Therapy Continuing Education Course
Clinical Implementation of IMRT for Lung Cancers
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Overview
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- Methodology
  - Patient Selection
  - Treatment Simulation
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  - Treatment Planning
  - Plan Evaluation
- Treatment Verification and QA

Prerequisites: Basic Concepts of IMRT
- Intensity modulation
- Fluence modulation (Open density matrix)
- Pencil beam or beamlets
- Beam delivery systems
  - DMLC
  - Delivery: step-shoot, sliding window
  - Control of Dose: Control points, segments
- MUs in IMRT
- Compensators
- Inverse planning or treatment planning optimization
Clinical Rationales

• The benefits of IMRT for Lung Cancers
  – Dose conformity to target volumes
  – Dose avoidance to normal structures
  • Sharper dose gradient for adjacent critical organs: spinal cord, esophagus, etc.
  • Dose sparing for parallel organs: lung, heart, liver

Comparison of IMRT vs 3D for NSCLC

Concerns and Myths

• IMRT spreads low dose volume for lung and normal tissues
  – Lung parenchyma may be sensitive to low doses (5-20 Gy)
  – Use of multiple IMRT beams (> 6) may result in increase of low-dose volume to normal tissues
  – The effect depends on
    • Beam angle selection
    • Inverse planning process
    • Type of leaf sequences, leaf leakage, MU efficiency


*Comparison based sliding-window technique, IMRT results will be improved further with step-shot technique.
Concerns and Myths

• Inter- and intra-fractional organ motion
  – Respiratory motion can be a significant source of
    uncertainty for target delineation
  – Interplay effect between tumor motion and leaf
    motion may increase dosimetry uncertainty
    • The effect maybe minor for treatment courses with large
      numbers of fractions
  – Respiratory motion may affect dose to normal
    structures (lung, heart, esophagus, cord, etc)
  – Patient anatomies may change during treatment
    courses

• Complexity of treatment planning and delivery
  – Simulation and planning process requires
    experience and more effort/time
  – Increase of treatment and delivery time may
    reduce patient compliance and comfort
  – More challenges in QA and dosimetry
    verification compared to 3DCRT

Clinical Applications

• Lung cancers
  – Non-small cell lung cancer
    • Superior sulcus tumors: improvement of target conformity
      and sparing of spinal cord
    • Advanced stage (stage III, IV): improvement of target
      coverage and sparing of lung and other OARs
  – Small cell lung cancer
    • Limited and advanced stage: same as above
• Mesothelioma
  – Improvement of target coverage and sparing of
    contra-lateral lung, liver, kidneys, cord, heart

Non-small cell lung cancers

Single Lesion

Multiple Hilar Lesions
Lung cancers

Superior Sulcus Tumors  Mesotheliomas

**Clinical Applications**

**Patient Selection**

- Patient selection based on disease characteristics
  - Nearby critical structures
  - Complex target volumes
  - Suitable target size
    - IMRT may not offer significant advantage over 3DCRT for small lesions (earlier stage) or extremely large lesions (late stage)
    - Primary NSCLC stage III lesions are ideal candidates for IMRT

- Patient selection based on organ motion
  - Immobile tumors are preferred for IMRT (tumor motion < 0.5 cm)
  - For mobile tumors, effects of tumor motion need to be considered with adequate margins and dosimetric impact on other structures

**Methodology**

**Treatment Simulation**

- CT simulation
  - Patient preparation
  - Immobilization device
  - Marking skin
  - Breathing training (optional)
  - PET-CT
  - CT attenuation correction
  - Regular PET
  - CT
  - Freebreathing CT (to be obsolete)
  - 4DCT
  - Data transfer

PET/CT suite with in-room laser
**Treatment Simulation**

- Patient Setups and Immobilization
  - Alpha cradle
  - Stereotactic bodybag maybe preferred for improved precision
  - Wing board
  - Head holder (optional)
  - T-Bar and arm up position
  - Reference markers are placed near carina with relatively stable anatomy
  - Isocenter shift based on planning CT
  - Position variations
  - Arm down or setup similar to head&neck cases can be customized for special situations

**Target Delineation**

- 4DCT: Assess tumor/anatomy motion
- PET/CT: Assess target extension and nodal involvement

**Target Delineation**

- Margins of target volumes
  - GTV
  - iGTV = U\{GTV\} (from all respiratory phases and PET/CT)
  - ITV = ICTV = iGTV + microscopic expansion
  - PTV = ITV + setup uncertainty

**Treatment Planning**

- Inverse planning for lung IMRT
  - IMRT Inverse Planning
    - Region-of-interests (ROIs)
    - Fluence optimization
    - MLC sequences
  - Plan Evaluation
  - Beam configuration
[Methodology]
Inverse Planning

- Optimization engine
  - Specification of objective functions (costs)
  - Distance between current solution to the desired one
- Free parameters for optimization
  - beamlet intensity
  - Search engine
    - Deterministic approaches (Gradient based)
    - Stochastic approaches
- Interface with optimization engine
  - Objective functions/constraints
  - Solution output and evaluation of results

[Methodology]
Inverse Planning

- Secrets of inverse planning for lung IMRT
  - Objective functions are the steering wheels for the optimization engine
  - Planners need to know the behavior of the optimization engine and effects of choosing objective functions
  - Planners need to know how to make compromises among conflicting goals
    - Tumor vs. lung
    - Different OARs: lung, heart, cord, esophagus, tissue

*Method is more specific to Pinnacle and similar systems*

[Inverse Planning]
Inverse Planning by Iterative Planning

- Problem
  - Each patient is unique
  - Appropriate objectives are difficult to foresee
  - Inverse planning involve many trial-errors
- Solution
  - Feedback guided, stepwise progressive, iterative planning

*Method is more specific to Pinnacle and similar systems*

[Inverse Planning]
ROIs specific for Lung IMRT

- In addition to ROIs that are needed for regular 3D planning, it will be helpful to have the following ROIs to drive the inverse planning:
  - PTV_Expanded: PTV + 1~2 cm margin
  - PTV_Moat: 1~2 cm moat outside PTV_Expanded
  - Normal tissue: skin contracted until PTV_moat
  - Cord_Expanded: cord + 1cm margin
  - Esophagus_Expanded: esophagus + 1cm margin
  - Other hot spots (at the end of the planning)
ROIs specific for IMRT

Inverse Planning by Iterative Planning

Step 1. Start by using default objective function templates that include:
• CTV: min dose
• PTV: min dose, max dose, (uniform dose)
• PTV moat: max dose
• Total lung: V5 (60%), V10 (45%), V20 (35%), Mean lung dose (15 Gy)
• Cord: max dose (45 Gy)
• Heart: V45 (30%)
• Esophagus: V45 (30%)
• Normal tissue: max dose or V20

Disadvantage: increase of parameter space

Step 2: Assign equal weighting to all objectives.

Step 3:
• Run 1 search iteration only;
• Evaluate current solution which is similar to a 3D plan;
• Adjust the objectives accordingly and their associated costs.

Step 4 and beyond: to balance the priorities and conflicting goals
– Evaluate optimization solution
– Re-adjust objective functions and their costs
– Objectives with the highest costs will be pushed down first during the next iteration loop
– Follow the sequence of priority and organ sensitivity
  A. Target coverage
  B. Lung dose/volume
  C. Heart, esophagus, cord
  D. Normal tissues, hot spot
– Continue based on existing solution

Demo of an Example Case
**Inverse Planning**

**Demo of an Example Case**

*Iterative feedback guided inverse planning*

- Number of optimization iterations does not have to exceed 5 - 8 for gradient algorithms
- Choose the battle wisely, the key issue is to set appropriate objectives
- Upon completion of each run, critically assess the results and re-adjust objectives and costs, and rerun upon existing results

**Plan Evaluation**

- **Isodoses**
  - Target conformity vs. hot spots
  - Dose avoidance to ROIs, particularly lung
  - Spread of low-dose volume to lung and normal tissue

- **DVHs**
  - Evaluate whether objectives/constraints being placed properly
  - Adjust objectives if reoptimization is required

- **Other biological parameters**
  - Mean dose or EUD for lung
  - NTCP

**Plan Evaluation**

- **MLC Sequence Conversion**
  - Deliverable plans are often degraded from fluence-optimized plan
  - May have to reoptimize plan due to degradation of leaf conversion
  - On Pinnacle: May perform direct segment optimization for converted plan. If this is necessary, adjust objective functions first before reoptimization
  - Minor manual adjustment to segments can be helpful to reduce cold/hot spots
  - Direct leaf sequence optimization is another option
**Inverse Planning**

**MLC Sequence Conversion**
- Balance between delivery efficiency (#segments and MUs) vs. dose gradient (conformity and avoidance)
- In general, #segment/beam should be < 20 for lung plans, it is not necessary to exceed more than 30 segments/beam
- Treatment planning system may not be adequate to compute dose accurately for plans with MU efficiency < 25%

$$\text{MU efficiency} = \frac{\text{Fractional prescription dose (cGy)}}{\text{sum(average_MU_per_angle)}}$$

$$\text{average_MU_per_angle} = \frac{\text{Total_MU_per_angle}}{\text{Num Beam per angle}}$$

**Beam Configuration**
- 6MV photon beams are preferred choice
- 18MV beams should be avoided if possible
  - Electron disequilibrium
  - Neutron production
- Coplanar beams are more practical and easy for planning
- Noncoplanar beams may offer additional choices for beam angle optimization

**Beam Configuration**
- Place of beam angles should carefully consider planning priorities for normal structures
  - PTV is not sensitive to the beam angles
  - Lung is the determining factor for selecting beam angles
  - Heart is more sensitive to angle selection than esophagus and cord
- 4-6 beams should be sufficient for lung IMRT
- Excessive beams will reduce MU efficiency and delivery complexity/time
- Experience from 3DCRT on optimal angles can be extended to IMRT

**Beam Configuration**
- Use of 4-6 beams can achieve essentially equivalent plan quality compared to 9 beams
- Use of fewer beams require beam angle optimization that minimize lung dose-volume
**[Inverse Planning]**

**Beam Configuration**

- MU's and #segments increase with #beams
- Reduction of #beams improves delivery efficiency and low-dose leakage
- Compromise between #beams and likelihood of hotspots

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**[Methodology]**

**Treatment Delivery and QA**

- QA procedure should be similar to other sites
- Frequent imaging maybe needed to ensure accuracy and precision of patient positioning
- Dosimetry issues specific to lung cancers
  - More significant tissue inhomogeneities
  - Large field sizes and high degree of intensity modulation
  - Low doses in lung and normal tissues maybe more difficult to compute accurately by conventional treatment planning systems

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**[Treatment Verification]**

**Dosimetry QA**

- Sources of dose calculation uncertainties
  - Tissue inhomogeneities
  - Beam modeling
  - MLC modeling
  - Dose calculation algorithms
    - Pencil-beam algorithms
    - Convolution algorithms

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**Dosimetry QA**

- Commissioning/Implementation of lung IMRT procedure
  - Intensity verification
    - Ion chamber in water phantom
    - Film in solid water phantom
  - In-vitro dosimetry
    - TLDs in anthropomorphic phantoms
  - Monte Carlo calculations
Phantom Measurements

- Comparison of Pinnacle calculations (v6.2) vs. TLD measurements for lung IMRT cases from high to low dose regions

Monte Carlo Based QA

- Comparison of Corvus calculations (v4; v5) with Monte Carlo simulation for mesothelioma cases

Dosimetry Verification

- Ensure dose calculation accuracy
  - In high-medium dose region
  - Using the types of leaf sequences generated within the planning system itself
- Treatment planning systems may underestimate dose in low dose region
  - Strongly depends on beam modeling and MLC modeling (leaf transmission, leakage)
  - Effects is more prominent for beams with low MU efficiency, i.e. greater leakage
Dosimetry Verifications

- Tissue inhomogeneity may not be a significant cause of error for lung IMRT, even using Pencil-beam algorithms (based on Corvus results)
- QA for single IMRT beam may not be adequate, composite dose distribution is more sensitive to dose errors
- Monte Carlo simulation is a powerful/effective tool for IMRT QA
  - Provide independent MU and dose distribution verification
  - However, MCS can also be subjective to beam parameters used for IMRT
  - Also requires rigorous commissioning process

Summary

1. IMRT can be an effective treatment modality for managing advanced stage NSCLC and other suitable lung cancers (superior sulcus, meso, etc)
2. Patient candidates need to be identified to maximize benefits of IMRT
3. Target delineation and organ motion need to be carefully considered during simulation
4. Low-dose volume of lung and normal tissue need to be reduced when planning for beam angles and dose distributions
5. Dosimetry accuracy should be validated for each treatment planning system

Questions & Discussions

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