Image based target tracking

- MRI framework for volunteer study for on-the-fly 4D anatomy



- **Adopted from MRI HIFU**
- **Average time gap between the 3D anatomical scans was 10 minutes**
- **9 consecutive 3D anatomical scans**

Courtesy Cornel Zachiu

3D T1w MRI, the "proxy" data (2 mm cubic)

Coronal plane **Sagittal plane**

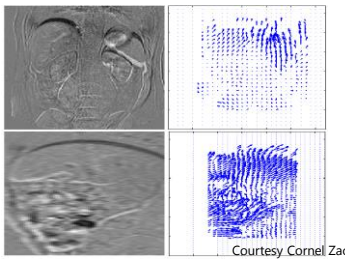
Courtesy Cornel Zachiu

3D deformation field relative to anchor

t = 80 min

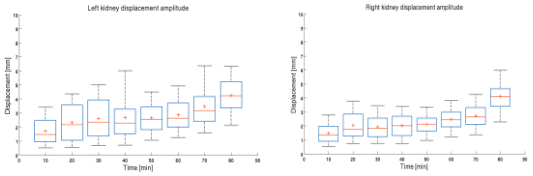
Coronal

Sagittal



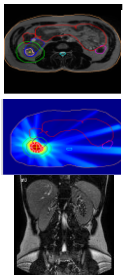
Courtesy Cornel Zachiu

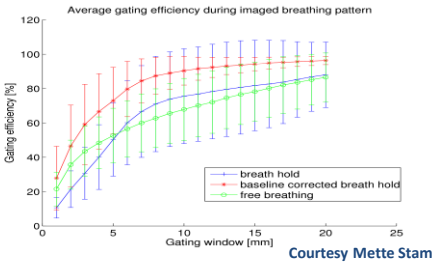
10 Volunteers, no failures
Evaluation of kidney motion over 80 minutes



Courtesy Cornel Zachiu

Gating efficiency of RT for kidney tumours: free breathing, breath hold, baseline corrected breath hold





Courtesy Mette Stam

Summary and conclusion

- Impact of magnetic field on dose can be compensated
  - Multiple beams
  - IMRT
- Virtual couch shift can be done by
  - Aperture shifting
  - Aperture morphing
  - Re-planning
- Re-planning allows accounting for daily changes
- Exploring compensation for on-the-fly anatomical changes
  - Start with intra-fraction baseline corrections

Next generation MRL arriving at UMC Utrecht (last month)