IMRT Process Flow

Intensity-modulated radiotherapy (IMRT) is a new development in three-dimensional conformal radiotherapy (3DCRT) combining several intensity-modulated beams to provide improved dose homogeneity and highly conformal dose distributions. This allows improved sparing of normal tissues in many tumour sites. Radiotherapy planning studies have confirmed the dosimetric advantages of IMRT over conventional or conformal techniques [1].

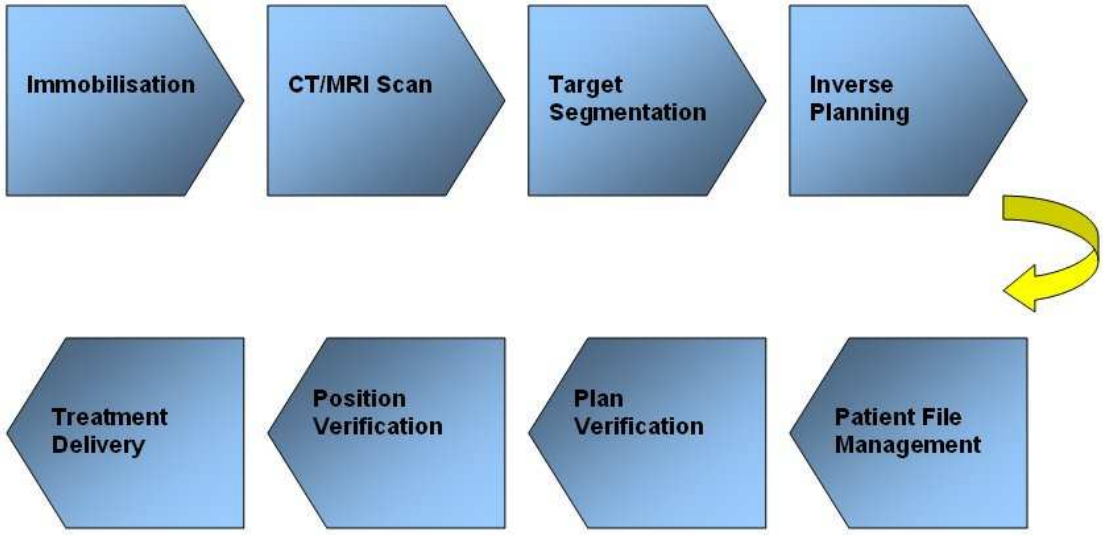

Figure 1: IMRT Treatment Planning and Treatment Delivery Flowchart

Immobilisation

Prostate patients are treated in the supine position with a headrest. The arms are on the chest and the knees immobilised using a knee support. The patient is treated with a full bladder.

CT / MRI Scan

The patient is positioned supine on the CT couch top and reference crosses are marked for the anterior and lateral views. Ball bearings are taped to these reference points. Tattoo marks are also made at the three reference points following a successful scan.

A pelvic scan protocol is used to acquire anterior and lateral scout views and these are used to assess the patient's position before running the full scan. The scan field encompasses an area from the mid sacro-iliac joints to about 2 cm below the ischial tuberosity (see figure 2). Axial CT slices are acquired at 5mm intervals. A planning MRI scan is only performed if specifically requested by the Oncologist.

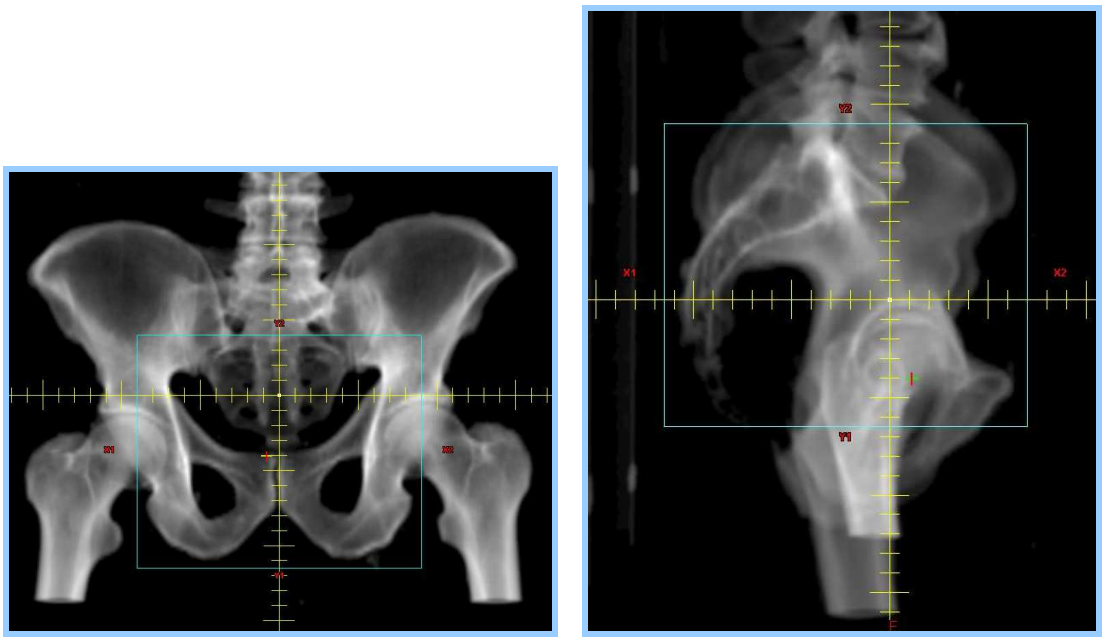

Figure 2: Anterior and Lateral Scan Views

Target Segmentation

The Clinician outlines the target according to ICRU 50 and 62 guidelines. For example the GTV (gross tumour volume) would consist of the total prostate gland as defined by clinical and radiological staging, with possible inclusion of the base of the seminal vesicles. A PTV (planning target volume) is then created which allows a 1-1.5cm margin inferiorly around the prostatic apex, superiorly above the tip of the seminal vesicles and anteriorly towards the pubic symphysis.
The Physicist might then outline the OARs (organs at risk) for example the femoral heads, bladder, rectum, bowel and urethral bulb (see figure 3). These outlines are checked by the Clinician before the plan is approved.

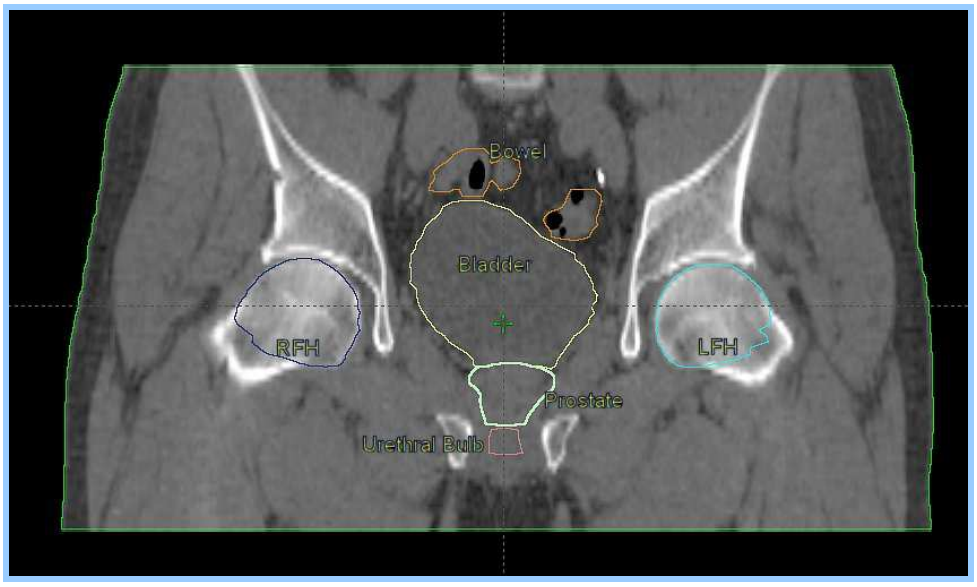

Figure 3: Organs at Risk: Rectum (green), Right Femoral Head (yellow), Left Femoral Head (blue). The Prostate (target) is shown in red.

Inverse Planning

Inverse Treatment Planning is used to solve the scenario of: "**Given a prescription of desired outcomes, compute the best beam arrangement**". A solution is found by computer with human guidance, not by humans alone.

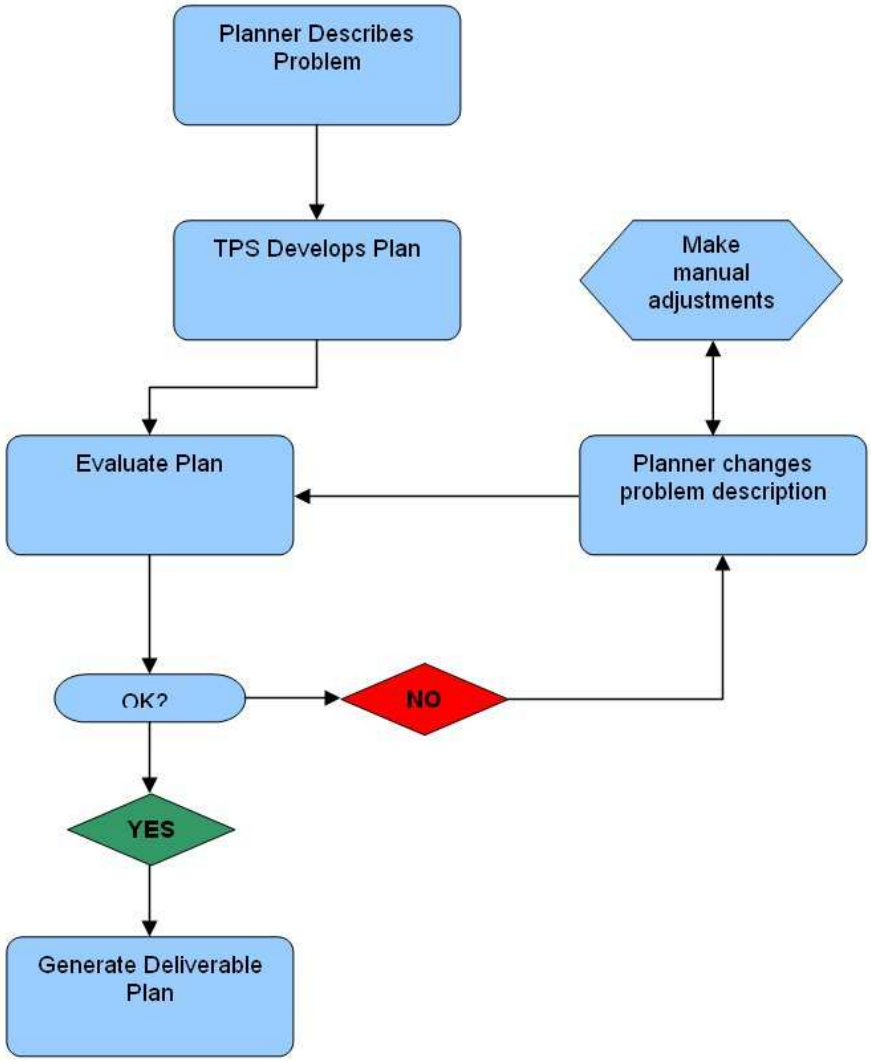

Figure 4: The Concept of Inverse Planning

For prostate cancer, a 5-beam arrangement may be used. This can usually be selected from a list of pre-defined templates in the planning system. The template may consist of 5 non-opposed coplanar 6MV fields with gantry angles of 180° (Post), 270° (RLAT), 325° (RAO), 35° (LAO) and 100° (RAO). The collimator angle and starting field size may be 0° and 20x20 cm respectively, depending on the local template. The isocentres is placed at the centre of the PTV and it should lie on a "true" slice. The dose prescription will vary according to local protocol or the constraints of any clinical trial the patient may have been recruited into.
The delivered dose is evaluated according to clinical protocol and this includes the starting dose volume constraints for the target and OARs. The TPS will attempt to optimise the plan to meet the constraints and a satisfactory plan may not be found until after a significant number of iterations. Some TPS systems allow "real time" adjustment of constraints. After optimisation, the leaf motions are computed and then the dose is calculated using a grid of 2.5 mm for example. Pre-defined isodoses lines are displayed and plans may be normalised to 100% of the target dose.

Once the dose distribution is deemed satisfactory, the X and Y collimator jaws are adjusted to ensure that they do not obscure IMRT delivery but still provide maximum shielding. The plan is then recalculated with the new jaw sizes to obtain the final dose distribution.
Final plans are assessed by critical appraisal of the DVHs (dose volume histogram) for each OAR and the dose distribution on each slice. Coverage of the PTV must be at least 95% on every slice and there must not be any hot spots in or near OARs. The dose in the PTV must be between 95 and 105% (ICRU).
It is also usual to generate DRRs (digitally reconstructed radiographs) for the anterior and one lateral field and these are attached to the approved plan in the TPS.
The Clinician should view and approve the final plan at the TPS workstation. A DVH containing all target volumes and OARs as well as one image each of the transverse, coronal and sagittal central slices must be printed to be appraised and signed by the Clinician, who will then prescribe the appropriate fractionation schedule on the treatment card. The approved plan is then checked by a senior physicist.
Once a plan has been approved it may become automatically available via the Patient Record and Verify System (for example ARIA) at the treatment console.
A program of patient specific QA then follows.

Patient Specific QA

The accuracy of any IMRT treatment plan can only be guaranteed through patient-specific quality assurance (QA). A comprehensive QA program encompasses machine-related parameters such as beam flatness and stability, MLC accuracy and accurate modelling of the linear accelerator at the commissioning stage of the treatment planning system (TPS). Pre-treatment patient-specific QA may be performed using film measurements in a phantom, 2D diode arrays placed on the treatment couch or attached to the treatment head, electronic portal imaging devices (EPIDs) or a combination of these. A common approach is to export the energy fluence or the dose in a specific plane from the TPS for a single field or multiple field arrangement and compare this to the measured data. For planar (beam-by-beam) verification, measurements are performed using a zero gantry angle. One disadvantage of this method is that possible MLC positioning or dose rate differences at other gantry angles are not detected.
Composite plan analysis in a phantom has the drawback that the patient geometry and anatomical details are lost. To circumvent these, various 3D dose models have been developed that reconstruct the 3D dose distribution inside a phantom facilitating easier analysis of a 3D dose distribution. The aim of pre-treatment verification method is to detect sources of error. For example incorrect dose distribution calculated using an unsuitable dose engine or the incorrect implementation of an algorithm. Pre-treatment verification may also highlight differences between the delivered and the planned dose distributions. This can arise from an incorrect dose distribution calculation (e.g. unsuitable dose engine, incorrect use of a calculation algorithm or linac head model) or due to sub-optimal performance of the linac itself.

Example of IMRT QA Procedure

After the final treatment plan has been approved verification plans for the patient are generated. These are saved in the Record and Verify system under a different treatment course and clearly labelled QA. Essentially, the entire patient plan is transferred to CT images of the local IMRT phantom. All gantry and collimators angles, fields and monitor units are retained in the QA plan.

Absolute Dose Measurements

These measurements are performed using the IMRT phantom with its centre at the plan isocentres and at 9 cm deep. A daily output check is performed on the linac and subsequent measurements are corrected accordingly. Dose point measurements are made at a suitable point in an area of high dose and low dose gradient, (isocentre). The action level may be set at ±3% difference between the measured and calculated point doses.
A point dose measurement point is placed in an area of uniform distribution, usually the isocentre and the dose distribution is assessed in combination with the fluence for each of the fields. A new volume (ion chamber) with diameter 0.8 cm and length 2.0 cm is created with the TPS and placed at an appropriate measurement position in the IMRT phantom, (the STD for the DVH for the chamber should be less than 2.00). Measure the point dose at the chosen measurement point, indicated by the centre of the chamber and record the percentage doses for each field from ± 1cm in the sup/inf direction in steps of 0.25 cm. Calculate the average value for each field.

Field Intensity Verification

Two coronal dose distributions are measured using Kodak EDR2 film inserted into the IMRT phantom at 1 cm above and below the isocentre and the results of the film analysis are compared to the doses predicted by the TPS using software such as OmniPro together with a high resolution scanner such as the Vidar type. Gamma analysis is used to compare the same region of interest (ROI) on the imported TPS dose plane and the digitised film. The "pass rate" should be ≥ 95% of points samples should be between 0 and 1 for gamma limits of 4 mm and 4%.
The fluence maps for each field can be verified using the EPIDs. The gantry is kept at an angle of 0 degrees and with the EPID fully extended (105 cm) a fluence map is recorded. This is then compared to the map predicted by the TPS using a point dose measurement at the central axis position. The action level is implemented if there is a ± 5% difference between the dose predicted by the TPS and the measured dose.
A summary of the QA results is compiled and checked independently by another physicist and approved by the oncologist prior to the commencement of treatment.

Treatment Verification

Electronic Portal Images (EPI) may be acquired on treatment days 1 to 3. These are compared offline with DRRs after treatment has been delivered and prior to the next treatment. Radiographer checks are made on each image. If the EPIs are within tolerance (2 mm) then subsequent images are acquired at weekly intervals. If the tolerance is exceeded, the systematic error is calculated and a corresponding isocentre adjustment is made. Three consecutive EPIs should be acquired after any adjustment. If the weekly images exceed tolerance, then two consecutive EPIs are acquired and assessed.

References

1. Guerrero Urbano MT, Nutting CM: Clinical Use if Intensity-Modulated Radiotherapy: Part 1. BJR 2004, **77**:88-96.