DEFINITION OF TREATMENT GEOMETRY IN RADIATION THERAPY

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Abstract

When accurate systems for quality assurance and treatment optimization are employed, a precise system for fixation and dosimetric and portal verification are as important as a continued and standardized code of practice for dosimetry and patient follow-up, including registration of tumor responses and acute and late normal tissue reactions. To improve the accuracy of existing dose response relations in order to improve future therapy the treatment geometry and dose delivery concepts have to be accurately defined and uniformly employed. A Nordic working group was set up in 1991 (by Nordic Association of Clinical Physics) to standardize the concepts and quantities used during the whole radiotherapy process in the Nordic countries. Now the group is finalizing its report "Specification of Dose Delivery in Radiation Therapy". The report emphasizes that the treatment geometry shall be consistent with the geometry used during the diagnostic work up. The patient fixation is of importance early in the diagnostic phase to ensure that the same reference points and patient position will be used both during the diagnostic work up, simulation and treatment execution. Reference Coordinate System of the patient is a concept based on defined anatomic reference points. This Patient Reference System is a local system which has validity for the tissues, organs and volumes defined during radiotherapy. The reference points of the Patient Reference System should in turn be used for beam set-up. The treatment geometry is then defined by using different concepts describing tissues which are mobile in the Patient Reference System, and finally, volumes which are fixed in this coordinate system. A Set-up Margin has to be considered for movements of the volumes defined in the Reference Coordinate System of the Patient in relation to the radiation beam. The Set-up Margin is dependent on the treatment technique and it is needed in the treatment planning procedure to ensure that the prescribed dose to the Target Volume is delivered.

1. INTRODUCTION

The performance of external beam radiation therapy accelerators and other radiation therapy devices has been developed considerably during the last two decades with regard to the quality and precision of the beams through new target and filter designs, improved stability of the accelerators, increased flexibility in beam collimation systems and compensation techniques and improved dosimetric and geometric treatment verification methods. New powerful 3 dimensinal diagnostic equipment has been developed starting from computed tomography to magnetic resonance imaging and spectroscopy. Simultaneously computerized treatment planning and dose delivery optimization methods have been developed considerably. Partly due to the inaccuracies in basic definitions one of the weak links in this development has been the way we define our target volumes and specify and prescribe the dose delivery.

An investigation among the Nordic radiotherapy centres in 1991 confirmed that inconsistent use of dose and volume concepts is jeopardizing the high standard of radiation therapy [1]. A Nordic Working group was set up by NACP to standardize the concepts and quantities used throughout the whole radiation therapy process. Now the group is finalizing its report "Specification of Dose Delivery in Radiation Therapy" [2]. One of the main subjects is the definition of treatment geometry in radiation therapy. The aim has been to recommend the use of concepts based on recent scientific developement in the field of radiation therapy which are needed for the developement of daily clinical practice.

The principal aim the draft report is to treat the situation at clinics with state of the art equipment and procedures. For obvious reasons the NACP report is also written primarily with the fairly uniform equipment situation in the Nordic countries in mind. However, it is our firm belief that once general high quality procedures have been developed for advanced equipment they can also be transferred and adopted to more traditional equipment once the basic underlying principles have been developed. Many of the definitions introduced have obvious counterparts in classical radiation therapy procedures, even though they are not always coinciding with all established methods since some new proposals have had to be made for new irradiation techniques. These proposals have evolved in discussions among radiotherapists and physicists in the Nordic countries during the last five years. Of course they have also been considerably influenced by discussions with, and work of (ICRU 50 [3]) the international radiation therapy community.

2. DEFINITION OF REFERENCE POINTS AND TREATMENT GEOMETRY

In the following the methods of defining the treatment geometry suggested by the NACP-draft report are presented.

2.1. Reference points and alignment markings

2.1.1. Reference coordinate system of the patient

The concept of a reference coordinate system of the patient is based on defined anatomic reference points. The patient reference system is local system which has validity for the tissues, organs and volumes defined during radiotherapy. There does not exit a general patient reference system, since the human body is not rigid. The patient reference system is defined with one of the anatomic reference points and the other reference points (or markings on the skin) are for orientation of the system and alignment of the patient. This is illustrated in Fig 1 for a cervix cancer patient. Note that alignment markings for patient set-up can not always be firmly connected to the reference points such as the symphysis or the sternal notch. The coordinate system with external reference points should therefore preferably be used for beam set-up in order to have a "more rigid" relation to the target volume than the more uncertain skin mark often used in radiotherapy. The reference points are preferably defined already during the diagnostic stage so that they can be used for a coherent set up on all imaging modalities and on the treatment machines. The reference points will then be able to work as markers for image matching and fusion and to form an accurate integrated diagnostic data set as a base for the planning procedure. During dose planning the reference points are used for the location and definition of the isocenter relative to the reference point as defined and indicated on the dose plan.

The tissues, organs and volumes delineated for radiation therapy planning should be defined in relation to the reference point of the patient coordinate system. These reference points should in turn be used for beam set-up. The aim of using reference points is that the definition of the target volume and beam set-up refers to one and the same local coordinate system. In clinical practice the reference point should be located on the surface of a bony structure, or on the skin close to bony structures. The reference point should: 1) be possible to visualize on simulator or verification films and beams-eye-views plots, 2) be as rigid as possible in relation to the target tissues, 3) be located as close as possible to the target tissues in order to minimize beam set-up errors due to patient misalignment. Unfortunately, a rigid connection between the target tissues and the reference point is rare situation. This implies that an anatomical margin has to be added to the target tissues to account for the movements of the tumor in relation to the reference points when specifying the target volume.

2.1.2. Internal reference points

The internal reference points are located inside the body. An internal reference point is used for beam set-up on the simulator, before the first treatment. The internal reference point should thus be selected so that it can be seen on diagnostic radiographs at the simulator. This makes it possible to have a very accurate beam set-up at the simulator, but also to take simulator films to which treatment unit verification films can be compared.

2.1.3. External reference points

External reference points are palpable or visible and located on the surface of the body or on the surface of fixation devices that fit closely to the exterior of the body (e.g. facemasks and shells). The external reference point may be palpable bony structure, a skin marking or an alignment tattoo preferably where the skin is tight over a bony structure as for example on sternum. The external reference point is used for beam set-up both at the simulator and the treatment unit. The external reference points are normally palpable bony structures which are easy to find. For the extremities this will typically be at the end of the large bones. For the trunc points on the pelvic bones can be used for the lower part, and the sternum for the upper part. For the head the lower point of the mandibula and upper point of the nose can be used for the sagittal plane, and the ears for the lateral points.

2.1.4. External reference systems

The external reference points on the surface of fixation devices may be developed in the form of a local stereotactic system and define an external reference coordinate system in which the target volume is described and defined. Several stereotactic systems has been used for the head. Reproducible systems for the abdomen has also been used. It is important that the same external reference system is used at the CT, at the simulator and at the treatment unit. The coordinates of the isocenter can then be defined in the external reference system during dose planning. Similarly, the internal and external anatomic reference points define the local coordinate system of the patient in which the target volumes and organs at risk should be delineated.

2.2. Treatment geometry

The following definitions are made so general that they pertain both to curative and palliative treatments. For curative therapy the terms target tissues or target cells can be replaced by the clonogenic tumor cells as normal tissues are not generally the target for the treatment. However, the target volume often has to contain normal tissues or ensure a curative dose to all tumor cells. For a postoperative treatment no gross tumor may be left, and the definition of the target tissues consists of the remaining microscopic disease. In some regions, e.g. in the head, the target tissues may be delineated partly by osseous barries, partly by surfaces, or on clinical grounds include areas with known probability of metastases. Thus, by the target tissues is understood the tumorous tissues with a sufficiently high probability of tumor cell spread to be considered for radiation therapy.

DEFINITIONS:

Gross Tumor

The Gross Tumor consists of solid demonstrable malignant tissues in the patient (see Fig. 1) and it is often mobile in the local coordinate system of the patient.

Verified Disease

The Verified Disease includes all demonstrable macroscopic malignant tissues in the patient (see Fig. 1). The verified disease includes all the Gross Tumor and verified nodes and it is often mobile in relation to the local coordinate system of the patient.

Presumed Microscopic Disease

The presumed Microscopic Disease (see Fig. 1) contains or has a high risk of containing clonogenic malignant cells to be eradicated. It is often mobile in the local coordinate system of the patient.

Target Tissues

The Target Tissues contain all verified and/or presumed disease to be treated to a prescribed time-dose pattern (see Fig. 1). To be more precise in radical radiotherapy the target cells are the clonogenic tumor cells of the gross tumor and associated microscopic disease. The Target Tissues are often mobile in the local coordinate system of the patient. The Target Tissues, when treating non malignant disease, will include benign tissues to be treated for example with a palliative intent.

Anatomic Margin

The Anatomic Margin is a margin around the Target Tissues to account for expected movements and/or changes of shape and size of those tissues or cell structures in relation to the reference points in the patient. The anatomic margin also contains possible uncertainties in microscopic spread. The outer boundary of the Anatomic Margin specifies a fixed volume in the local coordinate system of the patient.

Target Volume

The Target Volume is an anatomically defined volume fixed in the coordinate system of the patient, which contains or has a high risk of containing tissues or cells to be treated to a prescribed time-dose pattern. This volume is defined and enclosed by the outer boundary of the Anatomic Margin. The Target Volume is therefore specified in relation to internal and external anatomic reference points (see Fig. 1) which preferably should be rigidly related to each other through bony structures.

Organs at Risk

The Organs at Risk are normal tissues whose presence influence treatment planning and/or dose prescription. Like for the target volume, the location of the organs at risk should be defined in relation to the anatomical reference points.

Treated Tissues

The Treated Tissues are tissues enclosed by an isodose surface in the cumulated dose distribution in the patient being representative for tumor eradication or palliation (e.g. 0,95 x prescribed dose).

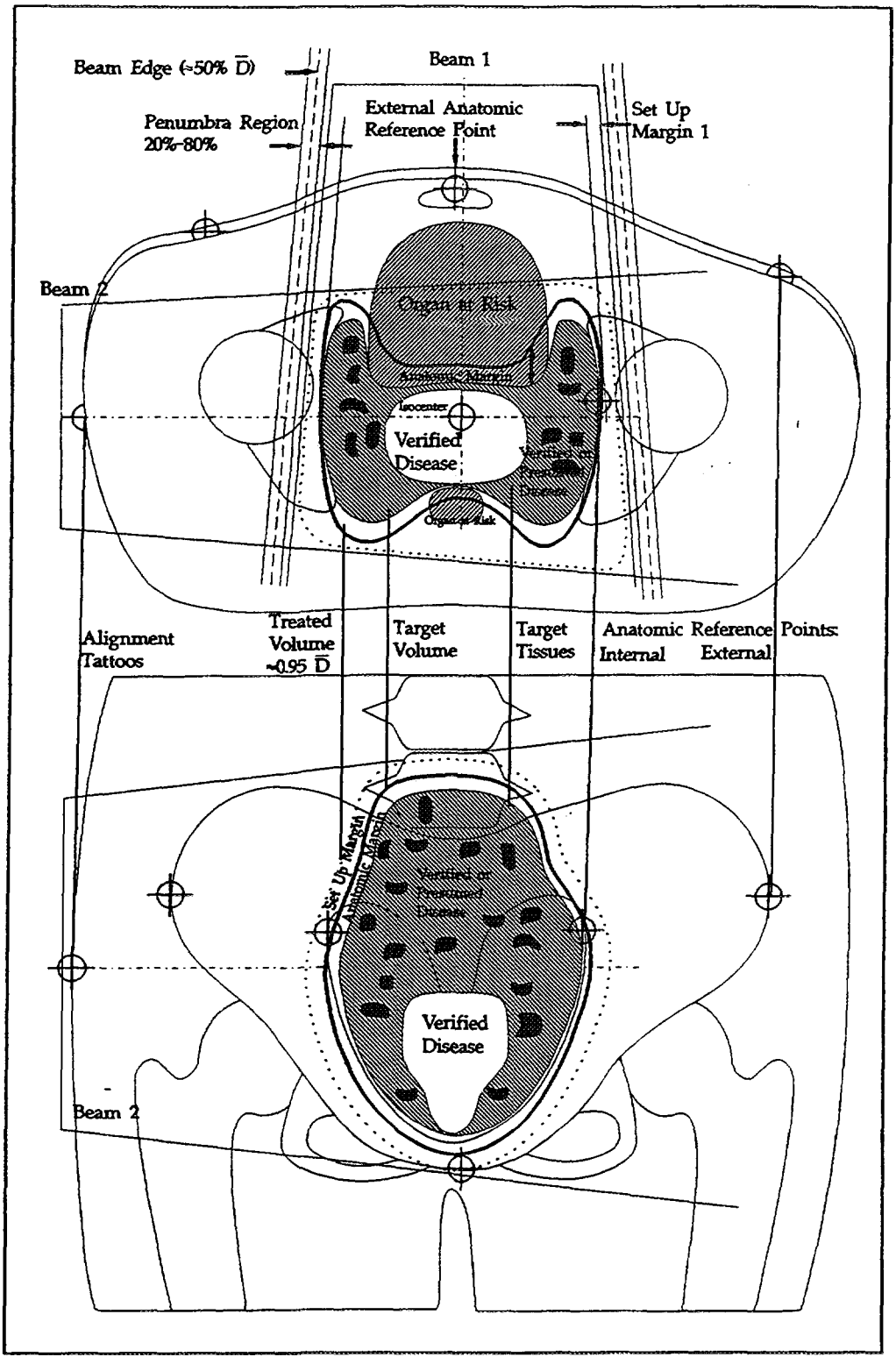

Fig 1. Illustration of the different anatomic reference points, margins, and volume concepts for an advanced cervix tumor. The internal anatomic reference points are essential for simulations and portal verification whereas the external reference points are primarily intended to improve the precision in patient and radiation beam set-up.

Irradiated Tissues

The Irradiated Tissues are tissues which receive a dose that is considered significant in relation to the biological effects of normal tissues.

Cold Region

A Cold Region is a volume inside the Target Volume, which receives a dose lower than the prescribed dose to the Target Volume. For quantification purposes it is recommended that the dose quoted should be the mean value in a volume of 0.1 cm^3 or less.

Hot Region

A Hot Region is a volume, which receives a dose larger than the prescribed dose in the Target Volume. For quantification purposes it is recommended that the dose quoted should be the mean value in a volume of 2 cm^3 or larger. A Hot Region outside the target volume is often called a Hot Spot.

Set-up Margin

The Set-up Margin is a margin for movements of the Target Volume or Organs at Risk in relation to the radiation beam. The Set-up Margin is dependent on the treatment technique and it is needed in the treatment planning procedure for example to ensure that the prescribed dose to the Target Volume is delivered and the dose to healthy normal tissues is as low as possible. This margin has to account for uncertainties in 1) patient positioning (interfractional movements), 2) movements of the patient during each treatment fraction (intrafractional movements), 3) dose planning and treatment technique in general and 4) treatment unit performance characteristics.

3. THE RECOMMENDED USE OF THE CONCEPTS

To deliver the right dose distribution to the target tissues would be no great problem provided there were 1) no uncertainly in microscopic tumor spread, 2) no positional uncertainties due to motions of internal tissues, 3) no uncertainty in the alignment of the patient with the therapy beams and finally, 4) no uncertainty in the delivered dose distributions. All these four categories of uncertainties decrease the probability of achieving complication free control of the tumor growth, especially if they are not accounted for in the planning procedure.

Obviously, the best thing would be if one could eliminate as far as possible the positional and set-up uncertainties by good fixation techniques, possibly combined with synchronization of the irradiation with breathing or other internal motions. However, the uncertainty in microscopic spread is very hard to eliminate both due to patient individual patterns of spread and due to the finite resolution of the diagnostic methods. In the first approximation one would think is does not matter much whether the uncertainty in the location of the target tissues is due to uncertainties in microscopic tumor spread, organ motions, or radiation beam set-up. However, accurate patient set up requires the use of external reference points and thus separation of internal (organ motions or microscopic spread) and external (set up) uncertainties.

When the target volumes and organs at risk have been accurately delineated relative to the reference points the dose delivery technique has to be considered. If there is no reason to expect different sensitivities for the verified gross disease and its presumed microscopic extension and the tumor cell densities are not too different, a single target volume and a uniform dose delivery may be sufficient.

However, if the verified gross disease may contain more resistant cell compartments such as hypoxic tumor cells, and/or if the density of tumor clonogens is considerably lower in the sub clinical region, different dose levels may generally be desirable. The definition of two or more distinct target volumes is then called for and the most suitable dose level for each must be specified.

REFERENCES

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