ICRU Recommendations

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Target Volumes in Radiation Oncology: ICRU 50 and 62:

• Gross Tumor Volume: GTV
• Clinical Target Volume: CTV
• Internal Target Volume: ITV
• Planning Target Volume: PTV
• Organ at Risk: OAR
• Planning Organ at Risk Volume: PRV
The Need for an New ICRU Report on IMRT

It was published and/or mentioned …

• Biological Target Volume (BTV): C. Ling, IJROBP 2000,

• Hypoxic TV (HTV), Proliferation TV (PTV), …: ESTRO physics meeting, 2003,

• working PTV (wPTV): Ciernik IF, IJROBP, 2005,

• AAPM 2005: “… with the use of IMRT, ICRU recommendations will not be needed anymore…”.
Issues for 3D-CRT and IMRT

• Multiple GTV, e.g. anatomic vs functional imaging; before and during treatment, …,
• GTV to CTV margins: clinical probability,
• CTV to PTV margins: geometric probability; overlapping volumes,
• ITV ???
• OAR: open vs closed volume? Remaining normal tissues?
• PRV: planning organ at risk volume - serial vs parallel OAR.
Right piriform sinus (ICDO-10: C12.9)
SCC grade 2
TNM 6th ed: T4N0M0

Fiberoptic examination

Before Rx-CH

46 Gy (Rx-CH)
Two Types of Margins

Microscopic Extension

Regional Involvement
Example 1

\[ \text{GTV}_1 \text{ (pre-RxTh CT+ iv contrast)} \]

\[ \text{CTV}_1 \]

\[ \text{PTV}_1 : \text{dose}_1 \]

\[ \text{CTV}_2 = \text{GTV}_1 \]

\[ \text{PTV}_2 : \text{dose}_2 \]
Example 2

GTV₁ (pre-RxTh CT+ iv contrast)

CTV₁

PTV₁: dose₁

GTV₂ (FDG-PET @ 46 Gy)

CTV₂ = GTV₂

PTV₂: dose₂
Clinical Target Volume (CTV)

• The Clinical Target Volume (CTV) is a volume of tissue that contains a demonstrable GTV and/or subclinical malignant disease at a certain probability considered relevant for therapy…,

• The CTV is thus an anatomical-clinical concept.
Clinical Target Volume (CTV)

• Sometimes the largest component of the margin between the GTV and CTV will be the delineation error in drawing the GTV,

• Consideration should be made for this in the clinical margin.
Selection and delineation of lymph node target volumes in head and neck conformal radiotherapy. Proposal for standardizing terminology and procedure based on the surgical experience

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The Planning Target Volume is a geometrical concept, introduced for treatment planning and evaluation. It is the recommended tool to shape dose distributions that ensure with a clinically acceptable probability that an adequate dose will actually be delivered to all parts of the CTV...
Planning Target Volume (PTV)

- Include both “internal” and “external” variations of the CTV,
- Separate delineation of the ITV is not necessary but motion should be included in the PTV,
- Expansion of the CTV using “rolling ball” algorithms,
- CTV to PTV margin recipe based on random and systematic errors, and beam penumbra,
- Priority rules when overlapping PTVs or PTV-PRV,
- Dose is prescribed and reported on the PTV.
- IMRT can result in hot and cold spots within the PTV.
‘Cheating on the PTV Margins’

• The practice of shrinking the CTV to PTV margin to accommodate an OAR is discouraged as it results in a deceptively better PTV homogeneity,

• In IMRT the trade-off can be accomplished by changing the planning aims in the optimizer,

• In 3-D CRT, the trade-off can be accomplished with a separate target delineation used to draw the beam boundary.
Can Use Sub-Volumes to Guide Optimization

\[ PTV = PTV_{SV-1} + PTV_{SV-2} \]
# CTV to PTV Margin Recipe

<table>
<thead>
<tr>
<th>Author</th>
<th>Application</th>
<th>Recipe</th>
<th>Assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bel et al 1996b</td>
<td>Target</td>
<td>0.7 s</td>
<td>Random errors only (linear approximation) S Monte Carlo</td>
</tr>
<tr>
<td>Antolak and Rosen 1999</td>
<td>Target</td>
<td>1.65 s</td>
<td>Random errors only, block margin?</td>
</tr>
<tr>
<td>Stroom et al 1999</td>
<td>Target</td>
<td>2 S + 0.7 s</td>
<td>95% dose to on average 99% of CTV tested in realistic plans</td>
</tr>
<tr>
<td>Van Herk et al 2000</td>
<td>Target</td>
<td>2.5 S + 0.7 s or (more correct): 2.5 S + 1.64 (s - s_p)</td>
<td>Minimum dose to CTV is 95% for 90% of patients. Analytical solution for perfect conformation</td>
</tr>
<tr>
<td>McKenzie et al 2000a</td>
<td>Target</td>
<td>2.5 S + b (s - s_p)</td>
<td>Extension of van Herk et al for fringe dose to due to limited number of beams</td>
</tr>
<tr>
<td>Parker et al 2002</td>
<td>Target</td>
<td>S + \sqrt{(s^2 + S^2)}</td>
<td>95% minimum dose and 100% dose for 95% of volume. Probability levels not specified</td>
</tr>
<tr>
<td>Van Herk et al 2002</td>
<td>Target</td>
<td>2.5 S + 0.7 s - 3 mm or (more correct): \sqrt{2.7^2 s_p^2 + 1.6^2 \sigma^2} - 2.8 mm</td>
<td></td>
</tr>
</tbody>
</table>

Symbols: \( S \) = SD of systematic errors; \( s \) = SD of random errors; \( s_p \) = describes width of beam penumbra fitted to a Gauss function; \( A \) = Peak-peak amplitude of respiration.
Organ At Risk (OAR) and Remaining Volume at Risk (RVR)

- Distinction between “serial-like” (e.g. spinal cord) and “parallel-like organs” (e.g. parotid gland),
- For “tubed” organs (e.g. rectum) wall delineation,
- Remaining Volume at Risk (RVR): aids optimization and may assist in evaluating very late effects (e.g. carcinogenesis).
Organ At Risk (OAR)

Contents of tubed organs should not be included

Prostate
Rectum With Contents
Rectal Wall
Planning Organ at Risk Volume (PRV)

- PRV is a geometrical concept (tool) introduced to ensure that adequate sparing of OAR will actually be achieved with a reasonable probability,
- A positive OAR to PRV margin for serial organ.
- Dose-volume constraints on OAR are with respect to the PRV,
- Priority rules when overlapping PTVs or PTV-PRV(OAR),
- Dose metrics are reported to the PRV.
Absorbed Dose in Radiation Oncology: ICRU 50 and 62:

Dose prescription:
• Responsibility of the treating physician.

Dose reporting:
• ICRU reference point,
• Three-levels of dose reporting,
• Point-doses: $D_{\text{ICRU point}}$, $D_{\text{min}}$, $D_{\text{max}}$, ...

Dose recording.
Issues for IMRT

- Discrepancy between dose-volume constraint prescription and dose delivery,
- Single point dose prescription,
- Single point dose reporting,
- Biological metrics (e.g. EUD, TCP, NTCP, ...),
- Uncertainties in dose prescription and reporting,
- More quality assurance required.
PRE-RADIOTherapy WORKUP

Diagnosis  
Patient History  
3-D Imaging and Staging  
Multi-Disciplinary Tumor Board

RADIOTherapy PREPARATION

Immobilization  
3-D Planning Images  
Delineation of Volumes of Interest (VOIs), E.g. GTV, CTV, OAR

PLANNING

Planning Aims  
Optimized Treatment Plan  
Prescription and Technical Data  
Accepted Treatment Plan

DElIVERY

Setup Patient with Immobilization  
Image Verification  
Adjust Setup  
Treat

Plan ADAPTATION (if necessary)

RECORD AND REPORT
RADIOTHERAPY PREPARATION

- Immobilization
- 3-D Planning Images
- Delineation of Volumes of Interest (VOIs), e.g. GTV, CTV, OAR

PLANNING

- Planning Aims
- Optimized Treatment Plan
- Modification of Aims and Creation of TV or Avoidance Structures

DELIVERY

- Setup Patient with Immobilization
- Image Verification
- Adjust Setup
- Treat

PLAN ADAPTATION (if necessary)

- Evaluate Dose Delivered
- Evaluate Images and Create New VOIs

RECORD AND REPORT

- Record
- Level 2 or 3 Reporting
Dose Prescription in IMRT

• Planning aims:
  - $\text{PTV}_1$: dose$_x$, D-V constraints, ..., 
  - Spinal cord: $D_{\text{max}} = x$ Gy, ..., 
  - ...

• Prescription:
  - Physician’s responsibility,
  - Acceptance of doses, fraction #, OTT, D-V constraints, beam number, beam orientation, ...

• Technical data for treatment delivery:
  - Instruction file sent to the linac and/or RVS.
ICRU Levels of Reporting

- Level 1: not adequate for IMRT,
- Level 2: standard level for dose reporting,
- Level 3: homogeneity, conformity and biological metrics (TCP, NTCP, EUD, ...) and confidence intervals.
ICRU Reference Point Not A “Typical Point” for IMRT

13 segment IM Field

Segments 4-7, 9-13
Reliability of Planning Metrics

Median dose is most reliable

From Indra Das
Absorbed dose in Radiation Oncology:  

**Metrics for Level 2 Reporting of PTV**

- Dose-volume reporting (i.e., $D_v$)
  - $D_{50\%}$ ($D_{\text{median}}$), prescription value, e.g., $D_{95\%}$
  - $D_{\text{mean}}$
  - Near Minimum dose: $D_{98\%}$
  - Near Maximum dose: $D_{2\%}$

- State the make, model and version number of the treatment planning and delivery software used to produce the plans and deliver the treatment.
• Doses at a point are not as reliable as DVH near-min and near-max
• PTV median dose is the “typical dose” to the PTV
• PTV mean dose and PTV median dose are nearly identical
• PRV mean dose and PRV median dose are not necessarily similar
Dose-Volume Reporting

D98 = 60 Gy

D50% is close to ICRU Reference Dose at a Point

Dv with v≠50 may require a change in prescription value
Metrics for Level 2 Reporting of PRV

• “Serial-like” organs:
  - $D_{\text{near-max}} = D_{98}$.

• “Parallel-like” organs:
  - $D_{\text{mean}}$ (e.g. parotid),
  - $V_d$ where $d$ refers to dose in Gy (e.g. $V_{20\,\text{Gy}}$ for lung).
Homogeneity and Conformity

Low Homogeneity – High Conformity

High Homogeneity – Low Conformity

Low Homogeneity – Low Conformity

High Homogeneity – Low Conformity
Absorbed dose in Radiation Oncology:

Examples of Metrics for Level 3 Reporting of PTV

• Homogeneity:
  - Standard deviation in dose to the PTV.

• Conformity:
  - Conformity Index: $CI = \frac{TV_{presc}}{PTV}$,
  - Dice Similarity Coefficient (DSC):

$$DSC = \frac{2(TV_{presc} \cap PTV)}{(TV_{presc} + PTV)}$$
Absorbed dose in Radiation Oncology:

Recording in IMRT

- Electronic archiving for at least the life of patient or 5 years – whatever is longer,
- Complete reconstruction of the treatment technical data, plan and delivery record,
- For clinical trials, longer archiving if scientifically justified.
Use Doses Corrected for Tissue Heterogeneities

A=Adipose, M=Muscle, B=Bone, L=Lung  
4 MV, Parallel Beam

Ahnesjo and Asparadakis, 1999 Phys Med Biol 44:R99-R155
Absorbed dose in Radiation Oncology:

**Report Dose to Water**

- While the dose is corrected for tissue heterogeneities, the dose to a small mass of water in tissue is reported.
- Consistent with the older methods as well as convolution/superposition methods.
- Monte Carlo dose computation will have to be corrected to dose to a small mass of water in tissue.
Monitor Units Calculations for Model-Based Dose Calculation

\[
\frac{D}{MU}(A, r) = \frac{\Psi_0}{MU}(A, r) \frac{D}{\Psi_0}(A, r) (1 + b(A))^{-1}
\]
Monitor Units Calculations for Model-Based Dose Calculation

\[
\frac{\Psi_0}{MU} = \left[ \frac{D}{M} (A_{cal}, d_{cal}) \right]_{\text{Measured}} \left( 1 + b(A_{cal}) \right) \]

Not including the effect of backscatter into the monitor chamber will result in about a 2% error at worst.
Backscatter into Monitor Chamber

The effect is due to backscattered photons entering the monitor and resulting in feedback to the linac to lower its output.

Varian 2100 - 10 MV. Results with other jaw completely open.

Monitor Backscatter for Square On-Axis Fields

Varian 2100 - 10 MV

QA for IMRT

• Appropriate QA of TPS and delivery equipment

• Patient-specific QA:
  • Delivery of individual fields into a dosimeter
  • Delivery of all of the fields into a phantom
  • Independent dose calculation algorithms with similar or better dose calculation accuracy
  • In-vivo dosimetry not limited to a single point.
Gap Error is Fundamental for Conventional MLCs

Gap error → Dose error

From Tom Losasso, Memorial Sloan Kettering
Leaf Latency is Fundamental for Binary MLCs

- TomoTherapy uses a linear fit of measured data to model leaf latency.
- Plans with small opening times lead to uncertainty in delivery, also leading to delivery inefficiencies.

![Graph showing latency data and fit for 300 ms projection interval. The equation of the line is $y = 1.022x - 0.016$.](image)
QA of Individual Fields

External diode/ion-chamber arrays
- MapCheck
- PTW Octavius phantom
- IBA Matrix

Integrated detector systems
- EPID portal dosimetry
End-to-End QA
QA Measurements

“Cheese” Phantom used for QA measurements

Film Plane
Phantom can be rotated or turned to acquire any orthogonal plane

Measure plane and point dose at the same time
On and Off-Axis Results

Film and Ion Chamber Absolute Dose

Delivered Dose: 2.5cm Treatment Beam

Dose (Gy)

Distance (cm)

On-Axis Tumor  Off-Axis Tumor

Tomotherapy Example
QA for All of the Fields

Tomotherapy Example
Comparison of Phantom Plan and Verification Film

Note the High Gradients

From Chet Ramsey, Thompson Cancer Survival Center
Independent Calculation
Gortec IMRT Test Phantom

TLDs are placed at seven locations.

- Point 1: Isocenter
- Point 2: Spinal cord isocenter
- Point 3: Spinal cord cranial
- Point 4: PTV T R
- Point 5: PTV T R cranial
- Point 6: PTV N L
- Point 7: PTV N L caudal

Courtesy M. Tomsej, Brussels
$D_m/D_c = f(\text{CENTER})$ per meas. pt

Sample Result
Inter-Institution Dose Accuracy

Accuracy Distribution

Number of Measurements = 2679
Mean = 0.995
Standard Deviation = 0.025

(Updated from Zefkili et al 2004)
Intra-Institution Dose Accuracy

Number of Measurements = 1591
Mean = 0.45%
Standard Deviation = 2.5%

(Updated from Dong et al 2003)
**IMRT Evaluation using Anthropomorphic Phantoms**

**Phantom Results**

Comparison between institution’s plan and delivered dose.

Criteria for agreement: 7% or 4 mm DTA (5%/5mm for lung)

<table>
<thead>
<tr>
<th>Site</th>
<th>Institutions</th>
<th>Irradiations</th>
<th>Pass</th>
<th>Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>H&amp;N</td>
<td>472</td>
<td>631</td>
<td>75%</td>
<td>25%</td>
</tr>
<tr>
<td>Pelvis</td>
<td>108</td>
<td>130</td>
<td>82%</td>
<td>18%</td>
</tr>
<tr>
<td>Lung</td>
<td>67</td>
<td>77</td>
<td>71%</td>
<td>29%</td>
</tr>
<tr>
<td>Liver</td>
<td>15</td>
<td>18</td>
<td>50%</td>
<td>50%</td>
</tr>
</tbody>
</table>

For H&N, using a criteria of 5% or 4mm, the passing rate drops from 75% to 58%
QA Accuracy for IMRT

• Previous ICRU 5% point-dose accuracy specification replaced by a volumetric dose accuracy specification.

• Proposed new ICRU volumetric dose accuracy specification:
  - High gradient (≥ 20%/cm): 85% of points within 5 mm (3.5 mm SD),
  - Low gradient (< 20%/cm): 85% of points within 5% of predicted dose normalized to the prescribed dose (3.5% SD).
Dose Accuracy and Distance to Agreement

Dose accuracy for low gradients:

\[ \delta(r_m, r_c) = \left[ D(r_m) - D(r_c) \right] / D_{50\%} \]

Low gradients < 20%/cm

Distance to agreement for high gradients:

\[ r(r_m, r_c) = |r_m - r_c| \]
Gamma Function

\[ \Gamma(r_m, r_c) = \left\{ \left[ \frac{\delta(r_m, r_c)}{\Delta D_M} \right]^2 + \left[ \frac{r(r_m, r_c)}{\Delta d_M} \right]^2 \right\}^{1/2} \]
\[ \Gamma(r_m, r_c) = \left\{ \left[ \frac{\delta(r_m, r_c)}{\Delta D_M} \right]^2 + \left[ \frac{r(r_m, r_c)}{\Delta d_M} \right]^2 \right\}^{1/2} \]
Summary of Changes Between ICRU 50 & 62 and IMRT ICRU (83)

- More emphasis on statistics.
- Prescription and reporting with dose-volume specifications.
- No longer use ICRU-Reference Point.
- Want median dose $D_{50}$ reported.
- Use model-based dose calculations.
- Include the effect of tissue heterogeneities.
- Report dose to small mass of water, not dose to tissue.