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Quality Assurancy in Conformal Radiation Therapy

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Background

The National Cancer Institute has funded several Collaborative Working Groups(C WGs) in the last decade to carry out research projects in the area of 3D treatme nt planning, beginning with the particle contracts in 1982 and ending with with t he radiotherapy "Tools" projects, scheduled to complete in March 1994.

In recognition of the state-of-the-art of 3D treatment planning in 1993 the Natio nal Cancer Institute is now in the process of fundings a Cooperative Group to c arry out a clinical trial in 3D conformal radiotherapy.

The headquarters will be located at the offices of the Radiation Therapy Oncolog y Group (RTOG) in Philadelphia with 3D treatment planning support and quality assurance oversight provided through a subcontract with Washington University at St. Louis.

The task of the Cooperative Group will be to determine a new maximum tolerat ed dose to the prostate using 3D conformal radiotherapy thechniques. Then the P hase I/Phase II dose-searching studies will proceed to Phase III studies, in which patients will be randomized to receive conventional radiotherapy or 3D conform al therapy at the higher dose. The completion of this clinical trial can potentially influence the future of radiotherapy by showing whether 3D radiotherapy techni ques have a measurable clinical impact.

The Particle CWG had the most difficult job as they first had to develop the fra mework of the collaborative group that was to be used by subsequent CWGs. T hey had to develop such as "mobile" target volume and "immobile" target volum e in the concepts of treatment planning. These concepts, initially spawned and d eveloped in the CWGs, although the names have been modified by the Internatio nal Commission on Radiation Units (ICRU) to be gross tumor volume(GTV), cli nical tumor volume(CTV) and planning target volume(PTV). In addition, the Part icle CWG developed 1) the first treatment planning protocols for simultaneous tr

eatment planning experiments between institutions using actual patient data, 2) th e first formats for exchanging data by magnetic tape, 3) the first models for eva luating competing plans, such as dose-volume- histograms (DVH), tumor control probability(TCP) and normal tissue complication probability(NTCP), and 4) many of the first 3D tools that are now part of every modern 3D treatment planning system.

Volume and Dose Specification for 3D Conformal Radiation Therapy

In ICRU Report 29, the definition of target volume invluded the oncological safe ty margin and the planning safety margin. For 3D CRT, a clear separation betwe en these two concepts appears to be nacessary in order to ensure that all the tis sue included in the target volume receive the appropriate dose. For example: 1) The target volume can move(e.g. to reference bony structures) due to patient bre athing. 2) The size and shape of the target volume can change(e.g. stomach, bla dder). 3) The inaccuracy of patient and/or beam positioning has to be taken into account.

To account for these factors, the volumes "Gross Tumor Volume", "Clinical Targ et Volume" and "Planning Target Volume" have been proposed by the ICRU W orking Group. GTV is the gross palpable or visible/demonstrable extent and locat ion of the malignant growth. CTV is a tissue volume that contains a GTV and/o r subclinical microscopic malignant disease, which has to be treated. The CTV is thus an anatomical-clinical concept that has to be defined before a choice of tr eatment modality and technique is made.

For 3D CRT, margins have to be added around the CTV to compensate for the effects of organ and patient movements and inaccuracies in beam and patient set up. This leads to the concept of the Planning Target Volume(PTV). The PTV is a geometrical concept, and it is defined to select appropriate beam sizes and be am arrangements, taking into consideration the net effect of all the possible geo metrical variations and inaccuracies in order to ensure that the prescribed dose is actually delivered to the CTV.

Principles of Conformal Radiation Therapy

3D conformal therapy is a mode of high precision therapy designed to conform

the high dose volume to the shape of the tumor in its entire 3D configuration. Multiple static coplanar and noncoplanar fields are used to focus the dose onto t he tumor while maximally excluding normal tissues from the volume receiving h igh radiation doses.

Treatment Planning Optimization

Optimization can be applied to all plan parameters including beam parameters (size, position, wedge angle and orientation, filters, blocks and boluses, relative w eight, energy) and fractionation parameters (dose per fraction, number of fracti ons and their distribution in time). however, this would be a very difficult and time consuming process. It has been shown that impressive results can be achiev ed even with the beam weights being the only optimized parameters.
There are two major components of any optimization systems: 1) the description of the plan goals (optimization model) and 2) the method of achieving the desi red goal (optimization algorithm).
The optimization model is usually expressed in a form of the objective(score) fu nction which describes a figure of merit of a particular plan and is to maximize d or minimized, and/or a set of constraints(requirements) which have to be satisf ied by the optimal plan and which define the domain of all feasible solutions.

The following have been investigated and judged to be clinically useful as object ive functions or components of the objective function: 1) TCP, 2) NTCP, 3) the maximun or minimum dose a volume or given proportion of the volume, 4) the volume receiving dose smaller or larger than a certain limit, 5) the range of dos es to the target volume, 6) the maximum/ minimum/ mean/ integral dose to a re gion of interest.
The optimization algorithm searches the domain of plan variables to find the opt imal plan, that is the set of plan variables parameters such as beam weight, bea m angles, field size and shape etc.) which maximize/minimize the chosen score f unction subject to constraints. A variety of optimization algorithms have been de veloped and those applied to treatment plan optimization can be grouped into the following categories: 1) exhaustive search techniques 2) linear, quadratic, and no n-linear mathematical programming 3) finding a feasible solution 4) inverse soluti on approach 5) heristic algorithms 6) artificial intelligence.

Quality Assurance for Treatment Planning of Conformal Therapy

Quality assurance for the treatment planning and delivery process is a very impo rtant part of high quality radiation oncology patient care. "Quality assurance for t he treatment planning" has often been taken to refer to a limited number of acti vities centered around verifying that the planning system's calculated dose distrib utions were in reasonable agreement with data measured in a limited number of situations. Image-based anatomy and target definition, conformal beam shaping, 3 -D dose calculations, plan evaluation tools, and plan verification data are now all part of the planning process. In the context of the expanded scope of treatment planning, quality assurance efforts must also be expanded to cover the above-de scribed functions.

1. Quality Assurance for Treatment Planning Software

The quality and quality assurance of the software used for treatment planning is of course a critical part of the quality assurance process, the QA of this soft ware is typically not under the control of the clinical user. For commercial vend ors, there are various regulations and good manufacturing code practices, but eve n these factors are hampered by the lack of standards from the radiotherapy com muniy about technically how these practices should be implemented in a practica l way.

2. Dosimetric Quality Assurance

Calculation verification checks and quality assurance of dose calculations gene rated by treatment planning systems have always been the subject of QA.

1) Measured Dataset

Measurement of a complete and self-consistent three-dimensional dataset for each beam is critical. Although there are a few different methodologies for these measurements, we have used a film-based method.

2) Dose Distribution Comparison and Verification Techniques

To perform quantitative comparisons of data and calculations in 3D, direct o verlays of 1D profiles and depth doses or perhaps 2D isodose curve plots are n o longer adequate. A more effective method is to use subtraction of 3D measure d and calculated distributions to generate a dose difference.

3) Verification of Input Data

The first step in the verification of the dose calculations is to verify the acc

uracy with which the algorithm reproduces the input data.

4) Study of the Applicability and Limits of the Dose Calculation Algorithm

The limits of usefulnes of the dose calculation algorithm must be investigate d and documented before it is clinically used.

5) Verification of the Calculations over the Range of Clinical Use

The accuracy of the dose calculations over the entire range of clinical use s hould be documented.

6) Absolute Dose Output and Plan Nonmalization

One of the most critical parts of the entire treatment planning and treatment delivery process is the determination of the absolute dose and monitor units use d to actually deliver the treatment to the patient. In 3D planning, the process in volving beam normalization, dose prescription definition and monitor unit calculat ions must be verified.

Non-Dosimetric Quality Assurance

Another major segment of planning system QA involves the non-dosimetric parts of the planning process, including:

Image conversion
Anatomical structure definition
Dataset registraton
Density representation
Image use
Anatomical display
Beam/block/MLC/compensator definition
Dose calculation grids, logic, etc.
Dose Display
Dose Volume Histograms
Plan evaluation tools
Plan verification tools
Measured dose distribution tools
Composite plans
Hard copy output
Absolute dose
Clinical system tests

QA for the Entire Clinical Planning/Treatment Process

Some of the most important features of an extensive QA program for 3D treatm ent planning involve the use of checks and balances which are not built in to th e treatment planning system, but rather are part of the routine treatment planning and treatment delivery process within the department.