Intensity Modulated RadioTherapy

A clinical application of a small accelerator

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Aims

• Introduction to radiotherapy
• The place of IMRT in radiotherapy
• The place of linac design in IMRT
• Realization of IMRT
• IMRT clinical examples
Mechanism of radiotherapy

- Treatment beam
- Photons
- Charged particles
- Ionization tracks
- Damage to DNA

Photons can be converted into charged particles, which then cause ionization tracks, leading to damage to DNA.
Introduction: a patient’s view

Localisator  CT  Simulator

Linac: multiple fractions
Behind the screens

Localisator

CT

Treatment planning

Simulator

Linac: multiple fractions
Treatment planning: step 1

- Definition of targets and critical structures
Treatment planning: step 1
Treatment planning: step 2

- Design of treatment technique
  - Number of beams and their directions
  - Modality: photons/electrons and energy
- Design of multiple beams
  - Beam shape
- Design of treatment plan
  - Weighting of beam contribution
- Example
  - Nasopharynx + bilateral neck nodes
  - Max. 85% dose (50 Gy) to spinal cord
  - 10 beams (4 shown)

BTW: why so many beams?
By the way: why so many beams??

Single beam  
- Very high dose to normal tissue  
- Inhomogeneous target dose

Multiple beams  
- Accepted dose to normal tissue  
- Homogeneous target dose
Treatment beams in Beam’s-Eye-View*

*Lateral

*Posterior

*Projection of the patient as seen by the linac target
Treatment beams in Beam’s-Eye-View

Lateral oblique  Caudal
Treatment planning: step 3

- Calculate dose distribution
Treatment planning: step 4

- Evaluate dose distribution
- Adapt treatment plan (step 2) until acceptable
Treatment planning: step 4

Acceptable spinal cord dose

50% 70% 80% 90% 95% 100%

Conformality to target

95%
Treatment plan = linac recipe

- Photon or electron beams
- 6 degrees of freedom ...
- ... all around the isocentre
Treatment planning: a step further needed

Acceptable spinal cord dose

50% 70% 80% 90% 95% 100%

Conformality to target

95%

No sparing of parotid gland
Radiotherapy develops towards ...

• Progress in radiotherapy depends on three areas in conjunction:
  – Medical knowledge                Medicine
  – Dose calculation                 Physics
  – Technical facilities             Engineering
Radiotherapy develops towards ...

- ... more conformal treatment

1983
Beam's-Eye-View with simple dose calculation
Beams must conform to target

1995
MLC: Multi-Leaf Collimator allows more and better shaped beams
Dose calculation with physics of linac model
High dose must conform to target
Radiotherapy develops towards ...

- ... IMRT

Homogeneous fluence/beam

Multi-Leaf Collimator allows modulation of a beam

Intensity modulated radiotherapy (IMRT)
Radiotherapy develops towards IMRT

1985
Beam’s-Eye-View with simple dose calculation
Beams must conform to target

1995
Dose calculation with physics of linac model
High dose must conform to target

2000
Math. optimization & linac construction
Dose distribution must conform to constraints
The place of IMRT in radiotherapy

Spinal cord: < 30 Gy
Target 2: > 50 Gy
Target 1: > 60 Gy

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The place of linac design in IMRT

- Linear accelerator
Linac construction

- Linear accelerator
  - Vacuum technology
  - High-voltage circuits
  - RF wave guide
  - (Fine) mechanics
  - Electronic control circuits
Linac construction

- Linear accelerator
  - Vacuum technology
  - High-voltage circuits
  - EM wave guide
  - (Fine) mechanics
  - Electronic control circuits
  - Rotatable over 360°
- In-house maintenance & support
  - 5 engineers
  - Automatic checks (servo)
  - Weekly & monthly checks
Wave guide and flight tube
Bending magnet, electron window
Filter carrousel and monitor ion chamber
Housing of 40 leafs of MLC with motors
Multi-Leaf Collimator (Elekta BM)
MLC motors
The place of linac design in IMRT

- Better isocentric stability: 1 mm
- Fast beam startup: coil sets magnetron plunger
- Beam starting stability: slitless without servos
- Multi-leafs: fast change beam shape
- Multi-leaf specification: leakage, travel range, speed
- Leaf calibration: field junction dose
- Geometry and materials: must be well-known for dose calculation in treatment planning system
Improved mechanics and gantry motors
Dose calculation and linac geometry

• Construction of Elekta Sl linac model for calculation of a 6 MV-X 3x3cm² photon beam
  - BEAM Monte Carlo model
Dose calculation

- Construction of Elekta Sli linac model
- Photon exiting linac head
- Characteristics of exiting photons is determined by linac geometry

1000 histories (= electrons on target)
Dose calculation and linac geometry

• Linac model in treatment planning system should yield:
  - 2D energy fluence distribution ..
  - .. i.e. the number of particles ..
  - .. times their energy ..
  - .. for all relevant linac parts ..
  - .. at actual field shape ..
Dose calculation and linac geometry

- Treatment planning system should distinguish
  - Head scatter contribution from linac head components
  - Based on dose-point’s-eye-view backprojection
  - MU calculation including backscatter into monitor chamber
Two other possibilities for IMRT

- Tomotherapy: CT-scan and linac in one
- CyberKnife: linac on a robotic arm

Tomotherapy at John Hopkins

CyberKnife
Conclusions first part

- IMRT offers new possibilities to better spare critical organs and/or enhance tumor dose
- The design of the linear accelerator plays a critical role in:
  - facilitating new treatment techniques
  - treatment accuracy
  - dose calculation
- Maintenance and quality control of RT apparatus such as a linac is of eminent importance