Abstract

The International Commission on Radiation Units and Measurements (ICRU) has published the Report 50 "Prescribing, Recording, and Reporting Photon Beam Therapy" (1993). The aim of the Report is to promote the use of a common set of definitions and concepts for specifying and reporting the doses in radiation therapy, as well as the volumes in which they are prescribed and delivered.
Different volumes need to be identified prior to treatment planning: the gross tumour volume (GTV) and the clinical target volume (CTV). The planning target volume (PTV) is defined for treatment planning. The treated volume and the irradiated volume are identified when the treatment techniques and irradiation plan have been decided upon.

As a general recommendation, the dose at, or near, the centre of the PTV, as well as the maximum and the minimum dose, shall be reported. Additional information when clinically relevant and available, should also be reported.

The system of recommendations for reporting dose is based on the selection of a point within the PTV, which is referred to as the ICRU Reference Point. The ICRU Reference Point is selected firstly at the centre, or in the central part, of the PTV, and secondly on, or near, the central axes of the beams.

A certain degree of inhomogeneity of the absorbed dose throughout the PTV cannot be avoided. Therefore, as a basic requirement, the best estimate of the maximum dose and the minimum dose to the PTV shall be reported together with the dose at the ICRU Reference Point. These 3 dose values then indicate the dose profile within the PTV.

ICRU Report 50 allows for reporting basic data for all treatments at any level of complexity for absorbed dose computation. It also allows for reporting additional clinical and relevant data obtained by sophisticated methods. The recommendations are thus applicable to all external radiotherapy procedures.

INTRODUCTION

If the irradiation techniques would be so perfect that it would be possible to irradiate the full "volume to be treated", in a homogeneous way (e.g. 60 Gy), and with (quasi) no dose to the surrounding normal tissues, the situation would be very simple. In this ideal situation, the prescribed dose would be 60 Gy, the recorded dose (in the patient treatment chart) would also be 60 Gy, and the reported dose (e.g. for publication, or multicentre studies) would be 60 Gy.

Unfortunately, it is not the case and within the "volume to be treated", one can identify a maximum and a minimum dose and, from the dose distribution, one can derive a mean or (several) weighted mean doses. In addition, some normal tissues receive dose levels which are high, often similar to the prescribed dose and which sometimes exceed their tolerance limit.

Actually, due to the limitations of the available irradiation techniques, the differences between the maximum and the minimum doses often reach 10, 15 and even 20%. Therefore, one can introduce large discrepancies depending on the criteria (thus the dose levels) used for prescribing, recording and reporting the treatment.
Figure 1: "Box technique" using 4 photon beams of 18 MV which converge toward one point. The dose distribution in the plane containing the beam axes (central plane) is displayed, as well as the dose profiles along the AP and left-right beam axes. The PTV (Planning Target Volume) is represented by the hatched area. According to ICRU Report 50, the dose should be specified at the centre of the PTV, at the intersection point of the 4 beams (indicated as 100%). The maximum and minimum doses within the PTV are 103% and 95% respectively. As can be seen from the dose distribution in the central plane and from the two dose profiles, the point at the intersection of the beams fulfils the criteria recommended in Table I. This would obviously not be the case if the specification point would have been selected at the periphery of the PTV.
The International Commission on Radiation Units and Measurements (ICRU) has recognized the importance of the problem many years ago and, in 1978, published Report 29 "Dose specification for reporting external beam therapy with photons and electrons".

Since then, it became clear that further interpretation of the concepts have become necessary, as well as more guidelines in order to apply the recommendations more widely. In addition, the rapidly expanding use of computers in radiotherapy, allowing for a better 3-D dose distribution, is changing clinical practice. In 1993, the ICRU published Report 50 "Prescribing, recording and reporting photon beam therapy", which superseded Report 29.

For other radiotherapy techniques, the problem of dose specification has also been studied by the ICRU, who in 1985 published Report 38 "Dose and volume specification for reporting intracavitary therapy in gynaecology". The Report "Dose and volume specification for reporting interstitial therapy" is now in press. Other ICRU Reports dealing with dose specification for special techniques, such as electron-, proton-, and neutron-beam therapy and BNCT (Boron Neutron Capture Therapy), are in preparation.

Before discussing the specification of the doses, it is necessary to define the volumes in which the doses are delivered.

**DEFINITION OF VOLUMES**

The process of determining volumes for the treatment of a malignant disease consists of several distinct steps during which different volumes may be defined.

The two first ones are defined prior to treatment planning: the Gross Tumour Volume and the Clinical Target Volume.

During the treatment planning process, other volumes have to be defined: the Planning Target Volume and the Organs at Risk.

As a result of treatment planning, further volumes can be described: the Treated Volume and the Irradiated Volume.

**Gross tumour volume (GTV)**

From the origin of medical terminology the word tumour was used to designate a swelling which could be of different natures.

The Gross Tumour Volume (GTV) is the gross palpable or visible/demonstrable extent and location of malignant growth.

The GTV may consist of the primary tumour, metastatic lymphadenopathy(ies), or other metastases.
The shape, size and location of the GTV may be determined by means of different diagnostic methods such as clinical examination (e.g. inspection, palpation, endoscopy), and various imaging techniques (e.g. x-ray, CT, ultrasound, magnetic resonance imaging and radioisotope methods).

The GTV may seemingly be different in size and shape, sometimes significantly, depending on what examination technique is used for evaluation (e.g. palpations vs mammography for breast). Therefore the therapist should, in each case, indicate which methods have been used for evaluation and delineation of the GTV.

The Gross Tumour Volume should be described in standard topographical or anatomical terms, e.g. "tumour of the roof of nasopharynx with metastatic nodes in the sternomastoid chain bilaterally in the neck". In many situations, a verbal description might be too cumbersome and also, for the purpose of data recording and analysis, a classification system is needed. Several systems are proposed for coding the anatomical description; some of them are mentioned in ICRU Report 50.

There are at least 3 reasons to identify the GTV. Firstly, accurate description of the GTV is needed for staging (e.g. TNM). Secondly, identification of the GTV is necessary to allow for recording of tumour response in relation to the dose and other relevant factors. It can be used (carefully ?) as a prognostic factor. Thirdly, an adequate dose must be delivered to all parts of the GTV in order to obtain local tumour control in radical treatments.

Clinical Target Volume (CTV)

Clinical experience indicates that around the GTV there is in general subclinical involvement, i.e. individual malignant cells, small cell clusters, or microextensions which cannot be detected by the staging procedures. The GTV together with this safety margin consisting of tissues with presumed or proved subclinical involvement is defined as a Clinical Target Volume (CTV). The tissues immediately surrounding the GTV have usually a high malignant cell density close to the edge of the GTV; the cell density decreases towards the periphery of the CTV.

Additional volumes (CTVs) with presumed or proved subclinical spread (e.g. regional lymph nodes) may also be considered for therapy.

The Clinical Target Volume (CTV) is a tissue volume that contains a demonstrable GTV and/or subclinical microscopic malignant disease. This volume has to be treated at an adequate dose level (and time-dose pattern) in order to achieve the aim of therapy, cure or palliation.

If different doses are prescribed, different CTVs have to be defined. Thus, for any given situation, there is often more than one CTV. One situation can be illustrated by considering
a primary tumour and its regional lymphatics separately (e.g. in breast saving procedures where the breast and regional lymphatics are separated anatomically). In other situations, the aim is to treat two CTVs at different dose levels ("boost" therapy), where the "high-dose" volume (often containing the GTV) is located inside the "low-dose" volume.

Delineation of a CTV will require consideration of factors such as the local invasive capacity of the tumour and its potential to spread to, e.g. regional lymph nodes.

One has to stress that definitions of the GTV and CTV are based only on general oncological principles, and are not specific to the field of radiation therapy. For example, in surgery, a safety margin is taken around the gross tumour volume according to clinical judgement, and this implies the use of the same Clinical Target Volume concept as in external beam therapy. Also, in brachytherapy, volumes to be irradiated are defined, and thus the concept of CTV is applied. Furthermore, the concept can be applied to other modalities, e.g. hyperthermia or photocoagulation.

Planning Target Volume (PTV)

To ensure that all tissues included in the Clinical Target Volume (CTV) receive the prescribed dose, one has, in principle, to plan to irradiate a volume geometrically larger than the CTV. It is the Planning Target Volume or PTV.

The additional safety margin, included in the PTV, results from a number of factors:

- movements of the tissues which contain the CTV (e.g. with respiration), as well as movements of the patient.

- variations in size and shape of the tissues that contain the CTV (e.g. different fillings of the bladder, rectum, stomach).

- all variations and uncertainties in beam geometry and patient-beam geometry. There are some uncertainties in the beam sizes, shapes and directions, as well as in the relative position of the beam with respect to the patient, the CTV and the normal tissues.

- all uncertainties in dose distribution, especially in or close to the penumbra region (see below), or where inhomogeneities have to be taken into account (e.g. beam penetration for electron beams).

The above uncertainties in dose distribution and geometry depend also on the quality of anatomical data acquisition. They may vary from centre to centre, and within a given centre from machine to machine. The use of patient immobilization devices and the skill and experience of the radiographer's team are important factors which have also to be taken into account.
Finally, the safety margin depends on the beam arrangement that the radiation oncologist will select.

When delineating the PTV, consideration may also be given to the presence of any radiosensitive normal tissue (organs at risk) as well as to other factors such as the general condition of the patient.

*The Planning Target Volume is a geometrical concept, used for treatment planning, and it is defined to select appropriate beam sizes and beam arrangements, taking into consideration the net effect of all the possible geometrical variations, in order to ensure that the prescribed dose is actually absorbed in the CTV.*

The dose distribution to the PTV has to be considered to be representative of the dose to the CTV. The PTV has thus to be clearly indicated on the different sections used for treatment planning.

Delineation of the PTV is a matter of compromise implying the judgement and thus the responsibility of the radiation oncologist and radiation physicist. In particular, it is not recommended that all uncertainties be added linearly because this would probably lead to too large margins, resulting in unnecessary side effects.

The penumbra is not included in the PTV margin. Penumbra has to be taken into account separately considering dose distribution.

**Treated Volume**

Due to the limitations of the irradiation techniques and in some specific clinical situations, the volume receiving the prescribed dose may not match accurately the PTV; it may be larger (sometimes much larger) and in general of a simpler shape. This leads to the concept of treated volume. It is defined when the treatment planning procedure is completed and the beam arrangement approved as well as all the other irradiation parameters.

*The treated volume is the tissue volume which (according to the approved treatment plan) is planned to receive at least a dose selected and specified by the radiation-oncologist as being appropriate to achieve the purpose of the treatment, e.g., tumour eradication or palliation.*

The treated volume is thus the volume enclosed by the isodose surface corresponding to that dose level. For example, if the prescribed dose is 60 Gy, with an accepted variation of ± 5%, the treated volume is enclosed by the 57 Gy isodose surface.
Normally, in the patient, the tissue volume which actually receives that dose level (i.e. "actual" treated volume) should match the "planned" treated volume. It is the goal of the quality assurance procedures.

**Irradiated Volume**

**The irradiated volume is the tissue volume which receives a dose that is considered significant in relation to normal tissue tolerance.**

If the irradiated volume is reported, the significant dose must be expressed either in absolute values (in Gy) or relative to the specified dose to the PTV. The irradiated volume depends on the treatment technique used.

**DOSE SPECIFICATION FOR REPORTING**

**General recommendations for reporting doses**

The dose at or near the centre of the Planning Target Volume as well as the maximum and the minimum dose to the PTV shall be reported.

Additional information, when available and clinically relevant, should also be reported, i.e. average dose (and its standard deviation) in different volumes, biologically weighted average doses in different volumes, dose/volume histograms, etc.

**The ICRU reference point**

The present system of recommendations for reporting is based on the selection of a point within the PTV, which is referred to as the ICRU reference point. The dose at the ICRU reference point shall always be reported. The ICRU reference point shall be selected according to the 4 general criteria listed in Table I.

The criteria listed in Table I will be met if the ICRU reference point is located firstly at the centre, or in the central part, of the PTV, and secondly on the central axes of the beams.

In some situations, the conditions do not allow for the ICRU reference point to be localized both at (or near) the centre of the PTV, and also on the beam axes. In these cases, the first criterion, i.e. localization at (or near) the centre of the PTV should be given preference.

In some situations, it will be found that the centre of the PTV will not be a meaningful concept, if it is taken to imply the purely geometrical centre or the centre of gravity. Such a definition could result in the centre being outside the tissues.
TABLE I

Criteria for selecting the ICRU reference point

(a) the dose at that point should be clinically relevant and representative of the dose throughout the PTV;

(b) the point should be easy to define in a clear and unambiguous way;

(c) the point should be selected where the dose can be accurately determined (physical accuracy);

(d) the point should be selected in a region where there is no steep dose gradient.

represented by the PTV (e.g. when treating the chest wall, where the centre of gravity of the PTV may be in healthy lung tissue, or, in the case of treatment of the regional lymph nodes of a pelvic tumour, where the PTV may be ring-shaped, and its centre of gravity is not in the tissue concerned).

In these cases, one has to select the ICRU reference point inside the tissues represented by the PTV, and in a place where dose specification is considered to be meaningful. Such a place could be in the GTV (Gross Tumour Volume).

The dose variation throughout the PTV

A certain degree of inhomogeneity of the absorbed dose throughout the PTV cannot be avoided.

As a minimum requirement, the maximum dose and the minimum dose to the PTV shall be reported, together with the dose at the ICRU reference point. The three dose values then indicate the dose to the CTV and the dose variation.

Other dose values considered to be relevant, when available, should also be reported, as indicated above.

The three levels of dose evaluation for reporting

The level of completeness and accuracy of reporting a therapeutic irradiation depends to a large extent on the situation in the department and on the aim of the treatment. For different clinical and practical considerations, different levels of ambition for dose evaluation can be identified. Three levels have been selected for reasons given below, but it is recognized that intermediate levels could also be identified.
Level 1: Basic techniques

The minimum requirements for reporting, as indicated above, can be followed in all centres, including those with restricted therapy equipment, dosimetric, computer, and staff facilities. This minimum level may sometimes be sufficient, in any centre, when simple treatments are performed (e.g. some palliative treatments).

At this level, it is assumed that the dose at the ICRU reference point and an estimate of the maximum and minimum doses to the PTV can be determined using, e.g. central axis depth dose tables. Some information about the dose outside the beam axis could also be obtained by means of standard isodose charts.

Level 2: advanced techniques

At this level, it is assumed that the GTV, CTV and PTV can be defined in one or more planes, using reliable patient data acquisition tools, and/or modern imaging techniques under reliable conditions (e.g. a series of CT and/or MRI sections).

It is also assumed that complete dose distributions are computed in the central plane and in other planes using central plane dose data, and with inhomogeneity corrections, when appropriate.

The standards of dose planning at this level allow the exchange between different centres of more complete and relevant information.

Level 3: developmental techniques

The performance of dose planning at level 3 provides for the development of new techniques and clinical research in radiotherapy.

At this level, 3-D dose computation of any beam arrangement and dose-volume histograms are available. It is only when 3-D dose computation is available that the "true" maximum and minimum dose levels in the PTV (volume) can be obtained.

Complex treatments with more than one PTV

With the increasing complexity of radiotherapy treatments, more than one PTV is frequently identified. In practice, the two most common situations are adjacent PTVs and overlapping PTVs.

Adjacent PTVs

In this situation, the PTVs are adjacent to each other; they do not overlap. A typical example may be the postoperative treatment of breast cancer including the breast and chest wall, and the regional lymphatics. When the PTVs are adjacent to each
other, as a minimum requirement, the dose to each PTV (at its ICRU reference point, as well as the maximum and the minimum dose to each PTV) should be reported. Note that since treatment of one PTV may give a dose contribution to the other PTV, reporting at level 1 may give information that does not take this into consideration.

**Overlapping PTVs**

In this situation, one PTV is totally contained within the confines of the other. A typical example is the boost technique. In this case, again, two situations may occur:

- the beam axes of the two PTVs are identical and the centres coincide
- the centres of the two PTVs and the beam axes differ

When the PTVs are overlapping the following procedures are recommended:

**At level 1:**

The dose to the ICRU reference point and the maximum and minimum dose to each PTV for each part of the treatment are calculated along the central beam axes and should be reported accordingly. At level 1, the report is confined to a simple description of technique.

**At levels 2 and 3:**

The dose distribution for each PTV are calculated and added and the dose to each ICRU reference point, as well as the maximum and minimum dose for each PTV, are reported, taking into account the cumulative contribution to each PTV. For the smaller PTV, the criteria of central position of the ICRU reference point in the PTV can usually be met. For the larger PTV, an ICRU reference point has to be selected at a specially selected position considered to be significant for tumour control in this PTV.

**Organs at risk and hot spots**

When reporting at level 3 is possible, dose-volume histograms for organs at risk, average doses, biologically weighted quantities, etc. could also be reported.

A Hot Spot represents a volume outside the PTV which receives the dose larger than 100% of the specified PTV dose. If a hot spot occurs, its size and position should be reported.

**DISCUSSION**

**THE DEFINITION OF VOLUMES**

In principle, the number of volumes to be defined (and on which one should agree) has to be kept as small as reasonably possible.
Gross Tumour Volume and Clinical Target Volume

They are pure oncological concepts and should be part of the medical record. Ideally, the GTV and CTV should be defined "collegially" by all clinical teams involved in the patient treatment, or at least the information should be made available to them. These two volumes are independent from any treatment method.

Planning Target Volume

The PTV is a geometrical concept used for treatment planning. When going from the CTV to the PTV, the additional safety margin depends on the technique and indeed may vary to a large extent with the selected technique.

For example, depending whether the patient is heavily suffering, restless or not, there are considerable differences in the inaccuracies or sources of mistakes and, as a result, this influence the thickness of the accepted safety margin.

If during the course of the treatment planning procedure, several plans are considered successively and compared (e.g. use of electron boost or not, change of machine, etc.), different PTVs may have to be delineated.

As mentioned above, one can identify different causes of uncertainties and for each of them propose a corresponding safety margin. It is not realistic to add (linearly) all these safety margins, since it could lead to too large PTVs which are probably useless for local cure and would certainly increase the risk of complications. The thickness of the final safety margin should thus be decided based on clinical judgement and experience. Of course, systematic analysis of some of the uncertainties may help to select the safety margin on more objective basis.

The use of the concept of PTV is needed during treatment planning and also for dose specification (for reporting).

Depending on the clinical situation, and on the selectivity of the irradiation technique, the PTV could be very similar to the CTV (e.g. small skin tumours, pituitary tumours) or in contrast much larger (e.g. bronchus carcinoma).

In most of the situations, the dose at the ICRU reference point (centre of the PTV) is close to the dose at the centre of the CTV. The maximum dose in the PTV is often the maximum dose in the CTV. In contrast, the minimum dose to the PTV is often lower than the minimum dose to the CTV (it is in principle its lowest limit). This is one of the reasons why the minimum dose to the PTV is probably not always relevant clinically.
Treated Volume, Irradiated Volume

The treated volume is fixed as soon as the treatment technique has been decided upon ("planned" treated volume). Determination of the "actual" treated volume in the patient implies quality control procedures. The same is true for the irradiated volume.

Differences between CTV, PTV, Treated Volume and Irradiated Volume reflect both the complexity of the clinical situation and the limitations of the radiotherapy techniques. They are important optimization parameters.

A recurrence within the treated volume is a true "in-field" recurrence due to inadequate dose (or inadequate time-dose pattern) or treatment delivery.

A recurrence adjacent to the treated volume is a "marginal" recurrence due to inadequate volume delineation (wrong evaluation of the CTV and/or PTV) or a mistake in treatment delivery.

DOSE SPECIFICATION FOR REPORTING

The ICRU reference point

ICRU report 50 recommends that a point in the centre, or in the central part, of the PTV be selected as the ICRU reference point and that the dose at that point be defined as the ICRU reference dose.

It is mandatory to report the ICRU reference dose and to describe the dose variation by reporting also the maximum and the minimum dose to the PTV.

The dose at the ICRU reference point is clinically relevant and can be considered as representative of the dose distribution throughout the PTV (Fig. 1). The point is easy to describe in an unambiguous way and it is located in a region where there is little dose gradient. Lastly, as far as dosimetry is concerned, the dose on the beam axes can be determined most accurately.

The isodose envelope

Some centres, traditionally, select the isodose surface encompassing at best the PTV and the corresponding dose level is used for reporting the dose to the PTV. The objective with this approach is to ensure that all tissues containing malignant cells will receive at least the prescribed dose. This practice is equivalent to report only the minimum dose to the PTV; it has several shortcomings.

The minimum dose is certainly not representative of the dose distribution to the PTV; most parts of it receive significantly larger doses (+15%, +20%, ...). Tumour regression and tumour control can thus not be correlated with this minimum dose. In general the minimum dose will be received by only a few cells or
often by no cell at all, depending on the distributions of the malignant cells in the safety margin. Of course we are not dealing here with a "geographical miss" of e.g. a part of the GTV! Lastly, the envelope isodose is generally located in an area where there is a high dose gradient and where in addition it is difficult to determine the dose accurately. The true minimum and maximum doses in the PTV can be reported only if 3-D dose computation is available.

For a given treatment the minimum dose in the PTV depends on the delineation of the PTV itself and thus on the safety margins which were selected to define the CTV and the PTV. For a given clinical situation, the safety margins may largely differ from a therapist to another one.

As recommended above, the best estimate of the minimum dose to the PTV has to be reported, but together with the dose at the ICRU reference point and the maximum dose to the PTV.

Average doses and biologically weighted average doses

According to biological models, the average dose to the cancer cell population is the parameter which should be best correlated with the treatment outcome (provided the dose heterogeneity is not too large).

However there may be several cancer cell populations with various radiosensitivities (e.g. hypoxic, quiescent, etc.) and in addition the cancer cell density varies to a large extent within the PTV. It is difficult today to take these variations into account in a clinically relevant way and the average dose to the PTV is thus probably not the average dose to the relevant cancer cell population.

This strongly weakens the value of the average dose to the PTV as the most relevant parameters to describe the treatment.

In addition, determination of average doses and biologically weighted average doses for reporting requires sophisticated computing facilities (e.g. at least 3-D treatment planning). Today only part of the centres in the world can perform these complex computations, and this approach can thus not be recommended as the only one for reporting a treatment.

However the need for collecting all possible relevant information is fully recognized and, as stressed before, the average doses, when clinically relevant, should be reported when available, but in addition to the set of the three values already recommended: i.e. the dose at the ICRU reference point and the maximum and minimum dose to the PTV.
REFERENCES

International Commission on Radiation Units and Measurements (ICRU):


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