Dose-volume concepts and treatment planning

Per Nilsson/Crister Ceberg
Specification of volumes and doses

- volumes (i.e. tumours, organs at risk, and other volumes of interest)
- prescribed doses to tumours and (acceptable) doses to organs at risk
ICRU 50, 62 and 71

1993 Photons
1999 Photons
2004 Electrons
Brachytherapy

Dose and Volume Specification for Reporting Intracavitary Therapy in Gynecology

1985

Dose and Volume Specification for Reporting Interstitial Therapy

1997
Specifications: why?

- Maintain a consistent treatment policy within the department (and improve it)
- Facilitate communication:
  - Compare the treatment results with other departments (especially in multi-center trials)
  - Benefit from experience
Specifications: why?

- Specification of **volumes** and **doses** has to be done for different purposes:
  - Prescription
  - Recording *(e.g. the treatment chart)*
  - Reporting *(e.g. clinical trials)*
Prescription

The ICRU recommendations give some freedom to use different methods to prescribe the dose, but

the prescription, recording, and reporting should be unambiguous
Recording

- to ensure further care and follow-up of patients
- to keep the treatment conditions reproducible, safe, and constant
- to continuously develop clinical experience improve the techniques
- to be able to exchange information on treatment conditions with other centers (trials)
- to be able to “reconstruct” the treatment conditions when needed
Reporting

- Collecting multi-center data
- Harmonization in reporting implies an agreement of
  - a certain number of concepts and definitions of terms
  - a general approach on how to report a treatment
Consequences of in-accurate recording and reporting

- A dose difference as small as 5% may lead to real impairment or enhancement of tumour response, as well as altering the risk of morbidity.
- Inadequate reporting may lead to a false interpretation of a study and to its wrongful application.
Precision in reporting the dose given in a course of radiotherapy

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Received 21 April 1993; Revised 12 August 1993; accepted 20 August 1993. Available online 11 March 2004.

Abstract

A knowledge of the precise dose given in a course of radiotherapy is vital to the interpretation of the result. Despite this, an acceptable level of reporting was found in only 72 (36%) of 200 papers published in the two leading journals of radiation oncology. Analysis of the treatment data of the cases with head and neck tumours in the pilot study of CHART showed that the mean of the minimum tumour doses given was 5.1% lower than the mean of those at the intersection points. Had the same total dose been prescribed to the intersection point instead of the minimum there would have been a similar lowering of dose. There is evidence from published clinical data and a suggestion from an analysis of the CHART pilot study data that a dose difference as small as 5% may lead to real impairment or enhancement of tumour response, as well as altering the risk of morbidity. Inadequate reporting may lead to a false interpretation of a study and to its wrongful application. It is strongly recommended that it should be editorial policy to publish only those papers where the radiation dose is fully described.

Author Keywords: Radiotherapy; Target absorbed dose; Dose response
Volumes
Volumes

- Gross Tumor Volume (GTV)
- Clinical Target Volume (CTV)
- Planning Target Volume (PTV)
- Treated Volume
- Irradiated Volume
- Organ at Risk (OAR)
- Planning Organ at Risk Volume (PRV)
Gross tumor volume (GTV)

- The **Gross Tumor Volume (GTV)** is the gross, palpable, visible or clinically demonstrable location and extent of the malignant growth
  
  - GTV is a clinical-anatomical concept

*Example: oesophagus cancer*
Gross tumor volume (GTV)

- **GTV**
  - **GTV-T** (primary tumour)
  - **GTV-N** (regional lymph node metastases)
    - If more than one GTV-N
      - GTV-N1, GTV-N2, ....
  - **GTV-M** (distant metastases)
Gross tumor volume (GTV)

- High tumor cell density (>10^6 mm^-3)
  - An adequate dose has to be delivered to the whole GTV for radical therapy
- There is no GTV after complete surgical resection
Gross tumor volume (GTV)

The shape, size and location of the GTV may be determined by:

- Clinical examination
  - inspection, palpation, endoscopy, …
- Different imaging techniques
  - x-ray, CT, MR, US, SPECT, PET, …

It may therefore vary in size and extension due to the diagnostic method used!!
"The GTV may vary in size and extent dependent on the diagnostic method used."

From ICRU 71

Figure 2.1. Different images of a breast cancer as obtained by different methods (note that the different figures are not reproduced to identical scales).

(a) Mammography screening shows a tumor in the right breast. There is a 20 mm large mass on palpation.
(b) Ultrasoundography shows a 13 mm × 8 mm large hypoechoic tumor. Fine needle aspiration biopsy shows cancer.
(c) MRI demonstrates a 20 mm large tumor (the arrows indicate directions for core biopsy).
(d) The fresh surgical specimen shows a 15 mm × 22 mm large tumor (marked by black arrows).
(e) The fixed specimen shows a 14 mm × 18 mm large tumor (marked by black arrows).
(f) Microscopy demonstrates the diffuse borders of the cancer.
GTV and imaging techniques

PET

CT
Clinical Target Volume (CTV)

- The *Clinical Target Volume (CTV)* is a tissue volume that contains the GTV(s) and/or subclinical malignant disease at a certain probability level. This volume thus has to be treated adequately.
Clinical Target Volume (CTV)

- The Clinical Target Volume, like the GTV, is a clinical-anatomical concept.
- Even if the cell density is as high as $10^3$/mm$^3$, the cells still cannot be detected clinically and thus are considered as a **subclinical volume**, but nevertheless part of the CTV
Clinical Target Volume (CTV)

- **CTV**
  - **CTV-T** (if the same dose is prescribed to both GTV and CTV)
  - **CTV-N** (additional volumes with presumed subclinical spread, e.g. regional lymph nodes)
    - If more than one CTV-N
      - CTV-N1, CTV-N2, ....

*Note: CTV-T and CTV-N (ICRU 71) is denoted CTV-I and CTV-II, respectively, in ICRU 50/62*
Expansion of GTV to CTV

From ICRU 71

Figure 2.4. Schematic illustration of the relations between GTV(s) and CTV(s) in different clinical situations.
 Clinical Target Volume (CTV)

Delineation of the CTV is based on:

- the available data on the probability of (subclinical) malignant cells outside the GTV
- the judgment of the radiation oncologist
The Planning Target Volume (PTV) is a geometrical concept, introduced for treatment planning.
Planning Target Volume (PTV)

- The PTV surrounds the CTV with an additional margin to compensate for the different types of variations and uncertainties of the beam relative to the CTV
Planning Target Volume (PTV)

- The PTV is used to select the appropriate beam sizes and beam arrangements to ensure that the prescribed dose is actually delivered to all parts of the CTV.
Penumbra

- The beam sizes are defined by the 50% dose-level
- The gradual dose fall-off (penumbra) is not considered when delineating the PTV.
- When selecting the beam sizes, the width of the penumbra has to be taken into account and the beam size must be enlarged accordingly to ensure coverage of the PTV by the prescribed dose.
Expansion of CTV to PTV: Margins

- **Internal margin (IM)**
- **Set-up margin (SM)**
Internal Margin (IM)

- IM compensates for expected physiological movements and variations in size, shape, and position of the CTV during therapy
- IM is often asymmetric around the CTV
IM: Breathing

Figure 2.5. Patient with cancer of the left breast after lumpectomy and whole-breast irradiation, now planned for electron boost irradiation to the tumor bed. The relations between the different volumes and margins are shown in one planar section. The internal and external reference points are indicated. Owing to respiratory movements, the PTV extends outside the average position of the body contour.

Key:
- Light red: CTV (Clinical Target Volume)
- Light blue: PTV (Planning Target Volume)
- Light green: PRV (Planning Organ at Risk Volume)
- ->: OAR (Organ at Risk, in this case the left anterior descending coronary artery, shown here as projected onto the section)
- Average position of the body contour
- Body contour at maximum inspiration
- Internal Reference Point
- External Reference Point

From ICRU 71
Set-up Margin (SM)

- SM accounts for uncertainties (inaccuracies and lack of reproducibility) in patient positioning and alignment of the therapeutic beams during treatment planning and through all treatment sessions.

- The uncertainties vary with different anatomical directions, and thus the size of such margins depends on the selection of beam geometries.
Set-up Margin (SM)

SM is needed due to

- variations in patient positioning
- mechanical uncertainty of the equipment (e.g. sagging of the gantry, collimators, and couch)
- dosimetric uncertainties
- transfer of set-up errors from CT and simulator to the treatment unit
- human factors
Adding uncertainties

- The margins should compensate for both random ($\sigma$) and systematic ($\Sigma$) uncertainties

- adding quadratically

$$\sum = \left( \sum_{\text{set-up}}^2 + \sum_{\text{organ motion}}^2 + \sum_{\text{delineation}}^2 \right)^{1/2}$$

$$\sigma = \left( \sigma_{\text{set-up}}^2 + \sigma_{\text{organ motion}}^2 \right)^{1/2}$$
Adding uncertainties

- Coordinate system (IEC 1217) to define positions and uncertainties

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Figure 2.9. The IEC patient coordinate system (the patient is lying in supine position) (IEC, 2000).

Figure 2.11. Coordinate system for a therapy machine and patient support system (IEC, 1996).
How to add $\Sigma$ and $\sigma$?

- Several formulas suggested in the literature
- Setting margin according to: $2 \Sigma + 0.7\sigma$ ensures $> 95\%$ of the dose to $99\%$ of the CTV
From GTV to CTV to PTV

From ICRU 71
Organ At Risk (OAR)

- Organs at Risk ("critical normal structures") are normal tissues (e.g., spinal cord) whose radiation sensitivity may significantly influence treatment planning and/or prescribed dose.
Planning Organ at Risk Volume (PRV)

- Any movements of the OARs, as well as uncertainties in the set-up must be considered
- An integrated margin has to be added to the OAR using the same principles of IM and SM as for the PTV
- This leads, by analogy with the PTV, to the concept of Planning Organ at Risk Volume (PRV)
More OARs: Left lung
More OARs: Right lung
More OARs: Heart

PTV overlapping OAR
2D representation
Let’s have a look in "3D"
Inter-doctor variation
Doses
Treatment planning
Dose distribution
The ICRU reference point

- The dose at the ICRU reference point should be clinically relevant and representative of the dose distribution throughout the PTV
- The point should be easy to define in a clear and unambiguous way
- The point should be selected where the dose can be accurately determined
- The point should be in a region where there is no large dose gradient
The ICRU reference point

- A point located at the center (or central part) of the PTV generally fulfills these requirements and is recommended as the ICRU Reference Point
- When possible at the intersection of the beam axes
Dose Volume Histogram (DVH)

ICRU recom: -5% to +7% OK

Differential DVH
Dose Volume Histogram (DVH)

Cumulative DVH
Dose values for "our" PTV

- ICRU reference dose, $D_{ICRU}$: 100 % (66.0 Gy)
- Minimum dose, $D_{\text{min}}$: 95.3 % (62.9 Gy)
- Maximum dose, $D_{\text{max}}$: 104.7 % (69.1 Gy)
- Average dose, $D_{\text{avg}}$: 100.6 % (66.4 Gy)
- Median dose, $D_{\text{med}}$: 100.5 % (66.3 Gy)
- Standard deviation $D_{\text{SD}}$: 1.3 % (0.9 Gy)
How to report?

3 levels recommended:

- Level 1 (simple techniques) based on e.g. PDD-tables
  - $D_{ICRU}$ and estimates of $D_{\text{min}}$ and $D_{\text{max}}$ to the PTV shall be reported

- Level 2 (3D CT-based treatment planning, GTV, CTV, PTV, OAR, PRV defined, DVHs)
  - $D_{ICRU}$, $D_{\text{min}}$ and $D_{\text{max}}$ to the PTV shall be reported
  - Other parameters derived from DVHs, e.g. $D_{\text{avg}}$, $D_{\text{SD}}$, $PTV_{95}$, etc.

- Level 3 (advanced developing techniques)
  - $D_{ICRU}$, $D_{\text{min}}$ and $D_{\text{max}}$ to the PTV shall be reported
  - Other parameters ??????
Fig. 3.1.b. Two opposed equally weighted 8 MV photon beams. The ICRU Reference Point (100%) is midway between the beam entrances and is also in the center of the PTV. The dose variation in the PTV is from 102% to 95%.

From ICRU 50
How to report

Doses to OARs (difficult)

- At least $D_{\text{max}}$
The Treated Volume is the tissue volume which receives at least the absorbed dose selected as the minimum dose to the PTV (or some specified percentage of the PTV) and specified by the radiation oncology team as appropriate to achieve tumor eradication or palliation, within the bounds of acceptable complications.
The Conformity Index (CI) is defined as the ratio of the Treated Volume to the PTV.

\[ CI = \frac{TV}{PTV} \]
Irradiated volume (IV)

The Irradiated Volume is the tissue volume which receives a dose that is considered significant in relation to normal tissue tolerance.
Doses and volumes for "our" case

PTV doses

- ICRU reference dose, $D_{ICRU}$: 100 % (66.0 Gy)
- Minimum dose, $D_{min}$: 95.3 % (62.9 Gy)
- Maximum dose, $D_{max}$: 104.7 % (69.1 Gy)
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Volumes (cm$^3$)

- GTV 59
- CTV 115
- PTV 266
- TV 492
- IV 2450

Conformity Index

CI=492/266=1.85