Uncertainties in the evaluation of treatment plans

T Knöös\textsuperscript{1,2}, H Benedek\textsuperscript{1}, C Ceberg\textsuperscript{1,2}, P Nilsson\textsuperscript{1,2}, and K Petersson\textsuperscript{2}

\textsuperscript{1)Radiation Physics, Skåne University Hospital and Lund University}

\textsuperscript{2)Medical Radiation Physics, Clinical Sciences, Lund University, Lund, Sweden}
Our problem

- Fast technological development
- New innovations
- Wide range of modalities or choices
  - 3D-CRT
  - IMRT
  - Rotational techniques
    - Helical tomotherapy
    - VMAT
  - Robotical systems
    - Cyberknife
  - Etc…
Our problem

- Fast technological development
- New innovations

How to evaluate and select a plan for a specific patient?

- Helical tomotherapy
- VMAT
- Robotical systems
  - Cyberknife
- Etc…
Remember also how these modalities are applied

by different

- Beam configuration
- Prescription priorities
- Other modality options

by different

- Users
  - planners/doctors/physicist…
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What we need?

- Tools to **evaluate and compare** the relative merits of plans from all these different modern treatment modalities

- Tools are needed to **select the proper treatment plan for an individual patient**

- These tools should also ensure that the department’s **resources are utilized in an efficient manner**, without compromising treatment quality and patient safety.

- For all purposes, it is important that the results of such comparisons are **not biased**
  - due to limitations or uncertainties of the evaluation method itself
  - **OR BY THE USER**
Evaluation of treatment plans

- A treatment plan can only be judged by how well it fulfils the prescription.
- The evaluation is therefore related to the statement of the treatment objectives.
  - Includes also the estimation of any limitations and uncertainties.
Evaluation of treatment plans

Choice of evaluation parameters

Formulation of treatment objectives

What you see is *not* what you get
Evaluation of treatment plans

What you see is not what you get

Choice of evaluation parameters

Formulation of treatment objectives
Which plan?

Morales-Paliza et al 2011
Which plan?

IMRT  Dyn Arc  3DCRT

Dose distribution → Dose Volume Histograms, DVH

Morales-Paliza et al 2011
Compile and use DVHs!

PTV (Prostate)  Bladder  Rectum  Left femoral head

Morales-Paliza et al 2011

 AAPM Summer School 2011
Spatial information is lost!

- Thorough review of the dose distribution for the whole volume
  - In all available 2D sections
- Hot-spots can appear where you least expect them
- Only a thorough review of the entire plan can show the location of minima and maxima, which can be important information for the RO
An example from Universitair Ziekenhuis Brussel

Patient treated for liver met

Images courtesy of Michael Duchateau
Accidental contouring
Accidental contouring

Images courtesy of Michael Duchateau
The resulting plan
Small volumes not revealed in DVHs

Images courtesy of Michael Duchateau

2011-August

AAPM Summer School 2011
What measures should be used for condensing DVH?

- $D_V$ – absorbed dose in fraction V of the volume of interest
- $V_D$ – volume receiving at least an absorbed dose of D
- Specific for the target volumes
  - Average dose – $D_{avg}$
  - Median dose – $D_{50\%}$
  - Near minimum dose – $D_{98\%}$
  - Near maximum dose – $D_{2\%}$.
- Usually one also derives “quality” indices
  - Homogeneity index – HI
  - Conformity index – CI
  - Standard deviation
- Some of these metrics are also applied for organs at risk
Treatment plans can also be evaluated by biological metrics

- TCP, NTCP and EUD.

- The uncertainty in the biological models and parameters adds to the dosimetric physical uncertainty discussed above

(See the QUANTEC reports, referring to the session during AAPM 2011)
Example of parameter influence

From ICRU 83

AAPM Summer School 2011
Awareness of normalization

The ICRU point dose for 200 prostate cases when normalized to the median dose in the PTV
Choice of evaluation parameters

- Different dose-volume parameters do not correlate

- Evaluation parameters should be based on the treatment objectives

Two DVHs can have the same average dose, but very different maximum doses. Or, the other way around, two DVHs can have the same maximum dose, but very different average doses.
Evaluation of treatment plans

What you see is not what you get

Choice of evaluation parameters

Formulation of treatment objectives

What you see is not what you get
Treatment objectives

- Specific treatment objectives
  - A necessity for an adequate evaluation of a treatment plan

- Priority
  - Regarding the relative weighting of the different treatment objectives
Dosimetry guidelines

- **Dose constraints – PTV**
  - 66-68 Gy /33-34 fractions to macroscopic tumor
  - 66 Gy to microscopic disease
  - 60-66 Gy to volumes of high risk
  - 46-50 Gy at elective lymph nodes

- **Volume constraint – PTV**
  - Minimum dose – 95%
  - Maximum dose – 107%

- **Organs at risk (OR, PRV)**

<table>
<thead>
<tr>
<th>Organ</th>
<th>OR</th>
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<tr>
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<td>45 Gy</td>
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<tr>
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<td>60 Gy</td>
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</tr>
<tr>
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<td>bagerste del af øjet</td>
<td>45 Gy</td>
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From a Scandinavian trial - DAHANCA
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From a Scandinavian trial - DAHANCA
Priority - YES

1st priority
• Critical normal tissue:
  ▪ Medulla
  ▪ Brain stem
  ▪ Chiasma opticum
  ▪ N. opticus
  ▪ Dorsal part of the eye for the “best” eye

2nd priority
• Cover of PTV
  ▪ PTV-T
  ▪ PTV-E-high risk
  ▪ PTV-E-low risk

3rd priority
• Less critical normal tissue
  ▪ Inner ear
  ▪ Gl. Parotis
  ▪ Larynx
  ▪ Frontal part of the eye

From a Scandinavian trial - DAHANCA

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Another example with a detailed and prioritized dose prescription

<table>
<thead>
<tr>
<th>Priority</th>
<th>Volume</th>
<th>Objective or constraint</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>CTV</td>
<td>(D_{\text{min}} \geq 95%), (D_{\text{min}} \geq 74 \text{ Gy})</td>
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<tr>
<td>2</td>
<td>PTV</td>
<td>(V_{95%} \geq 95%), (V_{74\text{Gy}} \geq 95%)</td>
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<tr>
<td>3</td>
<td>Rectum</td>
<td>(V_{90%} \leq 15%), (V_{70\text{Gy}} \leq 15%)</td>
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<tr>
<td>4</td>
<td>PTV</td>
<td>(D_{99%} \geq 90%), (D_{99%} \geq 70 \text{ Gy})</td>
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<tr>
<td>5</td>
<td>Rectum</td>
<td>(V_{75%} \leq 35%), (V_{59\text{Gy}} \leq 35%)</td>
</tr>
<tr>
<td>6</td>
<td>Femoral heads</td>
<td>(D_{\text{max}} \leq 70%), (D_{\text{max}} \leq 55 \text{ Gy})</td>
</tr>
<tr>
<td>7</td>
<td>Rectum</td>
<td>(V_{65%} \leq 45%), (V_{51\text{Gy}} \leq 45%)</td>
</tr>
<tr>
<td>8</td>
<td>Body</td>
<td>(D_{\text{max}} \leq 105%), (D_{\text{max}} \leq 82 \text{ Gy})</td>
</tr>
</tbody>
</table>

From a Scandinavian Prostate Study
Are the objectives appropriate?

Any region that is not explicitly constrained may be used by the optimizer, and this may give unexpected results. As for instance in this case, where a hot spot has appeared in the brain stem.

From Per Engström
Do we need constraints for normal tissue?

Difference dose distribution for treatment plans optimized with or without normal tissue constraints.

Treatment objectives should be specific and complete; in principle they cannot be too detailed.
The dilemma!

- We usually have mutually conflicting objectives
  - **Under** dosage of PTV – adequate dose to tumour
  - vs
  - **Over** dosage of OR – spare the healthy tissues

- Choose the “best” plan
From the same prescription…

1. A plan that emphasizes good target coverage, while letting the dose to the risk organ increase slightly

2. A plan that emphasizes a low dose to the risk organ, but then at the expense of less target coverage

Relative importance of the conflicting objectives is seldom BUT SHOULD BE described in protocols
Pareto optimal plans in multi objective optimisation

Ottosson et al 2008
Pareto optimal plans in multi objective optimisation

Under dosage of PTV
100-Min(PTV)

Average dose of parotids
Pareto optimal plans in multi objective optimisation

Based on a paper by Hoffman et al 2006
Ambiguity in comparisons of treatment modalities

IMRT vs. helical tomotherapy for a head-&-neck cancer case

From Benedek et al., 10th biennial ESTRO, 2009
Another example

Anal cancer, with sparing of the small bowels (OMP)

Comparisons between different systems based on single plans are at best unfair, but also that it may be grossly misleading, see any paper comparing modalities

From Hunor Benedek
Uncertainty – have we achieved as good plan as possible?

Different planners may work differently.
Evaluation of treatment plans

What you see is not what you get

Choice of evaluation parameters

Formulation of treatment objectives
What do we deliver?

Patient
- Immobilization
- Intra and inter motion

Models
- Dose calculation algorithms
- Optimization
  - System/process
  - Algorithm

Delivery system
- Stability
- Accuracy and precision
What do we deliver?

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What do we deliver?

- Immobilization
- Dose calculation algorithms
- Optimization system – process
- Stability
- Accuracy and precision

What You See Is NOT What You Get

- Stability
- Accuracy and precision
Driving optimization to far…

Intensity modulation of one field

...will undoubtedly lead to jagged intensity patterns and deterioration of the final plan quality.

Optimal fluence

After MLC sequencer

Carlsson and Forsgren Med Phys 2006
Do we really deliver?

The average QC results with a Delta4 detector, (3%/3mm). The error bars are 1 standard deviation.

Pareto sets for two different collimator angles. The plans have increasing OAR weights from left to right. It is clear that the 45-degree plans are slightly better than the 5-degree plans, with higher PTV coverage and less dose to the small bowel.

From Benedek et al, 2011, Poster at AAPM 2011
Better is best?

The study illustrates the potential danger of image guidance techniques to create a false sense of confidence as to possible margin reduction around the CTV.
Adaptive radiotherapy

Should we cone down or not when we see tumour shrinkage???

Graphics from Matthias Guckenberger
Dose calculation

Type a

Type b

Knöös et al 2006 PMB

AAPM Summer School 2011
## Dose calculation

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<th>18X Type a</th>
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<td>Max</td>
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<td>104.3</td>
<td>95.9</td>
</tr>
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**PTV dose**

**Lung dose**

Knöös et al 2006 PMB
Summary

- Evaluation of treatment plans depends on treatment objectives

- Ensuring that treatment objectives are
  - Specific
  - Measurable
  - Attainable

- may help avoiding pitfalls in comparing dose distributions for Radio-Therapy
Summary

- Evaluation of treatment plans depends on treatment objectives.
- Ensuring that treatment objectives are:
  - Specific
  - Measurable
  - Attainable

- May help avoiding pitfalls in comparing dose distributions for Radio-Therapy.
Remember
The plan to choose is the one that do NOT decrease the outcome for the specific patient
Thanks - The Lund Team