Treatment Planning
3-D CRT to IMRT
Aim

Introduce the student to the techniques and possibilities offered by IMRT
Specific Learning Objectives

- Differentiate between inverse and forward planning
- Describe the concept of an objective function
- Describe the concepts of objectives, constraints and “weights”
- Set appropriate dose objectives
- Identify the need for additional planning volumes
- Compare dose based planning with biologically based planning
- Compare the planning requirements for step and shoot, dynamic leaf movement and arc therapy
- Identify problems associated with IMRT planning
  - Skin dose, you get what you ask for
- Consider the possibilities for non-uniform dose distributions
  - Simultaneous integrated boost, nodal volumes
- Identify the risks associated with IMRT plans
- Identify appropriate methods to minimise such risks
Outline of lecture

- What is IMRT
- Forward Planned IMRT

*Inverse Planning*
- Adding Structures
- Adding beams
- Objectives and Cost Functions
- Setting Objectives
- Optimisation
- Creating deliverable fluences (Sequencing)

This slide is use as a placeholder throughout the lecture
Outline of lecture

• What is IMRT
  • Forward Planned IMRT
    *Inverse Planning*
  • Adding Structures
  • Adding beams
  • Objectives and Cost Functions
  • Setting Objectives
  • Optimisation
  • Creating deliverable fluences (Sequencing)
IMRT

- Conformal Radiotherapy (CFRT) uses Multileaf Collimators (MLCs) to conform radiation beams to the shape of the target
- MLCs can also be used to create many small beams (or "segments") from each beam direction
- This is called Intensity Modulated Radiotherapy (IMRT)

IMRT can also be done with solid compensators but this method is very time consuming and not a good alternative to MLCs. Solid compensators do, however, have a potential advantage when treating a moving target as the leaf interplay effect is not a problem.
Note that concave treatment volumes can also be achieved with non-coplanar conventional fields. Conformity with IMRT is almost always better than with conformal therapy even when concave volumes are not an issue.
Forward and Inverse Planning

- **Forward Planning**
  - Dose, volume to be treated and avoidance structures defined
  - Beam directions defined
  - Dose calculated
  - **Beam weights and wedges adjusted** iteratively by the operator for an optimum plan
    - Beam directions adjusted manually if needed

- **Inverse Planning**
  - Dose, volume to be treated and avoidance structures defined
  - Beam directions defined
  - Objectives defined
  - Computer optimises beam weights and shapes to meet objectives
    - Objectives adjusted if plan unsatisfactory

Text in red emphasises the differences
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• What is IMRT
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Forward Planned IMRT

- Suitable for reducing 3D dose inhomogeneities and concurrent boosts
- Makes use of tools that are available in commercial treatment planning systems which help design modulated beams
- Because fewer beam segments are used QA is simpler

Some people do not refer to forward planned IMRT as IMRT. However, for breast treatments with segmented fields it may be better than inverse planned IMRT. Once the segments are defined an optimiser can be used to optimise the beam weights. Multi-segment beams can usually be combined so that they are delivered automatically in sequence.
This is a 3D rendering of the dose surface. The hotspots can be considerably greater than for this patient.
Note the MLCs shielding the skin in the right hand image. This patient was being planned for the IMPORT High trial of partial breast irradiation so the high risk area has been outlined (in red)
Same patient with forward planned IMRT rather than wedges
Same patient but viewed from the other side. It is often inappropriate to prescribe the dose to the isocentre in IMRT patients.
The aim here is to treat the prostate GTV to a higher dose than the rest of the CTV which includes the seminal vesicles. This patient was included in the CHHIP trial of hypofractionated prostate radiotherapy.
Simultaneous Boost for Prostate

High Dose area  Lower dose area
Note the much lower doses given to the small field segments. Field labels LL_LG (Left lateral large) and LL_SM (Left lateral small) etc
Shows the final dose distribution – could be omitted
This is the detail of the plan where the boost segments are being treated as separate fields.
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Inverse Planned IMRT

- All tissues of interest must be outlined
- For target tissues maximum and minimum doses are required
  - Mean doses may also be specified
- For organs at risk maximum doses either for the whole organ or for percentages of the organ volume are specified
- These specifications are translated into objectives which the computer will aim to achieve as best it can and/or constraints which it is required to achieve

This slide and the next highlight the differences between IMRT forward planning and conventional planning. The most important thing that people need to understand is that if something is not specified to the optimiser the dose to that something is unpredictable. This means that much more careful outlining is required than for CFRT where the shape of the dose distribution is largely governed by the beam arrangements.
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What makes Inverse Planned IMRT Different?

- More difficult to spot errors
- More difficult to carry out in field imaging
- Beam is “ON” for longer (typically x3)
- Organ movement has an unpredictable effect
- Dose is often less uniform in the PTV
- What is outlined is what gets treated or spared
- Accuracy of delivery depends on machine adjustments

This is put in for completeness. The main issues are the effect of organ movement, the inhomogeneity of dose in the PTV and the need for complete outlining. The accuracy of delivery can be affected by the constraints put on the sequencer with many small fields being more difficult to deliver accurately and more likely to be affected by the tongue and groove effect.
What makes IMRT Different?

- More difficult to spot errors
- More difficult to carry out in field imaging
- Beam is “ON” for longer (typically x3)
- Organ movement has an unpredictable effect
- Dose is often less uniform in the PTV
- What is outlined is what gets treated or spared
- Accuracy of delivery depends on machine adjustments
Definition of Additional "Planning" Structures

- The optimiser will be confused if a voxel has opposing objectives
  - Subtract target volumes from OARs
  - Define parts of target where a dose limit is required

So for example the overlap region between the prostate and the rectum may be given an upper dose limit that is only just above the minimum acceptable dose to the prostate. If this is not done the rectum may get the maximum permissible prostate dose.
PTV subtracted from Bladder Volume

No hot spots are allowed in the Rectum part of the PTV
Need to consider overlapping regions

Courtesy of Philips Medical Systems
Some planning systems have other methods of ensuring that there is a sharp cutoff in dose at the edge of the PTV – e.g. Eclipse has a specific function for this purpose.

Definition of Additional "Planning" Structures

• The optimiser will be confused if a voxel has opposing objectives
  – Subtract target volumes from OARs
  – Define parts of target where a dose limit is required

• If a non-target voxel dose not have a dose limit the optimiser may assign a high dose
  – Create ring structures around target tissues
It is important to know whether spinal canal or spinal cord is contoured. The spinal canal provides a useful Planning Risk Volume (PRV)
Note the deliberate lack of sparing to the ipsilateral parotid. Recurrences have been reported when people try to spare both parotids.
Note the difference between the lines representing the prescription volumes and the shaded planning contours.
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Choice of Beam Direction

• 9, 7 and 5 beams have been used in coplanar plans
• Plans do not have to be coplanar
• Appropriate choice of beam direction can be very effective
• Some systems now allow beam angle optimisation
• Increasingly arc therapy with dynamic jaw movements is being used.

Beam angle optimisation is not necessarily of great benefit compared to a competent planner. Arc therapy produces much sharper dose falloff and is quicker to deliver. It is rapidly replacing IMRT in those centres who have this facility.
Example of a 5 field plan. A paper in the early 90s by Jorg Stein showed that for IMRT it is often better to bring one beam directly through an organ at risk. This may be counterintuitive but it works – probably because of the lower divergence of the beam.
Outline of lecture

- What is IMRT
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**Inverse Planning**

- Adding Structures
- Adding beams
- Objectives and Cost Functions
- Setting Objectives
- Optimisation
- Creating deliverable fluences (Sequencing)
The use of the words Objectives and Constraints originates from the Pinnacle system. Even if the planning system does not have this concept a very high weight can be applied to produce a similar effect. It is not advisable to introduce Constraints at the outset but only when there is difficulty when the objective is hard to achieve. If a Constraint is not met the plan will not be completed. Setting too tight Objectives as well as too loose Objectives can be counter productive.

Setting the objectives

• Constraints
  – Absolute requirements
  – Sometimes called "hard" constraints
• Objectives
  – Requirements we would like to achieve
  – Sometimes called "soft" constraints
• Weights
  – To balance the importance of objectives
Cost Functions

• In order to carry out the optimisation the computer needs a function to optimise – this is called a “cost function”
• Typically a quadratic cost function is used
  – For each point within a volume of interest the computer calculates the dose
  – If the dose meets the specified objective the contribution of that point to the cost function is zero
  – If the dose is outside the specified limits the square of the difference between that dose and the dose limit is added to the cost function
  – Cost functions are normalised so that the contribution of a volume of interest is not dependent on its size

Biological cost functions using TCP and NTCP are also possible. Currently CMS Monaco and Eclipse have these options. Pinnacle uses the EUD as an optimisation Objective
Weighting

- Often some objectives are more important than others
- To inform the computer of the relative importance of different objectives a weight can be assigned
  - The weight is applied as a multiplier to the cost function
- Constraints that must be achieved effectively have an infinite weight

Weighting can be difficult to understand. Philips recommend setting all the weights to 1 if you don’t know what to set them to
Cost Function

\[ C = \sum_{\text{objectives}} \sum_{\text{voxels}} W_i I_i (D_i - D_{\text{objectives}})^2 \]

W is the weight to allow more importance to be given to particular objectives
I=0 if the objective is met and =1 otherwise
A normalisation is applied so that ROIs with large numbers of voxels do not dominate
Application example

- A PTV Maximum Dose Objective is 72Gy with a weight of 1.0 and Minimum Dose Objective is 68Gy with a weight of 8.
- A dose point in the PTV is calculated as 70Gy
  - The addition to the cost function is 0
- Another dose point in the PTV is 66Gy
  - The addition to the cost function is $4 \times 8 = 32$
- Another dose point in the PTV is 75Gy
  - The addition to the cost function is $9 \times 1 = 9$

Important to emphasise that if the Objective is met that point will not contribute to the optimisation at all
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These are Pinnacle’s options. Note that Rec_H – the overlap region between the Rectum and the Prostate has both a Max and Min dose Objective. The PTV-shell prevents dose leaking out of the area close to the PTV.
DVH constraints are perhaps easier to think about than Max and Min constraints – which often have to be set tighter than the desired outcome. Arrows on the DVH curve show how they are applied
Assigning Weights

It may be helpful to start with a weight of 1 for all objectives

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This is discussed above. (Note that the 1’s were added as overlays on top of the actual values set in this slide – if the image is moved they will no longer line up.)
Assigning Weights

Weights can then be assigned based on how the optimisation proceeds

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Composite objective value: 0.295127

This image should match the previous one where the weights were set to 1
This is an example of an Eclipse optimisation window.
This is the same as the previous slide but magnified
Note that with dose based objectives the sparing of the brain stem is not as good. Biologically based objectives effectively have an exponential term.
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• What is IMRT
• Forward Planned IMRT

Inverse Planning
• Adding Structures
• Adding beams
• Objectives and Cost Functions
• Setting Objectives
• Optimisation
• Creating deliverable fluences (Sequencing)
This is from Pinnacle but most planning systems have similar displays. The nice thing about the Pinnacle display is that you can see how the cost function is made up. Clearly the Prostate (GTV) min dose Objective is easy to meet whereas the min PTV Objective is more difficult. This gives some indication to the planner of what the problems are going to be.
If the skin is defined as PTV the optimiser will try to give it the full dose in spite of the build-up effect. There were problems with this in the early days of IMRT. Two methods have been used to overcome it – a layer of bolus can be applied during the optimisation and then removed for the final calculation; or the PTV can be brought inside the skin by 5mm. The former is perhaps the more satisfactory approach.
Beware high skin doses
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_Inverse Planning_

• Adding Structures
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• Optimisation
• Creating deliverable fluences (Sequencing)
Conversion of Fluence Maps to Deliverable Beams

- Some optimisers calculate the optimum beam fluence but this is not deliverable
- The ideal fluence is input to the Sequencer
  - The Sequencer aims to produce the best match to the beam fluence with a minimum of segments
- Step and shoot sequencers often produce different results
- Dynamic sequencer more standardised
- Needs to be adapted for linac
  - e.g. when leaves will not close
This shows how the problem of lack of interdigitation can be solved for a linac (Elekta) whose MLC cannot interdigitate. Under the backup jaw there is 10% transmission. If the sequencer does not allow for this considerable dose errors can exist – or the beam will not be deliverable.
Example of Different Step and Shoot Sequencers

Comparison of Plato and Pinnacle sequencers for an Elekta linac

This sequence is designed to be run automatically. The timings are as they would be on the treatment machine. Note that the Pinnacle sequencer uses more open field segments that the PLato sequencer which has the constraint that all the segments shall have an equal number of MUs. Note that this was not done with the Direct Machine Parameter Optimisation (DMPO) sequencer on Pinnacle which includes the segmentation of the field in the optimisation. The aim is to illustrate the fact that two different step and shoot sequencers can produce very different solutions. The dynamic leaf sequencer used by Varian for dynamic delivery where the MLCs are constantly moving follows a mathematical formula to produce the leaf movements and is governed only by the max leaf speed and the dynamic leaf gap.
Pinnacle provides the possibility of reoptimising the segment weights after the sequencer has finished. This produces a better result, but is not needed with DMPO. In early Eclipse versions a pencil beam algorithm was applied during the optimisation and the final result with the AAA algorithm was often very different for lungs. They now allow a reoptimisation based on the AAA calculated distribution.
This is the DMPO control window.
The numbers after DMPO indicate the number of permitted segments. The total MUs for dynamic jaw movement are usually much higher than for step and shoot. The IM values were two versions of the standard Pinnacle sequencer.

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Evaluating the final plan

- Good conformity
- Steep gradients around the OAR
- Hot volumes distributed around the PTV
- High dose volumes can occur outside the PTV
- More beams result in a low dose bath to the body outside the PTV
- Assess the plan using both the DVH’s and the dose distributions on all the slices

This is covered properly in an earlier lecture. Here are emphasised things to look out for in IMRT
In Summary

• Appropriate outlining is vital
• Clear clinical specifications are essential
• Know your planning system’s algorithm
• Develop class solutions for consistency
• Collaborate with colleagues
Should we be doing IMRT?

- IMRT can be seen as an extension of 3D Conformal Therapy which is more demanding
  – Expertise in 3D conformal therapy is a prerequisite
- IMRT has been shown to be of benefit in a number of sites in reducing side effects
- Patients are increasingly expecting IMRT to be available to them
- IMRT is more expensive than conventional therapy – depending on how it is approached
Where is IMRT useful

• Prostate
  – Can minimise rectal dose

• Head and Neck
  – Simplifies treatment
  – Possibility of Parotid Sparing

• Brain

• Spinal irradiation compensation

• Breast compensation
  – Simple forward planned
  – Internal Mammary Chain treatment – full IMRT

• Mesothelioma
IMRT

Transverse

Sagittal
Conformal boost
IMRT

Dose Volume Histogram

Norm. Volume

Dose (cGy)
Cycle of IMRT introduction

• Commissioning
  – Design of IMRT technique
  – Setup of linear accelerators
• First patients
  – At least 10
• Treatment becomes routine
• Start another site
Getting started

• Form a team
  – Physicists, Radiation Technologists, Doctors
  – Requires adequate staffing
The Team

• Clinicians

• Planning
  – Physicists, Radiation Technologists (Radiographers), Dosimetrists

• Quality Control
  – Physicists, Dosimetrists

• Treatment
  – Radiation Technologists
Getting started

• Form a team
  – Physicists, Radiation Technologists, Doctors
  – Requires adequate staffing
• Understand the differences
Getting started

• Form a team
  – Physicists, Radiation Technologists, Doctors
  – Requires adequate staffing
• Understand the differences
• Decide on a site to start with
  – Head and neck gives most benefit
  – Prostate is simpler
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  – Requires adequate staffing
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  – Prostate is simpler
• Develop class solution and compare to 3D CRT
Getting started

- Form a team
  - Physicists, Radiation Technologists, Doctors
  - Requires adequate staffing
- Understand the differences
- Decide on a site to start with
  - Head and neck gives most benefit
  - Prostate is simpler
- Develop class solution and compare to 3D CRT
- Make phantom measurements
IMRT concepts

• Planning goals
Forward vs Inverse Planning

- Define target volumes
- Specify beam directions
- Calculate dose distribution
- Adjust plan parameters until plan is satisfactory

- Define target volumes
- Specify beam directions
- Define objectives
- Calculate optimised plan
- Adjust objectives and reoptimise until plan is satisfactory
IMRT concepts

- Planning goals
- Regions of interest
Simple Head and Neck IMRT

1. Create conventional plan
Simple Head and Neck IMRT

2. Use isodoses to create regions of interest
Simple Head and Neck IMRT

3. Create IMRT plan
Need to consider overlapping regions

Courtesy of Philips Medical Systems
IMRT concepts

- Planning goals
- Regions of interest
- Choice of beam direction
Choice of Beam Direction

- 9, 7 and 5 beams have been used in coplanar plans
- Plans do not have to be coplanar
- Appropriate choice of beam direction can be very effective
- Some systems now allow beam angle optimisation
IMRT concepts

- Planning goals
- Regions of interest
- Choice of beam direction
- Communication of intention
  - Objectives or “soft” constraints
  - Weights
  - Constraints (“hard” constraints)
IMRT concepts

• Planning goals
• Regions of interest
• Choice of beam direction
• Communication of intention
  – Objectives
  – Weights
  – Constraints
• Plan evaluation
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<th>Max.</th>
<th>Mean</th>
<th>Std Dev</th>
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<td>2470.0</td>
<td>6037.2</td>
<td>5493.7</td>
<td>25.1</td>
<td>0.00 %</td>
<td>0.03 %</td>
<td>5497.83</td>
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<tr>
<td>LL</td>
<td>19.2</td>
<td>8304.8</td>
<td>1897.7</td>
<td>2310.1</td>
<td>0.00 %</td>
<td>0.47 %</td>
<td>1999.03</td>
</tr>
<tr>
<td>Bl</td>
<td>15.6</td>
<td>5928.0</td>
<td>757.7</td>
<td>1247.2</td>
<td>0.00 %</td>
<td>0.00 %</td>
<td>757.57</td>
</tr>
<tr>
<td>cord</td>
<td>15.7</td>
<td>5215.2</td>
<td>825.5</td>
<td>1842.0</td>
<td>9.45 %</td>
<td>0.08 %</td>
<td>1092.23</td>
</tr>
<tr>
<td>PTV</td>
<td>2759.3</td>
<td>6206.0</td>
<td>5603.9</td>
<td>198.4</td>
<td>0.00 %</td>
<td>1.51 %</td>
<td>5503.46</td>
</tr>
<tr>
<td>Total Lung</td>
<td>19.2</td>
<td>6364.0</td>
<td>1154.4</td>
<td>1825.9</td>
<td>0.00 %</td>
<td>0.19 %</td>
<td>1154.31</td>
</tr>
</tbody>
</table>
### Biological Responses

<table>
<thead>
<tr>
<th>Percent of Dose</th>
<th>Probability</th>
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<tbody>
<tr>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>20</td>
<td>0.05</td>
</tr>
<tr>
<td>40</td>
<td>0.30</td>
</tr>
<tr>
<td>60</td>
<td>0.65</td>
</tr>
<tr>
<td>80</td>
<td>0.80</td>
</tr>
<tr>
<td>100</td>
<td>0.95</td>
</tr>
<tr>
<td>120</td>
<td>1.00</td>
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</tbody>
</table>

### Composites

<table>
<thead>
<tr>
<th>Trial</th>
<th>Line Type</th>
<th>Display Index</th>
<th>Type</th>
<th>ROI</th>
<th>Organ/Tumor</th>
<th>End Point/Stages</th>
<th>D01</th>
<th>Alpha</th>
<th>Beta</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>broad</td>
<td>Thin Solid</td>
<td>1</td>
<td>NTCP</td>
<td>brain</td>
<td>Spinal cord</td>
<td>Meyr/omeg</td>
<td>1000</td>
<td>1.9</td>
<td>3</td>
<td>0.001</td>
</tr>
<tr>
<td>iso-chk</td>
<td>Thin Solid</td>
<td>2</td>
<td>NTCP</td>
<td>lung</td>
<td>Lung</td>
<td>Meyr/omeg</td>
<td>2000</td>
<td>1.7</td>
<td>3</td>
<td>0.001</td>
</tr>
<tr>
<td>mx34</td>
<td>Thin Solid</td>
<td>3</td>
<td>TCP</td>
<td>ple</td>
<td>NEC lung</td>
<td>all stages</td>
<td>1000</td>
<td>1</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>
Systematic Approach to DVH Analysis

Developed by David Dearnaley for the CHHIP hypofractionation for prostate study
<table>
<thead>
<tr>
<th>VOLUMES [cc]</th>
<th>Rectum</th>
<th>Bladder</th>
<th>Left Fem Head</th>
<th>Right Fem Head</th>
<th>PTV1</th>
<th>PTV2</th>
<th>PTV3</th>
<th>PTV1-PTV2</th>
<th>PTV2-PTV3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>53.09</td>
<td>168.27</td>
<td>59.72</td>
<td>63.51</td>
<td>132.35</td>
<td>79.74</td>
<td>45.75</td>
<td>52.61</td>
<td>33.99</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>POSTERIOR MARGINS [mm]</th>
<th>PTV 3</th>
<th>PTV 2</th>
<th>PTV 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min/Max</td>
<td>0</td>
<td>5/5</td>
<td>10/10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PLAN MODIFICATIONS</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outlines Modified?</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Posterior Margins?</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Dose Prescription?</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Inverse Planned?</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>
### IAEA

#### NORMAL TISSUE DOSE CONSTRAINTS

##### Rectum

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>68</td>
<td>60</td>
<td>38.76</td>
<td>12.42</td>
<td>23.39</td>
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</tr>
<tr>
<td>60</td>
<td>81</td>
<td>50</td>
<td>46.17</td>
<td>8.36</td>
<td>15.63</td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>95</td>
<td>15</td>
<td>54.15</td>
<td>1.48</td>
<td>2.79</td>
<td></td>
</tr>
<tr>
<td>74</td>
<td>100</td>
<td>3</td>
<td>57</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
</tbody>
</table>

##### Bladder

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>68</td>
<td>50</td>
<td>38.76</td>
<td>39.87</td>
<td>23.69</td>
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</tr>
<tr>
<td>60</td>
<td>81</td>
<td>25</td>
<td>46.17</td>
<td>25.17</td>
<td>14.96</td>
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</tr>
<tr>
<td>74</td>
<td>100</td>
<td>5</td>
<td>57</td>
<td>2.16</td>
<td>1.29</td>
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</tr>
</tbody>
</table>

##### Femoral Heads

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Left</td>
<td>50</td>
<td>68</td>
<td>38.76</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>50</td>
<td>68</td>
<td>38.76</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
</tbody>
</table>

##### Bowel

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>68</td>
<td>17</td>
<td>39.76</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### TARGET DOSE ACHIEVED

<table>
<thead>
<tr>
<th>Target (Aim)</th>
<th>MinDose (%) (To 99% of volume)</th>
<th>Max Dose (%) (To 1% of volume)</th>
<th>Median Dose (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTV1 (min&gt;75%)</td>
<td>78.0</td>
<td>101.4</td>
<td>96.5</td>
</tr>
<tr>
<td>PTV2 (min&gt;91%)</td>
<td>91.6</td>
<td>101.6</td>
<td>99.0</td>
</tr>
<tr>
<td>PTV3(min&gt;95%, 99%=med&gt;101%)</td>
<td>96.7</td>
<td>101.7</td>
<td>99.7</td>
</tr>
<tr>
<td>PTV1:PTV2 (med=80%)</td>
<td>76.2</td>
<td>99.6</td>
<td>90.2</td>
</tr>
<tr>
<td>PTV2:PTV3 (med=96%)</td>
<td>90.1</td>
<td>101.0</td>
<td>96.8</td>
</tr>
</tbody>
</table>

Signed: [\_] Date: [\_] Accepted: [\_]
Mesothelioma

- Allen et al. IJROBP 65(3)
  - Fatal pneumonitis 6 out of 13 patients
  - V5 = 99%
  - Mean lung dose = 15.2 Gy
- Komaki et al. IJROBP 65(5)
  - Fatal pneumonitis 10%
  - V5 = 88%
  - Mean lung dose = 10.6 Gy
  - No pneumonitis: V5 72%
    MLD 8 Gy
Beware high skin doses
Beware high skin doses
Final Points

• For each site to be treated a detailed protocol is needed
  – Contouring guidelines
  – Additional planning contours
  – Clinical objectives
  – Starting point for planning objectives
  – Evaluation criteria

• General principles can be learnt on a course but most training needs to be related to the equipment to be used
These slides are included to cover Arc Therapy briefly. They are based on the Varian RapidArc implementation but are applicable to other systems. Arc therapy is very much faster to deliver than conventional IMRT and the patient therefore does not have to keep still for so long. The interplay effect is slightly more pronounced than with IMRT. Some argue that the dose bath effect is enhanced and if low dose hypersensitivity is real this may be a problem. However, many centres are now using Arc Therapy in preference to standard IMRT. Sometimes two arcs rather than one will produce a more uniform dose distribution.
What is VMAT?

- Volumetric arc therapy that delivers a 3D dose distribution.
- Inverse Planning Technique
- Delivered in a single arc or multiple arcs of angle up to 360°
- Simultaneously changes 3 parameters
  
  - Gantry rotation speed
  - Delivery dose rate
  - Movement of MLCs
Advantages compared to Fixed Field IMRT

• Shorter Treatment Times
  – Improves patient comfort
  – Limits unwanted patient movement
  – Decreases target motion

• Possibly better dose conformity and tissue sparing
Delivery of VMAT

• A Varian RapidArc™ plan is constructed as a sequence of 177 control points

• Each control point specifies the gantry angle, cumulative fractional MU and MLC positions

This is specific to Varian. The arc can in principle be divided into any number of segments
Prostate Plus Pelvic Nodes

Fixed field IMRT – 5 fields that split, 10 fields  
RapidArc – single arc

Note sharper dose fall-off with RapidArc
Also prostate and pelvic nodes
Chordoma

- PTV – 66 Gy in 33 fractions
- Cord – max dose of 50 Gy
- Cord PRV (5 mm margin around the cord) – 55 Gy
- RapidArc shows steeper dose falloff to the cord

Arc therapy is especially suited to sparing the cord at the centre of the PTV
Meningioma

• Aims
  – PTV – 54 Gy/30#
  – Ipsilateral Lens – max dose 20 Gy
  – Contralateral Lens – max dose 10 Gy
  – Optic nerves and chiasm – max dose 54 Gy
Others sites that are worth considering

Nasopharynx
Pancoast tumours – close or wrapped around the cord