3-D CONFORMAL RADIOTHERAPY

- External beam radiotherapy where the beams are closely shaped to the target, based on image based definition of the target and sensitive structures. It also includes the ways of delivery.

In Traditional Radiotherapy planning has been based on external patient contours with little or no information about internal patient structures. The targeting of the treated volume is based on clinical experience and rules developed on plain film images. The target is inferred mostly in relation to bony structures, to low density tissue such as lung and to air cavities.

The advent of CT made possible to delineate structures —slice by slice— and to visualize them in their full volumetric extent. Most targets are irregular in shape and different from patient to patient.

Without this information, the classical aiming of the beams can result in geometric misses and in unnecessary dose to sensitive organs.

Clinical studies of prostate cancer disease free survival show a dose response, indicating a marked benefit in dose escalation. This data itself was made possible with the use of 3D Radiation Therapy.

However, the increase in dose to the prostate is accompanied by an increase in complications. (Morbidity Vs. Dose)

The advent of Intensity Modulated Radiation Therapy represents a practical means of moving the boundary for dose escalation further along.

This presentation addresses several key aspects of IMRT.

- What Is It?
- Why Bother?
- How Is It Done
- What to Do and What to Watch for
- What other developments are needed and coming
IMRT is CONFORMAL THERAPY

Conforms low dose regions to sensitive structures to reduce complications while conforming the high dose regions to the target, but in addition it adds modulation to the geometric shaping of the beam.

Methods of Intensity Modulation are not new, but the advent of dynamic multileaf collimation makes the two-dimensional modulation at finely spaced levels, practical.

Clinical arguments for IMRT fall in various categories: Spare sensitive structures, treat large intracranial targets, treat irregularly shaped lesions, treat multiple targets, the need for dose escalation, replace radiosurgery with fractionated treatments, retreat of previously treated regions.

How is IMRT different from 3D-CRT?

- Definition of the prescription
- Optimization (Inverse Planning)
- Delivery Method
- Dose Calculation
- Quality Assurance
- Treatment Delivery and Verification

IMRT implies a new perspective on what is “the prescription”.

- Identification of the Target
  Better definition of the target requires CT information and often other imaging modalities such as MRI. In that case, the fusion of multimodality imaging is key to preserve the accuracy of targeting.

- Assign Uncertainties to the Volumes
  The conceptual distinction between the various types of volumes, and their derivation, is necessary in order to arrive at physically meaningful solutions that do not compromise the goal of the therapy.

- Definition of the Target DVH and the DVH’s for Sensitive Structures
  The goal set for target coverage has to be physically consistent with the goals for protection of structures, in order to arrive at reasonable solutions.
Goals and Priorities must be set, along with explicit numeric penalties associated with deviations from the goal.

The Inverse Planning Problem can be described as arriving at the solution for the intensities of beamlets that will result in a minimum deviation from a desired set of goals that describe dose distributions in targets and structures of interest.

There are different types of Objective Functions, and associated “cost” for deviation from the goal.

Conceptually, plan optimization proceeds as follows:

For each treatment field, a beam’s-eye-view of the target is used to divide the field into pencil-beams.

For each iteration during the optimization, the weight of each pencil beam, in each field, is changed.

After each iteration, the objective function is calculated, along with the DVH of the target and critical structures. The optimization iterations continue until the objective function is no-longer getting better or the maximum number of iterations has been achieved.

Delivery Methods for Modulating the Intensity include “sliding window”, “Step and Shoot” and Slit Arc. There are different methods to arrive at the leaf motions that will produce a particular intensity modulation.

Parameters that affect the leaf motion solution include

- Leaf end shape (geometric penumbra)
- Leaf Transmission
- “Tongue and Groove” effect
- Jaw transmission
- Leaf speed and acceleration

The Dose Calculation has to account for the characteristics of the MLC system, the effects of the head scatter and field size dependence.

Plan evaluation requires Dose Volume Histograms of the target and critical structures, and are reviewed in the same fashion as for a 3-D plan.
Isodose distributions are also reviewed in axial, sagittal and transverse displays, the same way as for a 3-D plan.

Quality Assurance specific to IMRT is designed to address issues such as:

- Is the Dose Calculation Correct
- Are the Fields Located on the Correct Anatomical Space
- What Is Covered by the “Fields”
- Is the same Treatment Delivered Every Time

One tool that addresses the individual field modulation is the Fluence Map Verification.

On the other hand, a film test of all the combined IMRT fields, applied to a Phantom can show the details of the planned dose distribution. This can be combined with absolute dose measurements to verify the dose calculation, in an independent fashion.

Anatomic Localization of the treated fields requires Digitally Reconstructed Radiographs (DRR). DRR’s are also used for Verification of Patient Setup.

Port films acquired during IMRT treatment are very hard to interpret due to the interference of anatomical features with the intensity modulation. Maximal Extension of Treated Fields, generated from the plan in conjunction with the DRR can be used as Reference for Port Films or EPID. These may be generated from within the TPS or by exporting the apertures back to a Virtual Simulator.

The question whether the same treatment is delivered every time requires to address the issue of patient repositioning as well as organ reproducibility.

The association of the d-MLC files to the fields in the Record and Verify system is a key element of the IMRT treatment.

A reference start configuration of the MLC for each field is also key in the daily execution of treatments.

In addition there are additional QA requirements on the dynamic function of the MLC. Periodic audits of the dMLC motion history for individual treatments are valuable QA tools that with time will be made easier to use and incorporate into Record and Verify systems.
Day-to-Day patient Repositioning can be made semi-quantifiable using video or Infrared systems. In one such system, Reference video images are subtracted, in real-time, from live video. Small positioning errors show as dark areas. Therapists can use the live subtraction images ‘online’ to return the patient to the reference position, before radiation is delivered.

The increased importance of “Record and Verify” systems can be illustrated by noting that during a typical day a Therapist has to reproduce about 2,000 parameters and 15,000 leaf positions, without a single error.

Summary

- Advanced imaging, planning and delivery tools, such as 3D TPS, ITP and IMRT, allow the creation of highly conformal dose distributions.

- The overall treatment is only as good as the ability to know where the target and the sensitive structures are at all times.

- Margins to the target volume should account for uncertainties in localization, for patient repositioning and immobilization and for organ motion.

A possible area of Improvement is to reduce the margin required to convert CTV to PTV, thereby sparing dose sensitive surrounding structures to a greater degree. However we may be approaching the limit in certain disease sites.

Other areas where we may see improvements are:

- Reduction of localization uncertainties
- Definition (Expansion?) Of CTV based on function
- Plan Optimization based on TCP and NTCP data
- Smoother integration of functions and subsystems
- On-line dose verification with epids
- Image based patient/target positioning (e.g.: EPID, US or IR based Beam gating), with or without On-line correction
- Monte Carlo based dose calculation