ICRU 83
Prescribing, Recording and Reporting Photon Beam IMRT

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ICRU Reports – A Brief History
Path from 3-D CRT to IMRT

New considerations are needed due to the “extraordinary control over the 3D absorbed dose distributions” and the accompanying “steep dose gradients”

- More availability of CT
- Additional imaging – CT + MRI, PET, PET/CT, functional imaging
- Improved conformality
- Reduced doses to normal tissues
- Adoption of detailed **DVH** for dose specification is **essential**
- Dose @ point is retained only for historical & comparative purposes
- Automated optimization, IMRT
1. Introduction

2. Optimized Treatment Planning for IMRT

3. Prescribing and Reporting in IMRT – Absorbed Dose and DVH

4. Definition of Volumes

5. Planning Aims, Prescription & Technical Data

Appendix

A. Physical Aspects of IMRT

B. Clinical Examples
   B.1 SCC of the Larynx
   B.2 Squamous-Cell Carcinoma of the Lung
   B.3 Adenocarcinoma of the Prostate
2-D era

“Target volume” & uniform prescription concepts
- Single slice (or few)
- Dose prescription to “ICRU reference point”
- External contour
- Coplanar beams
- Simple calculations
Specification of volume(s) & dose(s)
For prescription, recording, reporting

Purpose
• Consistent treatment policy
• Compare results of treatment - departmental colleagues
• Enable other radiation oncologists to benefit from department’s experience
• Enable department’s treatment results to be compared with those of other centres
• Especially multi-centred clinical trials
Advanced irradiation techniques, mainly driven by “improvements in 3-D imaging which allow exquisite definition of target volumes, volumes of interest and organs at risk”

- Separation of Internal Margin (CTV) and Set-up Margin (PTV)
- OAR’s discussed in greater detail (serial, parallel)
- Conformity Index is introduced – optimisation stressed
- Reporting for series of patients
- Clinical Examples - Breast, Prostate & Lung
ICRU Definitions – Changes Over Time

(A) ICRU 29
(B) ICRU 50
(C) ICRU 62

Purdy et al. Sem Rad Oncol 14: 27-40, 2004
**Gross Tumor Volume (GTV):**
Tumor visible on (CT, MRI, PET etc.)

**Clinical target volume (CTV):**
- Contains GTV and/or subclinical microscopic malignant disease
- Volume needs to be treated adequately to achieve cure or palliation
Gross Tumor Volume (GTV):
Tumor visible on (CT, MRI, PET etc.)

Clinical target volume (CTV):
- Contains GTV and/or subclinical microscopic malignant disease
- Volume needs to be treated adequately to achieve cure or palliation

Internal tumor volume (ITV):
- $CTV + IM = ITV$, accounts for motion of CTV in the patient
- Not accounting for setup uncertainties
4DCT – ITV Margins

MIP

ITV

Slide supplied by N. Hardcastle – 4DCT in-service training, Peter Mac 2014
Gross Tumor Volume (GTV): Tumor visible on (CT, MRI, PET etc.)

Clinical target volume (CTV):

Internal tumor volume (ITV):
- $CTV + IM = ITV$

Planning Target Volume (PTV):
- ITV including geometric uncertainties in daily set-up and machine tolerances
**Treated volume:**
To achieve the purpose of treatment

**Irradiated volume:**
Significant dose of normal tissues
Conformity Index

Treated Volume (e.g. V95%)/PTV

• first introduced in ICRU 50

Above example, ref. isodose = 74.1 Gy (yellow), C.I. = 1.198

Why is this important?

• put a lot of resources into reducing PTV margins but a plan with poor conformality still treats a large volume

C.I. ≤ 1.2 at Peter Mac for Prostate
## PTV – Geometric Uncertainties

<table>
<thead>
<tr>
<th>Author</th>
<th>Region</th>
<th>Recipe</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bel et al. (1996)</td>
<td>PTV</td>
<td>$0.7\sigma$</td>
<td>Statistical uncertainties only (linear approximation)—Monte Carlo.</td>
</tr>
<tr>
<td>Antolak and Rosen (1999)</td>
<td>PTV</td>
<td>$1.65\sigma$</td>
<td>Statistical uncertainties only, block margin?</td>
</tr>
<tr>
<td>Stroom et al. (1999a)</td>
<td>PTV</td>
<td>$2 \Sigma + 0.7\sigma$</td>
<td>95% absorbed dose to on average 99% of CTV tested in realistic plans.</td>
</tr>
<tr>
<td>van Herk et al. (2000)</td>
<td>PTV</td>
<td>$2.5 \Sigma + 0.7\sigma$ (or more correctly): $2.5 \Sigma + 1.64$</td>
<td>Minimum absorbed dose to CTV is 95% for 90% of patients. Analytical solution for perfect conformation. Extension of van Herk et al. (2000) for fringe dose due to limited number of beams. The factor $\beta$ depends on the beam organization.</td>
</tr>
<tr>
<td>McKenzie (2000)</td>
<td>PTV</td>
<td>$2.5 \Sigma + \beta + (\sigma - \sigma_0)$</td>
<td>95% minimum absorbed dose and 85% of 1% TCP. Not specified. Errors for various escalation to iso-NTCP, reducing target-dose homogeneity constraints. Margin for respiration on top of other margins when respiration dominates other uncertainties.</td>
</tr>
<tr>
<td>Parker et al. (2000)</td>
<td>PTV</td>
<td>$\sqrt{\Sigma^2 + \Sigma^2}$</td>
<td>Margin for respiration combined with random setup error of 3 mm SD, when respiration dominates other uncertainties ($A &gt; 1$ cm). Margins for small and/or serial organs at risk in low (+) or high (−) absorbed-dose region.</td>
</tr>
<tr>
<td>van Herk et al. (2000b)</td>
<td>PRV</td>
<td>$A$</td>
<td>95% minimum absorbed dose and 85% of 1% TCP. Not specified. Errors for various escalation to iso-NTCP, reducing target-dose homogeneity constraints. Margin for respiration on top of other margins when respiration dominates other uncertainties.</td>
</tr>
<tr>
<td>Ten Haken et al. (1995)</td>
<td>PRV</td>
<td>$2 \Sigma + 0.7\sigma$</td>
<td>95% minimum absorbed dose and 85% of 1% TCP. Not specified. Errors for various escalation to iso-NTCP, reducing target-dose homogeneity constraints. Margin for respiration on top of other margins when respiration dominates other uncertainties.</td>
</tr>
<tr>
<td>Engelsman et al. (2000)</td>
<td>PRV</td>
<td>$2.5 \Sigma + 0.7\sigma$</td>
<td>95% minimum absorbed dose and 85% of 1% TCP. Not specified. Errors for various escalation to iso-NTCP, reducing target-dose homogeneity constraints. Margin for respiration on top of other margins when respiration dominates other uncertainties.</td>
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<td>McKenzie et al. (2000)</td>
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</tr>
<tr>
<td>van Herk et al. (2003)</td>
<td>PRV (lung)</td>
<td>$0.25 A$ (caudally); $0.45 A$ (cranially)</td>
<td>Margin for (random) respiration combined with random setup error of 3 mm SD, when respiration dominates other uncertainties ($A &gt; 1$ cm). Margins for small and/or serial organs at risk in low (+) or high (−) absorbed-dose region.</td>
</tr>
<tr>
<td>McKenzie et al. (2002)</td>
<td>PRV</td>
<td>$1.3 \Sigma + 0.5\sigma$</td>
<td>95% minimum absorbed dose and 85% of 1% TCP. Not specified. Errors for various escalation to iso-NTCP, reducing target-dose homogeneity constraints. Margin for respiration on top of other margins when respiration dominates other uncertainties.</td>
</tr>
</tbody>
</table>

Symbols: $\Sigma$, standard deviation of systematic uncertainties; $\sigma$, standard deviation of statistical (random) uncertainties; $\sigma_0$, describes width of beam penumbra fitted with a Gaussian function; $A$, peak-to-peak amplitude of respiration.
Margin recipe to cover the CTV for 90% of the patients within the 95% isodose surface

PTV margin = 2.0 $\Sigma + 0.7\,\sigma$ \hspace{1cm} (Stroom \textit{et al.}, 1999)
PTV margin = 2.5 $\Sigma + 0.7\,\sigma$ \hspace{1cm} (van Herk \textit{et al.}, 2000)

$\Sigma = \text{SD of all systematic errors combined quadratically}$
$\sigma = \text{SD of all random errors combined quadratically}$
Systematic and random errors

Average of patient = systematic error for that patient

Standard deviation of all averages = $\Sigma$

Standard deviation within a patient = $\sigma_p$

Average of all $\sigma_p = \sigma$
PTV – Immobilisation Devices
Influence of margins on volume

Given the volume of a sphere:

\[ V = \frac{4}{3} \pi r^3 \]

1. Assume a spherical CTV with a diameter of 5.0 cm
2. Reduce CTV-PTV margin from 2.0 cm to 0.5 cm
3. The PTV target volume decreases from 380 cm$^3$ to ?:

   a) $48 \text{ cm}^3$
   b) $113 \text{ cm}^3$
   c) $206 \text{ cm}^3$
   d) $310 \text{ cm}^3$

Organ at risk (OAR):
Organ whose radiation sensitivity is such that the dose received by the treatment may be significant compared to its tolerance.
OARs may significantly influence treatment planning and/or prescribed dose.

Planning Risk Volume (PRV):
Includes margin around the OAR to compensate for changes in shape and internal motion and for setup variation.
GTV and CTV: NSCLC stage IIIA
Treated Volume
Irradiated Volume
Primary Rectal Tumor

Contrast CT

MRI

FDG PET

0 Gy             19 Gy             46 Gy
Remaining Volume at Risk (RVR)

- The RVR is defined by the difference between the volume enclosed by the external contour of the patient and that of the CTVs and OARs on the slices that have been imaged.

- Importance in evaluating plans; could be unsuspected regions of high absorbed dose in the patient - otherwise go undetected.

50 Gy Isodose far from target due to poor IMRT optimisation.
Dose distribution for conventional beam (A) and IMRT (B) treatment of an oropharyngeal tumour. The patient experienced a lip desquamation (dashed arrow) and hair loss in the occipital/posterior area (solid arrow), which are not expected with conventional bilateral opposing beams (Zhen et al., Med. Dos. 27, 155-159, 2002)
Level 1 – absorbed dose & 2-D distribution on central axis are known and available (minimum standard) not sufficient for IMRT

Level 2 – assumed all volumes defined using CT or MRI
  • 3-D dose distributions include heterogeneity corrections
  • DVH for all volumes are computed
  • Complete QA in place to ensure treatment accurately delivered

Level 3 – optional research and development reporting
  • Tumor-control probability (TCP)
  • Normal tissue complication probability
  • Equivalent uniform dose (EUD), ICRU 2007

Reporting criteria not yet established – may be added to Level 2 in the future
Dose Volume Histograms (DVH)

- Cumulative DVH – histograms of the volume elements that receive at least that given absorbed dose
- Differential DVH – increment of volume per absorbed dose at D (i.e. = \( \approx \) ICRU ref. pt.
  
\[ \text{near minimum} = \]

Min. dose covering 95% of the volume

\[ \approx \text{ICRU ref. pt.} \]

= near maximum
ICRU83 – Other Recommendations

Recommends TPS capable of computing absorbed dose accurately for
- Small fields
- Inhomogeneous tissues
- Regions of electronic disequilibrium

Dose-Volume specifications for reporting
- Target coverage = $D_{95\%}$ ....... $D_{100\%}$ not recommended as the PTV cannot be
determined with sufficient accuracy to dose every voxel
- $D_{98\%}$ / $D_{2\%}$ ....... not dependent on a single dose calculation point

NB: ultimately, radiation oncologist may decide to use max. point dose

- $D_{50\%}$ (median) should always be reported
  - representative of absorbed dose in PTV (analogous to ICRU ref. point)
- For IMRT target’s such as PTV .... Mean dose $\approx D_{50\%}$
Target Reporting In Practice - Prostate

Target coverage - $V_{95\%} \geq 98\%$ of PTV

<table>
<thead>
<tr>
<th>Structure</th>
<th>Min. Dose (Gy)</th>
<th>Max. Dose (Gy)</th>
<th>Mean Dose (Gy)</th>
<th>Hot Ref. (Gy)</th>
<th>Volume &gt; (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTV_7800</td>
<td>77.171</td>
<td>81.761</td>
<td>79.563</td>
<td>74.100</td>
<td>100.00</td>
</tr>
<tr>
<td>PTV_7800</td>
<td>67.909</td>
<td>82.058</td>
<td>78.662</td>
<td>74.100</td>
<td>98.93</td>
</tr>
</tbody>
</table>

- CTV (yellow)
- PTV (blue)
Parallel structures – more then 1 DVH point

- Mean dose useful measure (e.g. Parotid < 26 Gy mean dose)
- Non-homogenous dose distribution in OAR’s, Median ≠ Mean
- Entire organ be contoured – meaningful values of $D_{mean}$ and $V_d$

Serial structures

- Recommends D2% for maximum dose (previously, hotspot ≥ 15mm)
- Entire organ be contoured – meaningful values of $D_{mean}$ and $V_d$
ICRU 83
OAR Reporting In Practice – H&N

Target coverage - V ≥ 98% of PTV

CTV (yellow)
PTV (blue)

Mean V’s Median
Max Dose V’s D2%
Dose Constraints - QUANTEC
Dose Constraints - Rectum

QUANTEC & other dose constraints are good to use for DVH optimisation

- Represent upper limits ........ Good IMRT plans can always go lower

**Average Dose to Rectum for Intact Prostates IMRT**

(22 patients)

- RO Clinical Guidelines
- Sun IMRT (Ave)

<table>
<thead>
<tr>
<th>Rectum V75Gy (limit = 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectum V70Gy (limit = 20)</td>
</tr>
<tr>
<td>Rectum V65Gy (limit = 25)</td>
</tr>
<tr>
<td>Rectum V60Gy (limit = 30)</td>
</tr>
<tr>
<td>Rectum V50Gy (limit = 50)</td>
</tr>
<tr>
<td>Rectum V40Gy (limit = 65)</td>
</tr>
<tr>
<td>Rectum V30Gy (limit = 80)</td>
</tr>
</tbody>
</table>

**Dose (Gy)**

**Volume (%)**

- 0
- 10
- 20
- 30
- 40
- 50
- 60
- 70
- 80
- 90
- 100
Prostate Plan Evaluation Data

Level 3 Reporting

Techniques/Concepts under development:

• Dose conformality = ≤ 1.2
• Dose homogeneity = ≤ 0.1 (0 = homogeneous)

Other Reporting Metrics:

• Equivalent Uniform Dose (EUD)
• Tumour Control Probability (TCP) or Normal Tissue Complication Probability (NTCP)
Planning Aims

DVH concept introduced ....... where to start (Prostate)?

4.6.4 Dose Constraints
Please refer to clinical guidelines DRO 06.13.00 Urology Unit - Prostate Cancer.

Additional goals
- A mean dose to the PTV in the range -0.5Gy to +1.0Gy of the prescribed dose is ideal
  - Greater than this may be approved by the prescribing oncologist
- Minimum: The D98% to the PTV should be ≥95% of the prescribed dose
  - However D99% is ideal
- Maximum: The D2% of the PTV should be ≤107% of the prescribed dose
- The global maximum dose should fall within the CTV
- Assess any high dose areas outside PTV
- Calculate DVH & ensure dose constraints are met
- Total Monitor Units can be expected to fall between 800 and 1100
  - If outside of this range, consult with unit charge and/or physicist as appropriate

7.5 Dose Constraints (Also applicable for post-prostatectomy radiotherapy)

7.5.1 External Beam – Total Dose 64-78Gy
DVH rectal constraints:

<table>
<thead>
<tr>
<th>V30Gy</th>
<th>V40Gy</th>
<th>V50Gy</th>
<th>V60Gy</th>
<th>V65Gy</th>
<th>V70Gy</th>
<th>V75Gy</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤80%</td>
<td>≤65%</td>
<td>≤55%</td>
<td>≤50%</td>
<td>≤30%</td>
<td>≤25%</td>
<td>≤20%</td>
</tr>
</tbody>
</table>

7.5.2 External Beam – 46 Gy/23 fractions (combined with HDR boost)
DVH rectal constraints (based on proportion of 78Gy EBRt):

<table>
<thead>
<tr>
<th>V17.7Gy</th>
<th>V23.6Gy</th>
<th>V31Gy</th>
<th>V37Gy</th>
<th>V38.3Gy</th>
<th>V41.3Gy</th>
<th>V44.2Gy</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤80%</td>
<td>≤85%</td>
<td>≤50%</td>
<td>≤30%</td>
<td>≤25%</td>
<td>≤20%</td>
<td>≤10%</td>
</tr>
</tbody>
</table>

7.5.3 Non-rectal Bowel Volume (not small bowel)
D2% ≤ 60Gy

7.5.4 Small Bowel Volume
D2% ≤ 50Gy

7.5.5 External Beam Femoral Head Constraints

7.5.6 External Beam Bladder Constraints

<table>
<thead>
<tr>
<th>V65Gy</th>
<th>V70Gy</th>
<th>V75Gy</th>
<th>V80Gy</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤50%</td>
<td>≤35%</td>
<td>≤25%</td>
<td>≤15%</td>
</tr>
</tbody>
</table>

7.5.7 7.4.7 Penile bulb Optional
Mean dose < 52.5Gy
# ICRU 83 – Inside the Report

1. Introduction

2. Optimized Treatment Planning for IMRT

3. Prescribing and Reporting in IMRT – Absorbed Dose and DVH

4. Definition of Volumes

5. Planning Aims, Prescription & Technical Data

## Appendix

A. Physical Aspects of IMRT

B. Clinical Examples

   B.1 SCC of the Larynx

   B.2 Squamous-Cell Carcinoma of the Lung

   B.3 Adenocarcinoma of the Prostate
Appendix – Physics & QA

No offset
0.6 mm offset
1.0 mm offset

0.7 mm offset
0.6 mm offset
0.5 mm offset
0.3 mm offset

-0.5 mm
-0.2 mm
+0.2 mm
+0.5 mm
Appendix – Clinical Examples

Table B.1.2. Planned and reported absorbed-dose metrics for the CTVs, PTVs, OARs, and PRVs for Case B1.

<table>
<thead>
<tr>
<th></th>
<th>$D_{\text{mean}} \pm \text{SD (Gy)}$</th>
<th>$D_{\text{median}}$ or $D_{50 %}$ (Gy)</th>
<th>$D_{\text{near-min}}$ or $D_{98 %}$ (Gy)</th>
<th>$D_{95 %}$ (Gy)</th>
<th>$D_{\text{near-max}}$ or $D_{2 %}$ (Gy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTV-T2</td>
<td>68.9 ± 0.5</td>
<td>69.0 (69.0)</td>
<td>67.0 (≥62.1)</td>
<td>67.3 (≥66.5)</td>
<td>69.6 (≤73.7)</td>
</tr>
<tr>
<td>CTV-T2</td>
<td>69.4 ± 0.6</td>
<td>69.3</td>
<td>68.1</td>
<td>68.5</td>
<td>70.6</td>
</tr>
<tr>
<td>PTV-T1</td>
<td>60.9 ± 4.8</td>
<td>61.1 (55.5)</td>
<td>52.4 (≥49.9)</td>
<td>53.4 (≥52.7)</td>
<td>68.5 (≤59.4)</td>
</tr>
<tr>
<td>CTV-T1</td>
<td>65.7 ± 4.0</td>
<td>66.9</td>
<td>55.2</td>
<td>56.0</td>
<td>70.4</td>
</tr>
<tr>
<td>Left PTV-N</td>
<td>55.4 ± 0.6</td>
<td>55.5 (55.5)</td>
<td>53.7 (≥49.9)</td>
<td>54.3 (≥52.7)</td>
<td>56.5 (≤59.4)</td>
</tr>
<tr>
<td>Left CTV-N</td>
<td>55.7 ± 0.5</td>
<td>55.7</td>
<td>54.2</td>
<td>55.0</td>
<td>56.5</td>
</tr>
<tr>
<td>Right PTV-N</td>
<td>56.4 ± 2.6</td>
<td>55.7 (55.5)</td>
<td>53.7 (≥49.9)</td>
<td>53.8 (≥52.7)</td>
<td>66.7 (≤59.4)</td>
</tr>
<tr>
<td>Right CTV-N</td>
<td>56.3 ± 2.2</td>
<td>55.8</td>
<td>54.0</td>
<td>54.5</td>
<td>65.2</td>
</tr>
<tr>
<td>PRV spinal cord</td>
<td>24.2</td>
<td>25.7</td>
<td>0.9</td>
<td>—</td>
<td>36.7 (≤50.0)</td>
</tr>
<tr>
<td>Spinal cord</td>
<td>23.1</td>
<td>23.4</td>
<td>0.9</td>
<td>—</td>
<td>36.8 (≤48)</td>
</tr>
<tr>
<td>PRV right parotid</td>
<td>18.5 (40)</td>
<td>10.2</td>
<td>1.1</td>
<td>—</td>
<td>54.9</td>
</tr>
<tr>
<td>PRV left parotid</td>
<td>18.3 (26)</td>
<td>10.5</td>
<td>0.9</td>
<td>—</td>
<td>53.8</td>
</tr>
</tbody>
</table>
Table B.3.2. Planned and reported absorbed-dose metrics for CTVs, PTVs, OARs, and PRVs for Case B3.

<table>
<thead>
<tr>
<th>Volume</th>
<th>$D_{\text{near-min or } D_{98}}$ (Gy)</th>
<th>$D_{50}$ % (Gy)</th>
<th>$D_{30}$ % (Gy)</th>
<th>$D_{\text{near-max or } D_{2}}$ % (Gy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTV</td>
<td>74.1 ($\geq$ 74.1)$^a$</td>
<td>78.0</td>
<td>—</td>
<td>81.5 ($\leq$ 81.9)</td>
</tr>
<tr>
<td>CTV</td>
<td>78.6</td>
<td>—</td>
<td>—</td>
<td>81.5</td>
</tr>
<tr>
<td>PRV rectal wall</td>
<td>—</td>
<td>32.2 (55.0)</td>
<td>60.5 (70.0)</td>
<td>78.7 (79.0)</td>
</tr>
<tr>
<td>PRV bladder wall</td>
<td>—</td>
<td>27.6 (55.0)</td>
<td>42.5 (70.0)</td>
<td>78.1 (79.0)</td>
</tr>
<tr>
<td>PRV left femur</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>46.5 (53.0)</td>
</tr>
<tr>
<td>PRV right femur</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>51.3 (53.0)</td>
</tr>
</tbody>
</table>
References & Acknowledgements

ICRU 83, 62 and 50

Peter Mac Colleagues (in house TPS & slides)

IAEA & original authors of some slides

Dr Morten Høyer, Aarhus University Hospital, Denmark and ESTRO (& J. Van Dyke) for slides used in this presentation