The (R)evolution in Radiotherapy

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Why Radiotherapy?

- Cancer is a disease with many facets
- It requires:
  - Individualized treatment strategies
  - Synergy between surgery, radiotherapy and chemotherapy
  - Multi-targeted treatments, ability to adapt, per-treatment monitoring
- For radiotherapy this translates to:
  - Dose sculpting (and dose-painting-by-numbers)
  - Image-guided radiotherapy
  - Developments in radiobiology, functional imaging and adaptive radiotherapy (ART)
Why Radiotherapy?

Radiotherapy is the most cost-effective treatment for cancer

The Cancer Council of Australia
The aim of Radiotherapy

Maximizing outcome – Minimizing complications

It comes down to “DOSE SCULPTING”
Therapeutic opportunity of Radiotherapy

-> Enlargement of the therapeutic window
The evolution in a nutshell

“inaccurate positioning” ➔

“simple dose distributions”
Conformal radiotherapy
(3D - CRT)

- **3D-CRT**: to conform with a high precision the spatial distribution of the prescribed dose to the 3 D target volume,
  - excluding critical structures as far as possible
- **Volume effect**: small volumes of critical structures can tolerate high(er) doses
- Reduced doses to normal tissue allow dose escalation

→ **Possibility to improve local control and outcome**
Conformal radiotherapy (3D - CRT)

- NOT a new concept
- ONLY **technological improvements** allowed its technical realization
  - better localization modalities (CT / MR / PET imaging)
  - fast computers for full 3 D treatment planning / allowing direct use of other imaging modalities (matching) / more accurate dose calculation
  - new hardware for treatment delivery (customized blocking, MLCs, compensator, ...)

⇒ **IN PARALLEL** - investigation of new radiation qualities (n, p, ...)
Multi-Leaf Collimator (MLC)
Electronic Portal Imaging (EPID)

**APPLICATION**

- verification of patient position (geometrical uncertainties)
- dosimetry purposes (beam characteristics, transit dosimetry)
Conventional RT ⇔ Conformal RT

Prostate case

Bony anatomy based

CT data based
Conventional RT ↔ Conformal RT

Bony anatomy based

CT data based

Irradiated Volume

700 cm³

430 cm³
Conformal Radiotherapy

beam 1

beam 2

beam 3

tumour

high dose area
Conformal Radiotherapy

- beam 1
- beam 2
- beam 3
- high dose area
- same ray intensity
- tumour
- radiation sensitive organ
Intensity Modulated Radiotherapy

- tumor
- high dose area
- brain stem
INTENSITY MODULATION

- Special form of conformal therapy
  - geometric field shaping + intensity variation
  - helps to overcome some limitations of 3D-CRT
- Intensity of the primary photon fluence varies across the target volume
- Each beam may treat only portions of the target

Geometrical field shaping

IM and geometrical field shaping
‘MLC’ - IMRT DELIVERY TECHNIQUES

‘STEP AND SHOOT’ - technique

Intensity Modulation by superposition of MLC beam segments

DYNAMIC technique

Intensity Modulation by scanning the beam with an MLC
In dynamic rotation therapy the following parameters might vary during dose delivery:

- MLC aperture
- Dose Rate
- Gantry velocity
- Collimator angle
Volumetric Modulated Arc Therapy

- Different implementations:
  - Tomotherapy
  - Rapid Arc (Varian)
  - VMAT (Elekta)
  - mArc (Siemens)

- ADVANTAGE:
  - Faster delivery
  - Fewer MU
mArc

(Arc Modulated CBT):

“Step and shoot” approach

- CP0 – CP1: MLC adapt.
- CP1 – CP2: Dose deliv.
- CP2 – CP3: MLC adapt.
- CP3 – CP4: Dose deliv.
Planning comparison

- RapidArc® improves PTV coverage (V95%):
  - RapidArc®: 90.2±5.2%
  - IMRT: 84.5±8.2%
  - 3D-CRT: 82.5±9.6%

- Most planning objectives for OARs are met by all techniques, excepting for some 3D-CRT plans.

- MU/fraction:
  - RapidArc®: 2186±211
  - IMRT: 2583±699
  - 3D-CRT: 1554±153

- Effective treatment time:
  - RapidArc®: 3.7±0.4 min
  - IMRT: 10.6±1.2 min
  - 3D-CRT: 6.3±0.5 min

Head and Neck Plan

9-beam DMPO

SmartArc
Head and Neck Plan

SmartArc = dashed
DMPO = solid

Target Volumes

L Parotid

R Parotid

Cord
IMRT advantages

⇒ high conformal isodose distribution
⇒ less irradiation dose to the OAR  OR  higher dose to the PTV
⇒ NO reduction of the safety margin
IMRT Drawback

“We are at increased risk of missing very precisely” 
(J. Rosenman)
RT is a four dimensional problem
TARGET VOLUME CONCEPTS

Graphical representation of the volumes-of-interest, as defined by the ICRU 50 and 62 reports.

See various ICRU Reports
ICRU 50, 62, 78, ....

Verellen et al
IGRT (Image Guided Radiotherapy)

⇒ correction of patient positioning errors
Matching of Cone Beam CT (Linac) with Planning CT
CBCT: soft tissue matching

soft tissue correction
(directly or indirectly via gold markers)
Enlargement of the therapeutic window
IGRT equipment

- Elekta
- Siemens
- Novalis TX
- Varian
- Tomotherapy

"Image of the day" vs treatment planning information
HYBRID MRI linac

- Closed bore high field MRI
- Gantry ring based 6 MV accelerator with MLC
  - accelerator and MRI system have to operate simultaneously and independently

Courtesy J. Lagendijk
IGRT: advantages

⇒ correction of patient positioning errors
⇒ high probability to hit the tumor
⇒ reduction of safety margin
IMRT allows
- Dose reduction to OAR
- Higher dose to the PTV

or

IGRT allows
- Reduction of the safety margin
- Higher probability to hit the target
High Precision RT

- IMRT without IGRT =
  - High Dose gradients + low probability to hit Target => unpredictable dose distribution

- IMRT + IGRT =
  - Lower probability of side effects
  - Higher dose to tumor
What do we need for high-tech RT?

- Imaging equipment & software tools
- Treatment planning
- Beam delivery systems
- Patient immobilization
- Dedicated QA procedures
- Dedicated personnel
Robotics developments

- To reposition patient or the treatment delivery unit
  - couches with 6 degrees of freedom and tracking MLC
- To position automatically dosimetry and QA tools

Courtesy Siemens

Courtesy H. Deutschmann

Courtesy Siemens
DOSE PAINTING (by numbers)

Grosu et al IJROBP 69, 2007

Fractionation effects!
Maximal conformity at maximal cost?
General Areas of Responsibility of the Medical Physicist

- Clinical
- Research
- Education
- Regulatory Compliance

From “Medical Physics as a Career” (AAPM 2005)
Clinical Responsibilities of the Medical Physicist

- Daily clinical support
- Equipment acquisitions
- Equipment calibration and commissioning
- Quality assurance
- Dose calculations
- Liaison between other medical professionals, manufacturers, and regulatory agencies
SUMMARY

- Linacs are the most widely used delivery equipment in RT
  - Important technological developments during last 2 decades, machines designed for VMAT
  - Important clinical achievements

- Geometric accuracy in treatment delivery >> accuracy in target definition & patient immobilization
  - Research focuses on “Image guidance” for target definition and beam delivery
  - Increasing demand for new infrastructure and well trained personnel
  - Photon IGRT also sets standards for particle therapy
“The difference between theory and practice ... is larger in practice than in theory!”

John Wilkes

Credits: Dietmar Georg, Dirk Verellen, Hilke Vorwerk