Communication of Uncertainties in Radiation Therapy

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Disclosure

The Netherlands Cancer Institute – Antoni van Leeuwenhoek Hospital has a research cooperation with Elekta concerning the development of cone-beam CT and EPID dosimetry software

Communication of Uncertainties in Radiation Therapy

Learning objective: To describe methods of uncertainty communication and display
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• in target volume delineation
• in treatment planning
• in treatment delivery
Radiation oncologist to physicist: What dose will this patient receive?

Physicist: 60 Gy with an uncertainty of ±3.5%
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Radiation oncologist to physicist: What dose will this patient receive?
Physicist: 60 Gy with an uncertainty of ±3.5%
Radiation oncologist: I don’t want any uncertainty, just 60 Gy to the target volume

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• in target volume delineation

Intra- and inter-observer variability in contouring on CT

(Leunens et al., Radiat Ther Oncol 29: 169, 1993)
Delineation variation: CT versus CT + PET

CT (T2N2)  CT + PET (T2N1)
SD 7.5 mm  SD 3.5 mm
(Steenbakkers et al., IJROBP, 64, 435-448, 2006)

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Delineation variation: CT versus MRI and PET

Delineation of a GTV can vary according to the diagnostic modality (From ICRU Report 83)
What can be done to reduce target delineation variation?

- A correct identification of the macroscopic extension of a tumour requires a long training of a radiation oncologist, and an awareness of the specific abilities of a given imaging method
- Image quality plays also an important role (slice thickness, patient motion during acquisition, equipment characteristics...)
- Medical physicists and radiation oncologists should communicate about the possibilities and limitations of the various imaging tools available in their department
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- in target volume delineation
- in treatment planning

Comparison of isodose distributions

Clinical implementation of a more advanced dose calculation algorithm

- When introducing a more advanced (type b) dose calculation algorithm, e.g. convolution-superposition, instead of a (type a), e.g. pencil-beam algorithm, considerable lower dose in the PTV and a somewhat higher dose in most of the lung becomes visible for the same beam setup and number of MUs
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• Recalculate some old plans with the new algorithm for various approaches; e.g., coverage of the PTV by 95% (i.e., using larger field sizes) or by 90% at the lung side.

• Optimize plans for the same constraints on PTV and/or OAR (lung) using the new approaches.

Discussion is needed between physicists and radiation oncologists to fully understand the differences when introducing a more advanced dose calculation algorithm.

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Effect of type of geometric uncertainty on dose in the CTV

CTV to PTV margin recipes

To cover 99% of the CTV with 90% of the specified dose:

\[ \text{PTV margin} = 2.0 \Sigma + 0.7 \sigma \]  
(Stroom et al., 1999)

To cover the CTV for 90% of the patients within the 95% isodose surface:

\[ \text{PTV margin} = 2.5 \Sigma + 0.7 \sigma \]  
(van Herk et al., 2000)

\( \Sigma = \text{SD of all systematic uncertainties combined quadratically} \)

\( \sigma = \text{SD of all random uncertainties combined quadratically} \)
PTV margins

- CTV-PTV margin recipes are population based and do not cover the CTV in all patients.
- PTV margins are designed to cover geometrical uncertainties, but they should also cover microscopic disease.
- When using a GTV-CTV margin, there still is a finite chance that some patients of a population of "identical" patients have a microscopic extension outside this margin.
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- CTV-PTV margin recipes are population based and do not cover the CTV in all patients
- PTV margins are designed to cover geometrical uncertainties, but not to cover microscopic extension
- When using a GTV-CTV margin, there is still a finite chance that some patients have a microscopic extension outside this margin
- Reducing margins after introducing IGRT may therefore lead to poorer outcome and should be done with utmost care

Discuss margins with the whole team!

Probabilistic treatment planning

- The PTV is a surrogate for estimating the position of the CTV
- Probabilistic treatment planning uses modeling of all geometric uncertainties in the position of the CTV and provides assessment of the most likely dose distribution, e.g. the 90% probability of a minimum dose in the CTV
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- A (Monte Carlo) mathematical model is often employed to simulate and evaluate many possible treatments

**Results of probabilistic treatment planning of 56 prostate VMAT treatments**

- Stars: Minimum dose in PTV from TPS (Dplan)
- Circles: Minimum dose in CTV from probabilistic planning (Dexpected)
- Delivered dose: Actual dose recalculated from CBCT data

Probabilistic treatment planning leads to a better prediction of the delivered dose compared to conventional planning

- Probabilistic treatment planning is still a research tool; commercial software is not (yet) available
Probabilistic treatment planning

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- Patient-specific evaluation is performed, but based on population-based $\Sigma$ and $\sigma$ values

Another approach: worst case scenario

- Instead of using a population-based uncertainty calculation, every single case is evaluated separately
- If the variation in the PTV/OAR position in the beginning of a specific patient treatment is known, design a worst case scenario to decide if the treatment can be continued

Example:
- Lung cancer treatment using 24x 2.75Gy on the lymph nodes and 3x18Gy on the tumor in the second week
- Measure the first week with CBCT the change in relative position of the tumor and the lymph nodes
- Generate a worst case plan
- Discuss with the radiation oncologist if the dose in the OARs (PRVs) is still acceptable
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Hybrid plan of a lung cancer treatment
3x18Gy on tumor and 24x2.75Gy on lymph nodes

No shift

5 mm shift of tumor relative to lymph nodes
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- Example:
  - Lung cancer treatment using 24x2.75Gy on the lymph nodes and 3x18Gy on the tumor in the second week.
  - Measure the first week with CBCT the change in relative position of the tumor and the lymph nodes.
  - Generate a worst case plan.
  - The dosimetrist and/or physicist should discuss with the radiation oncologist if the dose in the OAR(s) is still acceptable.

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- In treatment delivery.

EPID-based in vivo 3D dose verification using a back-projection model

1) Calculate plan
2) Measure EPID dose
3) Reconstruct dose in multiple planes
4) Compare planned and reconstructed 3D dose distribution.
Lung step & shoot IMRT:

**EPID DOSIMETRY REPORT**

Patient name: [redacted]
Medical Record No.: [redacted]
Plan UPI: [redacted]

**Automatic classification**

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Fully automated dosimetry report generation showing results of 3D gamma evaluation and the dose at the isocenter.

Lung step & shoot IMRT: recovery from atelectasis

Based on the in vivo dosimetry and CBCT result the physicist and radiation oncologist should discuss if replanning is necessary.

Anatomical changes during a series of patient treatments: the traffic light protocol

- Uncertainties in dose delivery arise when anatomical changes, such as contour variation, tumor shrinkage or tumor growth, occur during the course of a treatment.
Anatomical changes during a series of patient treatments: the traffic light protocol

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• CBCT scans are often made to verify and correct patient setup.

• The information available in a CBCT scan can also be used to observe and quantify changes in anatomy.

• By using a “traffic light protocol” therapists contact radiation oncologists depending on the severity of change.
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| Action level 1 | Action before next fraction | Communication by telephone |
| Action level 2 | No immediate action | Communication by email |
| Action level 3 | No action | Communication by email |

Dosimetric effects of weight loss or gain during IMRT and VMAT for prostate cancer

The target mean dose, decreased or increased by 2.9% per 1-cm SSD decrease or increase in IMRT and by 3.6% in VMAT.

(Pair et al., Medical Dosimetry 38, 251–254, 2013)
Final remarks

• Reducing uncertainties in radiation therapy needs the expertise from radiation oncologists, physicists, dosimetrists and therapists

• Talk to each other and discuss all (difficult) cases

• Be pragmatic; the vast majority of our treatments are “correctly” delivered if a comprehensive QA program is performed
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• Talk to each other and discuss all (difficult) cases

• Be pragmatic: the vast majority of our treatments are “correctly” delivered if a comprehensive QA program is performed

• The challenge is to select those cases where knowledge of the uncertainty is of paramount importance for the optimal treatment of that particular patient

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