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Dose Uncertainty Modeling

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Special acknowledgement: Hosang Jin PhD

Disclosure

- Vice-President, Center for the Assessment of Radiological Sciences
  - A non-profit organization with a goal of improving quality and safety of imaging and radiotherapy

Objectives

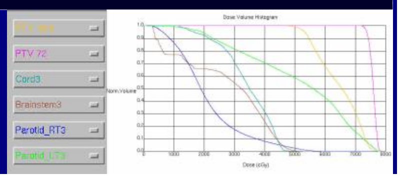
The objective of this presentation is to suggest simple strategies that may potentially change "WYSINWYG" to "WYSIWYG"

WYSINWYG - "What You See Is Not What You Get"
WYSIWYG – "What You See Is What You Get"

Modified from the acronym WYSIWYG, coined by R Mohan (2008)

IMRT Treatment Plan Documentation

Transverse, coronal, and sagittal dose distribution through the isocenter



Dosimetric Uncertainties

(95% confidence level)

- Combined incertainty in dose to a patient **(5%)**
  - Cumulative uncertainty in dose delivered to a tissue-phantom **(2.5%)**
  - Uncertainty in the treatment planning compuation of dose a to a patient **(4.2%)**
    - Effect on dose computation of tumor localization and contour delineation **(2%; 5 mm accuracy)**
    - Computation of relative dose dose distribution (without heterogeneity) **(3%)**
    - Central axis factors for beam modifiers **(2%)**

AAPM Report #13

Spatial Uncertainties

(95% confidence level)

- Spatial uncertainty from machine and patient motion **(9 mm)**
  - Displacement due to mechanical inaccuracies **(4 mm)**
    - Isocentric accuracy **(2mm)**
    - Radiation field **(2mm)**
    - Jaw accuracy **(2mm)**
    - Radiation Isocenter **(2mm)**
  - Positional errors due to patient or organ motion **(8 mm)**
    - Setup error **(6mm)**
    - Breathing motion **(4mm)**
    - Organ motion (4mm)

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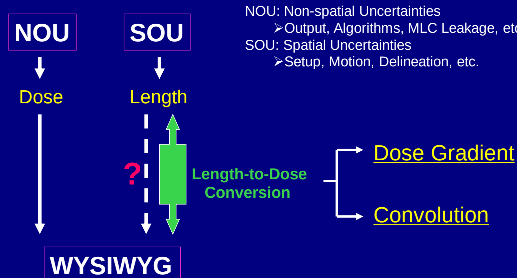
IMRT Treatment Plan Documentation

Expect that PTV and PRV are sufficiently large to deliver the prescribed dose to CTV and spare OAR respectively

Representing Uncertainty

NOU: Non-spatial Uncertainties
➢Output, Algorithms, MLC Leakage, etc
SOU: Spatial Uncertainties
➢Setup, Motion, Delineation, etc.



A Simple Dose Uncertainty Model

Potential Uncertainty – Information that was forgotten

Siyong Kim[1], Hosang Jin[1], Heeteak Chung[1], Jatinder Palta[1] and Sung-Joon Ye[2]

Kim et al. 2004

A novel dose uncertainty model and its application for dose verification

Hosang Jin and Heetaek Chung
Department of Nuclear and Radiological Engineering, University of Florida, Gainesville, Florida 32610
Chihray Liu and Jatinder Palta
Department of Radiation Oncology, University of Florida, Gainesville, Florida 32610
Tae-Suk Suh
Department of Biomedical Engineering, Catholic Medical University, Korea
Siyong Kim[a)]
Department of Radiation Oncology, University of Florida, Gainesville, Florida 32610

Jin et al. 2005

Assumptions

Dose Uncertainty

$(\sigma^2 = \sigma_{ns}^{\ 2} + \sigma_s^{\ 2})$

Spatial

proportional to the gradient of Dose

$$\sigma_s = \left|\vec{G}(\vec{r}) \bullet \Delta\vec{r}\right| (cGy)$$

Space oriented dose uncertainty at point, *r*

Dose gradient at *r*

SD of spatial displacement at *r*

Non-spatial

Relative uncertainty is inversely proportional to the level of Dose

$$\sigma_{ns} = \sigma_{r_o} \sqrt{D\ D_o}\,(cGy)$$

Convolution Method

Implementation of random positioning error in computerised radiation treatment planning systems as a result of fractionation

Joseph Leong

Division of Radiation Biophysics, Department of Radiation Medicine, Massachusetts General Hospital and Harvard Medical School, Boston, MA, USA

Leong 1987

Expected Dose = Dose ⊗ Spatial Probability Density Function

Application of Convolution Method - Margin Determination

Target margins for random geometrical treatment uncertainties in conformal radiotherapy

A. Bel,[a] M. van Herk, and J. V. Lebesque

Netherlands Cancer Institute, Antoni van Leeuwenhoek Huis, Plesmanlaan 121, 1066 CX Amsterdam, The Netherlands

Bell et al. 1996

INCLUSION OF GEOMETRICAL UNCERTAINTIES IN RADIOTHERAPY TREATMENT PLANNING BY MEANS OF COVERAGE PROBABILITY

Joep C. Stroom, M.Sc.,* Hans C. J. de Boer, M.Sc.,* Henk Huizenga, Ph.D.,† and Andries G. Visser, Ph.D.*

*University Hospital Rotterdam, Daniel den Hoed Cancer Center, Department of Clinical Physics, Rotterdam, The Netherlands; and †University of Nijmegen, Institute of Radiotherapy, Nijmegen, The Netherlands

Stroom et al. 1999

THE PROBABILITY OF CORRECT TARGET DOSAGE: DOSE-POPULATION HISTOGRAMS FOR DERIVING TREATMENT MARGINS IN RADIOTHERAPY

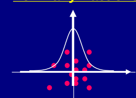
Marcel van Herk, Ph.D., Peter Remeijer, Ph.D., Coen Rasch, M.D., and Joos V. Lebesque, M.D., Ph.D.

Radiotherapy Department, The Netherlands Cancer Institute/Antoni van Leeuwenhoek Huis, Amsterdam, The Netherlands

van Herk et al. 2000

Geometric Errors

For many fractions

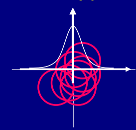


Gaussian

Random errors (treatment execution errors)
= day-to-day variations
= lead to a blurring of dose distribution
= denoted with σ

Please note that some treatment execution errors can also be systematic

For many patients



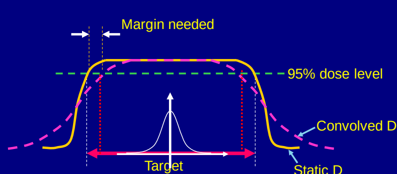
Systematic errors (preparation errors)
= systematic for a single radiotherapy course of a single patient, but stochastic over a group of patients (i.e., for a patient population)
= lead to a displacement of the dose distribution with respect to the target (CTV)
= denoted with Σ

Margin for Random Errors

Target margins for random geometrical treatment uncertainties in conformal radiotherapy

A. Bel,[a] M. van Herk, and J. V. Lebesque
Netherlands Cancer Institute, Antoni van Leeuwenhoek Huis, Plesmanlaan 121, 1066 CX Amsterdam, The Netherlands

Bell et al. 1996



Margin ≈ 0.7 σ

Margin for Systematic Errors

INCLUSION OF GEOMETRICAL UNCERTAINTIES IN RADIOTHERAPY TREATMENT PLANNING BY MEANS OF COVERAGE PROBABILITY

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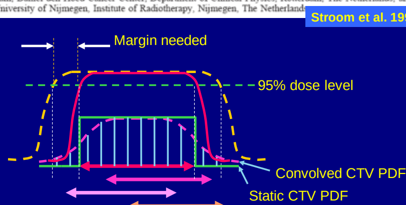
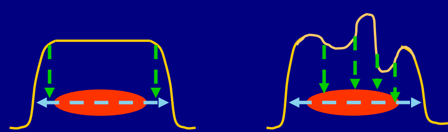
Stroom et al. 1999



Coverage Probability (CP)
– probability for each point to be covered (occupied) by the CTV

Conventional Conformal vs. IMRT



Dose Uncertainty at each point?

Dose Uncertainty Model

$$D_{actual}(r) = \overline{D_{cal}}(r) \pm \left|\overline{I}(r) + Z \cdot \sigma_{total}(r)\right|$$

Overall dose uncertainty

Planning

Inherent uncertainty ($I(r)$)

- **Grid size effect** ($I_{grid}(r)$)
- **Algorithm effect** ($I_{algo}(r)$)
- **Off-axis effect** ($m_{oa}(r)$)

Delivery

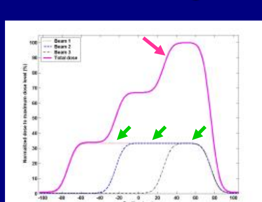
Statistical uncertainty ($\sigma_{total}(r)$)

- **Space-oriented Uncertainty (SOU; σ_{SOU})**
- **Non-space-oriented Uncertainty (NOU; σ_{NOU})**

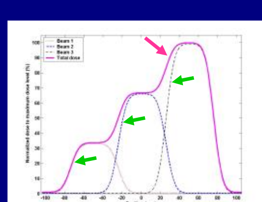
Jin *et. al.* Med. Phys. 35, 2008

1-D IMRT Simulation

3-Segmented IMRT Field

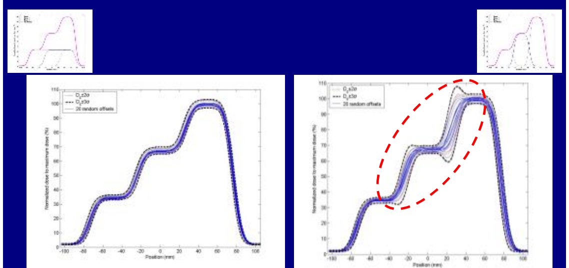


Beam set 1
Different beam width
Same beam fluence



Beam set 2
Same beam width
Different beam fluence

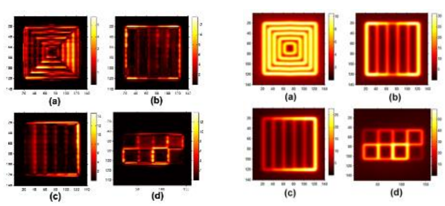
Results (1-D: 3 IMRT Beam Fields)



Beam set 1
Different beam widths
Same beam fluences

Beam set 2
Same beam widths
Different beam fluences

Uncertainty Model Validation



Dose difference distribution between calculation and measurement

Overall dose uncertainty of 95.4% confidence level

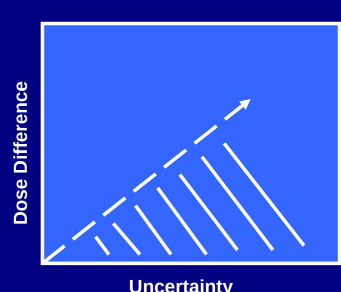
(a) pyramid, (b) valley, (c) wedge, (d) checkerboard

All dose difference points in the test patterns were contained within the overall dose uncertainty distribution of 95.4%

Jin *et. al.* Med. Phys. 35, 2008

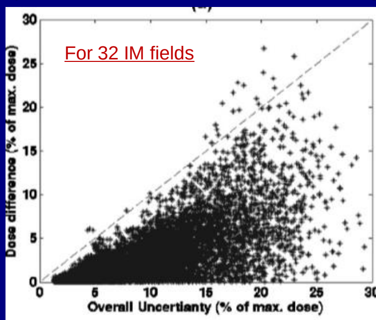
Verification

(Dose Difference vs. Predicted Uncertainty)



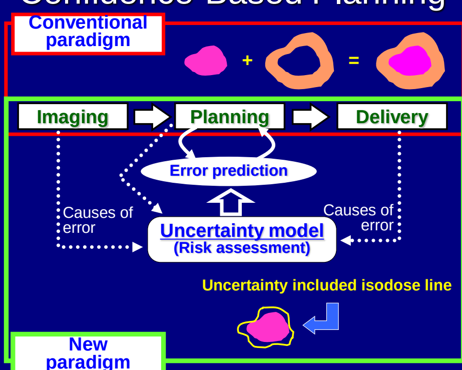
Verification

(Dose Difference vs. Predicted Uncertainty)



Jin *et al*. Med Phys., 35(3), pp 982-996, 2008

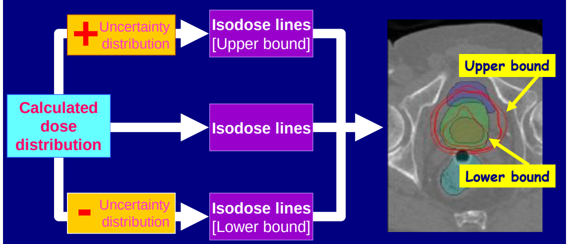
Confidence-Based Planning



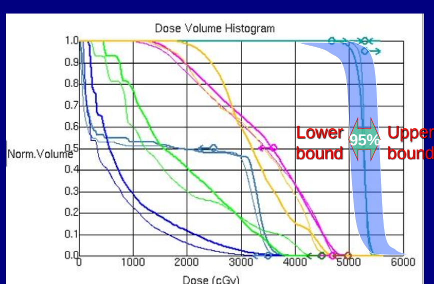
Confidence-Based Planning Evaluation Tools

- **CW-DVH**
  Confidence-weighted dose volume histogram
- **CWDD**
  Confidence-weighted dose distribution
- **DUVH**
  Dose uncertainty volume histogram

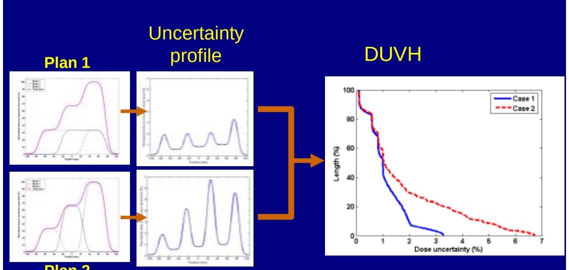
Confidence-weighted dose distribution (CWDD)



Confidence-weighted dose volume histogram (CW-DVH)



Dose Uncertainty Volume Histogram (DUVH)



Summary

- Each step of the radiation therapy process has spatial and dosimetric uncertainties, which can be quantified for each treatment protocol and possibly for each patient.
- Uncertainties arise in 4 stages:
  - 1) treatment planning,
  - 2) patient setup (including inter-fractional motion),
  - 3) treatment delivery system, and
  - 4) patient intra-fractional motion (including deformation).
    - uncertainties from patient intrafractional motion and deformation are temporally variant and are both patient and disease-site specific.

Summary

- Spatial uncertainty can be converted to dose uncertainty with acceptable accuracy,
- *A priori* knowledge of potential uncertainties in the form of an uncertainty map in conjunction with the conventional dose distributions provide an opportunity to evaluate comparative plans and select one that satisfies all planning goals with the most accurate dose delivery to patients.