Computed Tomography Simulation in Radiation Therapy for Non-small Cell Lung Cancer

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Introduction

- Lung cancers are the most common invasive malignancies in the U.S.
- Classified as small cell or non-small cell carcinomas (NSCLC). NSCLC are more common & spreads/grows slower. (Washington & Leaver, 2016, p. 621)
- Computed Tomography (CT) is the process of creating a cross-sectional tomographic plane of any part of the body. (Long, Rollins, & Smith, 2019, p. 206)
- CT technology is used during the simulation step of the radiation therapy process to create 3D images of the patient's anatomy.
- Based off these images, a treatment plan is created that maximize dose to a target and minimize dose to normal surrounding tissue.
- For lung tumors, four critical structures are of primary concern: the spinal cord, esophagus, heart, & healthy lung.
- Four-dimensional CT (4D-CT) & advanced respiratory motion management techniques are used in NSCLC treatment to avoid dosing these critical structures.
- Ultimate success of treatment is directly related to effectiveness of the simulation procedure. (Washington & Leaver, 2016, p. 451)

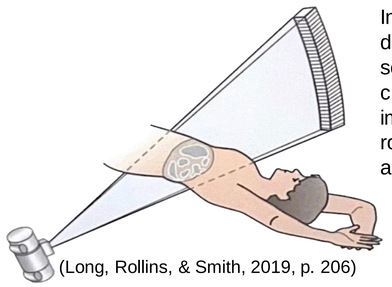


Image demonstrates CT scanner creating cross-sectional image using rotating x-ray tube around patient.

(Long, Rollins, & Smith, 2019, p. 206)

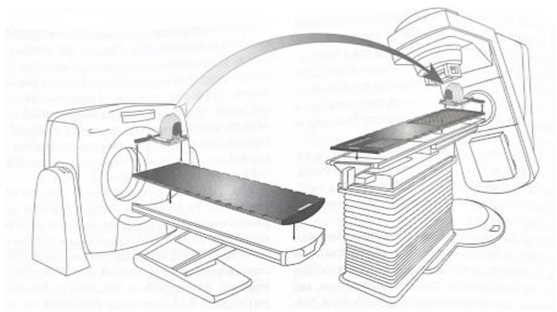
Principles of Radiation Therapy

- Definition: The medical specialty that uses ionizing radiation to treat cancer.
- Goal: Deliver radiation to target volume while reducing dose to normal surrounding tissue (Washington & Leaver, 2016, p. 1)
- Process typically includes:
  1. Diagnosis and consultation with radiation oncologist
  2. Simulation
  3. Planning
  4. Treatment
  5. Follow-up with the radiation oncology team.

  (Church, 2018, p. 399)
- Radiation to the tumor is delivered during the treatment step using a linear accelerator. (Washington & Leaver, 2016, p. 154)

What is CT Simulation?

- Is the next step in the radiation therapy process after diagnosis. Therapist positions patients in the way they will be positioned during treatment. (Church, 2018, p. 399)
- Uses CT imaging to assist the physician and other members of the radiation therapy team in treatment planning process.
- Establishes appropriate volume to be treated & identifies normal structures within, or adjacent to, this volume. (Washington & Leaver, 2016, p. 449)
- Uses images to localize the treatment isocenter & define the size and shape of treatment volume relative to important tissues.
- Translates information back on the patient with a laser-based patient marking system.
- Patient is marked and documented for daily setup & treatment.
- Information used to initiate treatment planning process. (Washington & Leaver, 2016, p. 451)



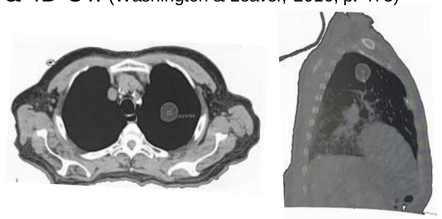
CT scanner (Left) has flat couch top that mimics flat therapy couch top on linear accelerator (Right). Helps immobilization devices to be universal between CT & treatment. (Washington & Leaver, 2016, p. 144)

Why is CT the Standard Simulation Method?

- A single integrated operation that fuses the process of:
  - patient scanning
  - tumor and target localization
  - treatment planning
  - treatment field verification
- Patient data can be gathered in all three anatomical planes: axial, sagittal, and coronal.
- One CT simulation procedure can replace a total of three procedures. (Long, Rollins, & Smith, 2019, p. 206)
- Provides the anatomical and structural information needed to define patient's body contour and electron density map needed for dose calculations. (Church, 2018, p. 399)

Challenges in CT Simulation for Patients with NSCLC

- Motion artifacts historically have been recognized in CT scanning.
- Breathing motion remains a challenge in localizing lung tumors since organs can move several centimeters during a few seconds.
- Two methods to overcome breathing motion include deep inspiration breath hold (DIBH) & 4D-CT. (Washington & Leaver, 2016, p. 473)



Axial (Left) & sagittal (Right) images of patient with NSCLC. Note proximity of tumor to critical structures of healthy lung & heart. (Washington & Leaver, 2016, p. 640)

Deep Inspiration Breath-Hold (DIBH)

- Lungs are inflated which changes the heart position & respiratory motion is decreased.
- Benefits:
  - Simple, cost-effective technique; Enables dose reduction due to larger lung volume and increased distance between tumor & heart. (Josipovic et al., 2019, pp. 1-2)
  - There is evidence that DIBH for patients with NSCLC can decrease the risk of radiation pneumonitis, or inflation to lung caused by radiation. (Fjellanger et al., 2022, p. 1).
- Disadvantages:
  - Many patients cannot hold their breath for long periods of time due to their condition.
  - The amount of inspiration is not very reproducible, meaning not every breath will be the same. (Washington & Leaver. 2016, p. 473)

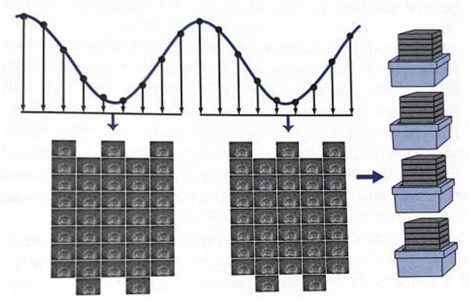
What is Four-dimensional Computed Tomography (4D-CT)?

- A method of CT that evaluates tumor and critical structure motion during the respiratory cycle; The fourth dimension refers to motion.
- Development of 4D-CT caused an increased interest in treating moving targets.
- Enables physician & treatment planner to conform dose around the target volume more closely, radiate tumor with highest possible dose while sparing healthy tissues. (Washington & Leaver, 2016, p. 455)

Advanced Respiratory Motion Management Techniques

- To perform 4D-CT scanning, a method to measure the respiratory phase is needed. (Washington & Leaver, 2016, p. 474)
- Motion management techniques are used to monitor motion & modify treatment in real time.
- Benefits include smaller target volumes plus lower dose to organs at risk.
- Two main types of techniques used in NSCLC treatment are respiratory gating & tumor tracking.
  - Respiratory gating- delivers treatment only to a pre-specified portion of the respiratory cycles; limits delivery of the treatment beam to within a specified respiratory gate
  - Tumor tracking- tumor motion is followed by dynamic movement of the treatment field; dynamic tumor tracking uses orthogonal real-time radiographic imaging to track radio-opaque implanted fiducial markers

(Aridgides et al., 2018, pp. 103-104)



CT image acquisition during specific phases of respiration. An example of advanced respiratory motion management during 4D-CT. (Washington & Leaver, 2016, p. 455)

Conclusion

- Radiation therapy is a multi-step process that seeks to maximize dose to the target volume (tumor), while reducing dose to normal surrounding tissues and critical structures.
- The use of CT simulation provides vital anatomical & structural information used in planning and treatment of radiation therapy.
- In simulation, either DIBH or 4D-CT utilizing advanced respiratory motion management techniques are used to overcome breathing motion when treating patients with NSCLC,
- Overall, CT simulation in radiation therapy helps to achieve personalized and precise treatment to each patient in hopes of curing the patient.

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