Three-Dimensional Conformal Radiotherapy (3DCRT)
Treatment planning for external beam

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Professionals involved in the treatment planning process (IAEA)

<table>
<thead>
<tr>
<th>People</th>
<th>Process</th>
<th>QA activity</th>
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</thead>
<tbody>
<tr>
<td>Radiation therapist</td>
<td>Imaging/contouring</td>
<td>Patient set-up Imaging protocols</td>
</tr>
<tr>
<td>Diagnostic radiology technologist</td>
<td>Target volume and normal tissue definition</td>
<td>Training of radiation oncologist in GTV, CTV and PTV Use of clinical protocols</td>
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<tr>
<td>Radiation oncologist</td>
<td>Dose calculation/optimization</td>
<td>TPS commissioning and QA Training of treatment planners to use the TPS</td>
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<tr>
<td>Treatment planner</td>
<td>MU/time calculation</td>
<td>TPS commissioning and QA Training of treatment planners to use the TPS and MU/time calculation</td>
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<tr>
<td>Physicist</td>
<td>First treatment</td>
<td>Process QA Check of set-up parameters</td>
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<td>Treatment planner</td>
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<td>Physicist</td>
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<td>Radiation therapist</td>
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A characteristic feature of modern radiotherapy is a **multi-disciplinary approach**, consisting of and usage of many complex devices and procedures.

- Clinical examination
- Treatment planning: Simulation and dose calculation
- 3D Imaging
- Treatment planning: Evaluation and assessment
-Dosimetric verification and checks
- Radiotherapy
- Localization of target volume and organs at risk
- Patient-positioning
- Aftercare, evaluation

The radiotherapy chain

**Imaging**
- CT

**Radiation Planning**
- TPS

**Linear Accelerator**
- Photon / Electron

**Localization**
- Dose calculation
- Radiation
The Radiotherapy Chain example:

Computertomograph

Linear accelerator

Image data

Treatment planning system

Simulated and marked radiation fields

Therapy simulator

Planned radiation fields
Radiotherapy treatment goal

- The objective of radiotherapy is the destruction of local tumour without severe side effects
- Removal of the tumour
  - (Local tumour control / Regional tumour control)
- Avoidance of treatment effects
  - disfigurement
  - loss of function
  - restriction of quality of life
- Therapy optimization: maximum effect with minimal burden
Tolerance doses in Gy (*Emami et al*).

<table>
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<tr>
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</table>
Tolerance doses (Organ types)

- **Serial organs** - *example*
  - spinal cord

- **Parallel organ** - *example*
  - lung

What difference in response would you expect?

In practice not always that clear cut
3-D-Treatment planning process (positioning)

Fixation aids and markers on the skin permit reproducibility of the settings by means of a stationary laser-coordinate system.

Example: HNO-Area A technician places the mask on the patient.
3-D-Treatment planning process (positioning)

Various tools for the positioning and immobilization:
Areas: Skull, chest, abdomen, pelvis, upper and lower extremities.
3-D-Treatment planning process (3-D Imaging)

Fixing of the treatment position (positioning, immobilization)

Example: HNO-Area planning CT

The patient is positioned according to skin markers or anatomical reference points by using mechanical or optical viewing aids, but actually stationary laser.
Fixing of the treatment position (positioning, immobilization)

MRT  CT  PET  SPECT  →  Fusion

3-D CT data or optional PET /MR images will be acquired.
Image fusion serves for a better recognition of the target

3-D-Treatment planning process (3D Imaging - Fusion)
Fixing of the treatment position (positioning, immobilization)

MRT, CT, PET, SPECT

Fusion

Contouring

For the treatment planning, the images must be exported from the acquisition unit and imported to the TPS unit.
3-D-Treatment planning process (Contouring)

**Contouring:**
- On each slice of the CT (e.g.: Larynx Ca.) is drawn ...
- an **outer contour** which limits the body (**brown**)
- a **target volume** that encloses the planning target volume **PTV (red)**
- **organs at risk** (here the spinal cord) (**blue**)
- The radiation oncologist is responsible for defining and contouring the target volume.

Depending on tumour location, other organs at risk are taken into consideration during the irradiation.
3-D-Treatment planning process (Contouring)

**Strategy**

- tumour mass (X-Ray, CT, MRT)
- tumour localization (X-Ray, CT, MRT)
- tumour character (MR-Spectrom, SPECT, PET)

=>

**Target 1 (Tumour detected)** → higher dose
**Target 2 (Tumour suspected)** → lower dose
ICRU: Changes Over Time

(A) ICRU 29

(B) ICRU 50

(C) ICRU 62
3-D-Treatment planning process (Contouring)

ICRU 29, 1978

- Single slice (or few)
- External contour
- Coplanar beams
- Simple calculations
- Dose prescription to “ICRU reference point”
3-D-Treatment planning process (Contouring)

**Target volume definition (ICRU 50) 1993**

- **Gross Tumour Volume (GTV) =** clinically demonstrated tumour
- **Clinical Target Volume (CTV) =** GTV + area at risk (e.g. potentially involved lymph nodes)
- **Planning Target Volume (PTV) =** volume planned to be treated = CTV + margin for set-up uncertainties and potential of organ movement
3-D-Treatment planning process (Contouring)

Target volume definition (ICRU 62)

- PRV: Includes margin around the OAR to compensate for changes in shape and internal motion and for set-up variation.

- Irradiation techniques have advanced
  =>
- More accurately formulate definitions & concepts
  - Reference points and coordinate systems
  - Introduction of
    - Internal Margin (IM)
    - Setup Margin (SM)
    - Internal Target Volume (ITV)
    - Planning organ at Risk Volume (PRV)
    - Conformity Index (CI)
3-D-Treatment planning process (Contouring)

**Planning Target Volume (ICRU 62)**

- Imaging: CT, PET, MRI
- Biology
  - Gross Tumor Volume (GTV)
  - Microscopic Spread
- Respiratory gating
  - Internal Motion
  - Set-up Errors
- On board imaging

- Clinical Target Volume (CTV)
- Internal Target Volume (ITV)
- Planning Target Volume (PTV)
3-D-Treatment planning process (Contouring-example)
3-D-Treatment planning process (Beam Modelling)

Fixing of the treatment position (positioning, immobilization)

MRT  CT  PET  SPECT

Fusion

Contouring

Setting of the radiation fields virtual simulation

Optimization of the dose distribution

Evaluation

3-D-Treatment plan
3-D-Treatment planning process (Beam Modelling)

Optimization criterion - field form

Satellites blocks

Adjustment of the field form to PTV

Multileaf Collimator (MLC)

Beam eye view

Siemens factory Photo
3-D-Treatment planning process (Beam Modelling)

Optimization criterion - field form

Field formation in the AP and lateral fields with a pelvic irradiation (4-field box) based on the Beam Eye View (BEV)
3-D-Treatment planning process (Beam Modelling)

**Optimization criterion - radiation type and energy examples**
3-D-Treatment planning process (Beam Modelling)

**Optimization approaches-Entry point**

- Choice of best beam angle
- Use of a beam modifier, compensator, …
3-D-Treatment planning process (Beam Modelling)

Optimization approaches: Beam number and weighting
3-D-Treatment planning process (Beam Modelling)

Optimization approaches - use of wedges

- Wedged pair
- Three field techniques

Patient

Isodose lines

Typical isodose lines
3-D-Treatment planning process (Beam Modelling)
Combination of photons and electrons

Optimization criterion - Radiation type
3-D-Treatment planning process (Beam Modelling)

Combination of photons and electrons

**Optimization criterion - Radiation type**

Breast
3-D-Treatment planning process (Beam Modelling)

Optimization criterion - field number

2 opposite fields

2 wedged fields
3-D-Treatment planning process (Beam Modelling)

Optimization criterion - field number

3 fields

Rotational irradiation
3-D-Treatment planning process (Beam Modelling)

5 Felder non-coplanar

transversal

sagital
3-D-Treatment planning process (Dose Distribution criteria)

Radiotherapy - Spatial dose distribution

Criteria of a uniform dose distribution within the target

- Recommendations regarding dose uniformity, prescribing, recording, and reporting photon beam therapy are set forth by the International Commission on Radiation Units and Measurements (ICRU).

- The ICRU report 50 recommends a target dose uniformity within +7% and −5% relative to the dose delivered to a well defined prescription point within the target.

- The limits of the tolerance doses for the organs at risks are given in the next slide.
## Tolerance doses in Gy (Emami et al.)

<table>
<thead>
<tr>
<th>Organ</th>
<th>Volume part</th>
<th>TD&lt;sub&gt;5/5&lt;/sub&gt; 1/3</th>
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<tr>
<td>Parotiden</td>
<td>32&lt;sup&gt;a&lt;/sup&gt;</td>
<td>32&lt;sup&gt;a&lt;/sup&gt;</td>
<td>46&lt;sup&gt;a&lt;/sup&gt;</td>
<td>46&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Xerostomie</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rectum</td>
<td>Volume: 100 cm³</td>
<td>60</td>
<td>Volume: 100 cm³</td>
<td>80</td>
<td>Proktitis, Stenose, Nekrose, Fistel</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Retina (I+II)</td>
<td>no Volume effect</td>
<td>45</td>
<td>no Volume effect</td>
<td>65</td>
<td>Blindness</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rippen</td>
<td>50</td>
<td>65</td>
<td>Pathologische Fraktur</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spinal Chord</td>
<td>5 cm: 50</td>
<td>10 cm: 50</td>
<td>20 cm: 47</td>
<td>5 cm: 70</td>
<td>10 cm: 70</td>
<td>20 cm: -</td>
<td>Myelopathie, Nekrose</td>
<td></td>
</tr>
<tr>
<td>Optic Nerve, Retinae (I+II)</td>
<td>no Volume effect</td>
<td>50</td>
<td>no Volume effect</td>
<td>65</td>
<td>Blindness</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3-D-Treatment planning process (Optimized dose Distribution)

Fixing of the treatment position (positioning, immobilization)

- MRT
- CT
- PET
- SPECT

Fusion

Contouring

Setting of the radiation fields
virtual simulation

Optimization of the dose distribution

Evaluation

3-D-Treatment plan

Example: Optimized dose distribution in larynx Ca.
3-D-Treatment planning process (Dose Volume Histogram)

- Fixing of the treatment position (positioning, immobilization)
- MRT, CT, PET, SPECT
- Fusion
- Contouring
- Setting of the radiation fields
- Virtual simulation
- Optimization of the dose distribution
- Evaluation
- 3-D-Treatment plan

Example: Evaluation (DVH) in Larynx Ca
3-D-Treatment planning process (Dose Volume Histogram)

The ideal DVH

- **Tumour:**
  - High dose to all
  - Homogenous dose

- **Critical organ**
  - Low dose to most of the structure
3-D-Treatment planning process (Dose Volume Histogram)

Comparison of three different treatment techniques (red, blue and green) in terms of dose to the target and a critical structure.

- **Volume (%)**
- **Dose (Gy)**

Critical organ

Target dose
3-D-Treatment planning process (Dose Distribution examples)

Examples: Malignant tumors such as: Mamma ca., Bronchial ca., Prostate ca., Rectum ca., Larynx ca., Metastasis, Sarcomas, lymphomas, ...
3-D-Treatment planning process (DRRs)

Digitally reconstructed radiographs (DRRs)

- Computer generated virtual images
- Requires patient CT dataset
- Choice of image quality - diagnostic or therapy type image
- Depends significantly on the number of CT slices available
- Important to compare with the verification
3-D-Treatment planning process (DRRs)

DRRs can mimic any geometry

- Divergent beams
- 3D
- Dose images

Here: Case Prostate
3-D-Treatment planning process (Simulation)

- Fixing of the treatment position (positioning, immobilization)
- MRT, CT, PET, SPECT
- Fusion
- Contouring
- Setting of the radiation fields
- Virtual simulation
- Optimization of the dose distribution
- Evaluation
- 3-D-Treatment plan

Example: DRR of 0° in Larynx Ca.
3-D-Treatment planning process (Verification System)

Fixing of the treatment position (positioning, immobilization)

MRT  CT  PET  SPECT

Fusion

Contouring

Setting of the radiation fields virtual simulation

Optimization of the dose distribution

Evaluation

3-D-Treatment plan

Simulation

Radiotherapy information system

Evaluation

3-D-Treatment plan
3-D-Treatment planning process (Positionning on LINAC table)

- Fixing of the treatment position (positioning, immobilization)
- Simulation
  - MRT, CT, PET, SPECT
  - Fusion
  - Contouring
  - Setting of the radiation fields virtual simulation
  - Optimization of the dose distribution
  - Evaluation
  - Reproducibility of positioning and settings on the linear accelerator from fraction to fraction
- Radiotherapy information system
- 3-D-Treatment plan
3-D-Treatment planning process (Positionning on LINAC table)

- The patient is usually positioned on skin markers or on anatomical reference points.
- With stationary lasers, the positioning of the head and neck is easier and more often reproducible than in the pelvic area or by obese patients.

- A stable and reproducible patient positioning is necessarily required.
  - Use of thermoplastic masks or other positioning aids.
3-D-Treatment planning process (Image Field Control)

Fixing of the treatment position (positioning, immobilization)

MRT  CT  PET  SPECT

Fusion

Contouring

Setting of the radiation fields virtual simulation

Optimization of the dose distribution

Evaluation

3-D-Treatment plan

Simulation

Radiotherapy information system

Reproducibility of positioning and settings on the Linear accelerator from fraction to fraction

Image field control
3-D-Treatment planning process (Image Field Control)

- The positioning uncertainty can be checked by comparing simulation / DRR images from the CT simulation with direct multiple acquisition of the field in use.

- Computer-based video systems are available with versatile software support.
3-D-Treatment planning process (DRRs)

Radiotherapy example Breast-Ca.

DRR

Simulation

Verification

Breast-Ca. on the left o.a. pT1c pN1biii (7/15) G2 L1 V0
3-D-Treatment planning process (Image Field Control)

- Fixing of the treatment position (positioning, immobilization)
- MRT, CT, PET, SPECT
- Fusion
- Contouring
- Setting of the radiation fields
  - virtual simulation
  - Optimization of the dose distribution
  - Evaluation
  - 3-D-Treatment plan
- Reproducibility of positioning and settings on the linear accelerator from fraction to fraction
- Image field control
- Radiotherapy
3-D-Treatment planning process (uncertainties)

- Random uncertainties
- Small variations in the positioning of the patient from day to day
  - Setting of the iso-centre
  - Breathing
  - Intestinal peristalsis
  - Different bladder, bowel and stomach fillings lead to internal organ motion and organ deformation
- Systematic uncertainties
- Delineation of target volumes
- A snapshot of the shape and position of the organs in the treatment planning CT
  - Changes in position of adjacent structures with a dotting of pleural effusion or seroma
  - Bladder and bowel movements lead to breathing or fillings position and deformation of organs
- Deviations in the transmission of geometrical data to the therapy simulator or directly to the irradiation device
3-D-Treatment planning process
(Documentation/Archive)

- All documents relating to the implementation of radiotherapy must be kept for 30 years.
- The radiation treatment and the decisions must be transparent.
- Recordings include the duration and timing of radiotherapy, the dose to the target volume, localization and delineation of the radiation fields, setting parameters, setting of protection against scattered radiation.

[Diagram showing documents being transferred from electronic to printed format]
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Thanks for your Attention