Implementation & optimization of a lung cancer screening CT program

Presented by Izabella Barreto
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Izabella Barreto, Nathan Quails, Catherine Carranza, Nathalie Correa, Michael Bickelhaup, Tan-Lucien Mohammed, Nupur Verma, Lynn Rill, Manuel Arreola

Department of Radiology
University of Florida College of Medicine
Gainesville, FL

MOTIVATION

1.8 million
new lung cancer cases worldwide in 2012

1.59 million
lung cancer deaths worldwide in 2012
1.8 million new lung cancer cases is the most common type of cancer & cancer death in 1.59 million lung cancer deaths worldwide in 2012

LUNG CANCER IN THE UNITED STATES

<table>
<thead>
<tr>
<th>Common Types of Cancer</th>
<th>Estimated New Cases 2016</th>
<th>Estimated Deaths 2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Breast Cancer (Female)</td>
<td>246,660</td>
<td>40,450</td>
</tr>
<tr>
<td>2. Lung and Bronchus Cancer</td>
<td>224,390</td>
<td>158,080</td>
</tr>
<tr>
<td>3. Prostate Cancer</td>
<td>180,890</td>
<td>26,120</td>
</tr>
<tr>
<td>4. Colon and Rectum Cancer</td>
<td>134,490</td>
<td>49,190</td>
</tr>
<tr>
<td>5. Bladder Cancer</td>
<td>76,960</td>
<td>16,390</td>
</tr>
<tr>
<td>6. Melanoma of the Skin</td>
<td>76,380</td>
<td>10,130</td>
</tr>
<tr>
<td>7. Non-Hodgkin Lymphoma</td>
<td>72,580</td>
<td>20,150</td>
</tr>
<tr>
<td>8. Thyroid Cancer</td>
<td>64,300</td>
<td>1,980</td>
</tr>
<tr>
<td>10. Leukemia</td>
<td>60,140</td>
<td>24,400</td>
</tr>
</tbody>
</table>

Second most common cancer in the US

Leading cause of cancer-related deaths in the US

International Agency for Research on Cancer, GLOBSCAN 2012, World Health Organization
National Cancer Institute, SEER 18 2000 – 2012
RISK FACTORS

• Lung cancer is also the most preventable form of cancer

• Cigarette smoking is responsible for more than 80% of lung cancers

• Other risk factors:
  • Exposure to secondhand smoke, radon, asbestos, radiation, air pollution

SURVIVAL RATE

• 5-year survival rate of 17.4%

• Compared to 90.3% for breast cancers and 99.7% for prostate cancers
LUNG CANCER AT STAGE OF DIAGNOSIS

<table>
<thead>
<tr>
<th>Stage at Diagnosis</th>
<th>Percent of Cases</th>
<th>5-Year Relative Survival</th>
</tr>
</thead>
<tbody>
<tr>
<td>Localized</td>
<td>16%</td>
<td>54.8%</td>
</tr>
<tr>
<td>Regional</td>
<td>22%</td>
<td>27.4%</td>
</tr>
<tr>
<td>Distant</td>
<td>57%</td>
<td>4.2%</td>
</tr>
</tbody>
</table>

LUNG CANCER SCREENING

• It is crucial to detect lung cancer as early as possible to increase chances for treatment and survival.

• Many studies have attempted to identify an effective screening test for detecting early stage lung cancer in asymptomatic patients with the goal of decreasing mortality.

Chest radiography
• Used as a lung cancer screening tool for several decades
• Studies showed no significant improvement in lung cancer mortality

Multidetector Computed Tomography
• Improved spatial resolution & increased scan speed
• Inherent contrast in lung parenchyma
• Cross sectional data acquisition and display
• Enables visualization of more subtle abnormalities

• Several studies showed that low-dose CT (LDCT) screening detects more early stage lung cancers than chest radiography
• However, none addressed the effects of LDCT screening on lung cancer mortality
2002 **NATIONAL CANCER INSTITUTE**

**National Lung Screening Trial**

- Assigned 53,439 participants
  - current or former heavy smokers who were 55-74 year old
  - to receive annual screenings for 3 years
    - with **low-dose CT** (LDCT) or **standard chest x-ray** (CXR)
  - Screening took place from 8/2002-9/2007, patients were followed until 2009

2011

- Results found 20% fewer lung cancer deaths in participants screened with LDCT than with CXR

2013

**The US Preventive Services Task Force (USPSTF)**

- Recommended annual lung cancer screening with LDCT

2015

**Centers for Medicare & Medicaid Services (CMS)**

- Approved coverage of annual lung cancer screening with LDCT

2015

**American College of Radiology (ACR)**

- Lung Cancer Screening Registry (2015)
- Designated Lung Cancer Screening Center (2014)

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**REQUIREMENTS FOR REIMBURSEMENT**

Patient eligibility:

- Asymptomatic
- Age: 55-77 years of age
- Current smokers or quit within 15 years
- ≥ 30 pack-year smoking history
- Must receive a written order for LDCT lung cancer screening
REQUIREMENTS FOR REIMBURSEMENT

Radiology imaging facility eligibility:

• Makes available smoking cessation interventions

• Screening read by thoracic radiologists
  • with >300 chest CT interpretations in the past 3 years

• Utilizes a standardized lung nodule reporting system
  • ACR Lung Reporting and Data System (Lung-RADS™)

• Collects and submits data to a CMS-approved registry
  • ACR Lung Cancer Screening Registry (LCSR)

• Provide LDCT with CTDIvol ≤ 3.0 mGy for standard size patient (5’7, 155 lbs)
  • with modified CTDIvol for smaller/larger patients

REVIEW OF OUR SCREENING PROGRAM

3/1/15: Radiology department implemented lung cancer screening with LDCT
  • Lead by thoracic radiologists and CT supervisors

5/10/15: Physics investigated LCS protocol in a CT scanner

Findings:

• Protocol called “low-dose chest CT”
  • Not specific to lung cancer screening

• Protocol CTDIvol ~ 10 mGy ➔ Dose too high

• Standard deviation (SD) image quality noise index
  • Set to 12.5 SD ➔ Same as standard chest protocol

Physics informed CT supervisor & changed protocol’s noise index to 19 SD
RETROSPECTIVE ANALYSIS

11/20/15: Physics submitted IRB application
  • Retrospective review of patient doses for 8 months of screening
    • 122 patients examined with lung cancer screening CT
    • Between 3/1/15 - 11/20/15

11/30/15 – 1/15/16: Using a PACS image viewer, recorded:
  • CT scanner model
  • Scan protocol (kVp, mAs, SD)
  • Scanner reported dose metrics (CTDîvol, DLP)
  • Patient size (measured diameter)

CT SCANNERS USED

<table>
<thead>
<tr>
<th></th>
<th>Iterative Reconstruction</th>
<th>Tube Current Modulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siemens Sensation 16</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>Siemens Sensation 16</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>Toshiba Aquilion 16</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>Toshiba Aquilion ONE</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Toshiba Aquilion PRIME</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
CTDI\textsubscript{vol} OF 122 EXAMS

- Toshiba AQ 16 protocols produced too high dose

- AAPM's CTDI\textsubscript{vol} upper limits for:
  - Toshiba AQ 16
  - Toshiba AQ ONE

CTDI\textsubscript{vol} OF ALL EXAMS AFTER 5/10/15

- Toshiba AQ 16 SD=15 (No AIDR-3D)
- Toshiba CT Scanner
- Siemens CT Scanner

- CT Technologist stated LCS exams are rarely routed to Toshiba AQ16 due to lack of iterative reconstruction

- AAPM's CTDI\textsubscript{vol} upper limits for:
  - LARGE PATIENT
  - AVERAGE PATIENT
  - SMALL PATIENT
DOSE ADJUSTMENTS FOR PATIENT SIZE

• Physics measured patient AP & Lateral dimensions
  • On central slice in CT scan

• Calculated effective diameter:

\[ \text{effective diameter} = \sqrt{\text{AP} \times \text{LAT}} \]

CTDI\text{vol} VS PATIENT SIZE

CTDI\text{vol} was nearly constant for patients of varying sizes with Siemens CT scanners
DOSE ADJUSTMENTS FOR PATIENT SIZE

1/20/16
• Physics presented findings to Radiology Practice Committee (RPC)
  • Thoracic radiologist leading lung cancer screening program
  • Radiology chairman
  • Lead CT supervisor
• Discussed pros & cons of turning on tube current modulation
• Discussed noise target levels in Siemens scanners
  • CareDose, Quality Reference mAs

1/25/16
• Tube current modulation implemented on Siemens CT scanners

DOSE ADJUSTMENTS FOR PATIENT SIZE: SIEMENS SENSATION 16 CT SCANNER
DOSE ADJUSTMENTS FOR PATIENT SIZE: TOSHIBA & SIEMENS CT SCANNERS

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SCREENING RISK ASSESSMENT

- Potential risks from CT need to be considered for the risk-benefit analysis of Lung Cancer Screening CT
- Scanner reported metrics (CTDI<sub>vol</sub>, DLP) do not represent true patient doses
- Requires individual organ dose assessment

What typical organ doses are expected from LDCT lung cancer screening exams?
HOW CAN WE MEASURE ORGAN DOSES?

Simulations with computational phantoms

- **Patient approximations**
  - Allows calculations for a variety of patient sizes

- **Radiation source simulations**
  - Difficult to model true CT scanner
    - X-ray Spectra, bowtie filtration
    - Tube current modulation
    - Iterative reconstruction

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HOW CAN WE MEASURE ORGAN DOSES?

Direct measurements in cadavers

- **Closest representation of a patient undergoing a CT exam**
  - Allows measurement inside actual organs
  - Allows image quality assessment for protocol optimization

- **Utilizes a clinical radiation source**
  - No simulations or approximations
  - Tube current modulation, iterative reconstruction
CAN WE DO THIS?

- Postmortem Concerns: Livor mortis, Rigor Mortis, Decomposition

We investigated attenuation changes in cadaver versus living patient tissue, assessing changes in $\mu$ by looking at HU in various organs.

$$HU_{tissue} = 1000 \left( \frac{\mu_{tissue} - \mu_{water}}{\mu_{water}} \right)$$

- Natural variations were observed in organs in both cadavers and patients groups, due to varying state of health of individuals

- Lung attenuation differences due to fluid infiltration in cadaver lungs

**YES, WE CAN**

<table>
<thead>
<tr>
<th>Tissue Type</th>
<th>Hounsfield Units</th>
<th>% Difference versus Patient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lung</td>
<td>-772</td>
<td>-750</td>
</tr>
<tr>
<td>Fat</td>
<td>-102</td>
<td>-75</td>
</tr>
<tr>
<td>Muscle</td>
<td>50.6</td>
<td>55</td>
</tr>
<tr>
<td>Bone</td>
<td>555</td>
<td>550</td>
</tr>
<tr>
<td>Kidney</td>
<td>42.6</td>
<td>50</td>
</tr>
<tr>
<td>Liver</td>
<td>58</td>
<td>45</td>
</tr>
</tbody>
</table>

* Measuring organ doses in cadaveric subjects is an accurate method for estimating dose in patients undergoing CT examination
**ACCESS TO POSTMORTEM ORGANS**

- **Plastic PVC tubes**
  - Inserted into Organs of Interest
  - By radiologist specialized in CT-guided biopsies

- **OSL dosimeters**
  - Corrected for energy and scatter dependence
  - Sealed in plastic and inserted into affixed PVC tubes

- Utilizing organ dosimetry methodology developed in-house by Griglock et al.

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<table>
<thead>
<tr>
<th>Organs</th>
<th>Number of Dosimeters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skin</td>
<td>15</td>
</tr>
<tr>
<td>Thyroid</td>
<td>2</td>
</tr>
<tr>
<td>Breast</td>
<td>8</td>
</tr>
<tr>
<td>Lung</td>
<td>8</td>
</tr>
<tr>
<td>Liver</td>
<td>5</td>
</tr>
<tr>
<td>Stomach</td>
<td>2</td>
</tr>
<tr>
<td>Colon</td>
<td>2</td>
</tr>
<tr>
<td>Ovary</td>
<td>3</td>
</tr>
</tbody>
</table>

Example:
- 8 OSLDs in breasts
- 8 OSLDs in lungs
LUNG CANCER SCREENING CT PROTOCOL

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT Scanner</td>
<td>Toshiba Aquilion ONE 320</td>
</tr>
<tr>
<td>Scan Range</td>
<td>Thoracic inlet to bottom of lung</td>
</tr>
<tr>
<td>Scan type</td>
<td>Helical</td>
</tr>
<tr>
<td>Detector configuration</td>
<td>80 x 0.5 mm</td>
</tr>
<tr>
<td>Tube Voltage (kVp)</td>
<td>120</td>
</tr>
<tr>
<td>Tube Current Modulation</td>
<td>Exposure 3D enabled</td>
</tr>
<tr>
<td>Iterative Reconstruction</td>
<td>AIDR-3D enabled</td>
</tr>
<tr>
<td>mA limits (min - max)</td>
<td>10 – 150</td>
</tr>
<tr>
<td>Target Noise Level (SD)</td>
<td>20</td>
</tr>
<tr>
<td>Effective mAs</td>
<td>32</td>
</tr>
<tr>
<td>Rotation Time (s)</td>
<td>0.35</td>
</tr>
<tr>
<td>CTDI vol (mGy)</td>
<td>2.2</td>
</tr>
<tr>
<td>DLP (mGy cm)</td>
<td>65.9</td>
</tr>
<tr>
<td>Soft Tissue Reconstruction</td>
<td>3x3 mm</td>
</tr>
<tr>
<td>Lung Reconstruction</td>
<td>2x2 mm</td>
</tr>
</tbody>
</table>

MEASURED ORGAN DOSES

- Small cadaver: 87 lb, 4.36 ft, 22.6 BMI, Deff 21.64 cm, CTDIvol 2.2 mGy
- Organs located within the scan range are directly exposed by the CT beam:

<table>
<thead>
<tr>
<th>Organs</th>
<th>Average Dose (mGy)</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skin</td>
<td>3.89</td>
<td>0.52</td>
</tr>
<tr>
<td>Thyroid</td>
<td>4.16</td>
<td>0.16</td>
</tr>
<tr>
<td>Breast</td>
<td>3.56</td>
<td>0.70</td>
</tr>
<tr>
<td>Lung</td>
<td>3.28</td>
<td>0.68</td>
</tr>
<tr>
<td>Liver</td>
<td>4.19</td>
<td>0.12</td>
</tr>
<tr>
<td>Stomach</td>
<td>3.07</td>
<td>0.02</td>
</tr>
</tbody>
</table>

- All others are exposed to scattered radiation:

<table>
<thead>
<tr>
<th>Organs</th>
<th>Max Dose (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colon</td>
<td>2.62</td>
</tr>
<tr>
<td>Ovary</td>
<td>1.32</td>
</tr>
</tbody>
</table>
MEASURED ORGAN DOSES

• Larger cadaver: Deff 25.63 cm, CTDIvol 5.3 mGy
• Organs located within the scan range are directly exposed by the CT beam:

<table>
<thead>
<tr>
<th>Organs</th>
<th>Average Dose (mGy)</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skin</td>
<td>7.31</td>
<td>1.23</td>
</tr>
<tr>
<td>Thyroid</td>
<td>10.47</td>
<td></td>
</tr>
<tr>
<td>Breast</td>
<td>6.56</td>
<td>0.46</td>
</tr>
<tr>
<td>Lung</td>
<td>6.01</td>
<td>0.75</td>
</tr>
<tr>
<td>Liver</td>
<td>7.33</td>
<td>0.08</td>
</tr>
<tr>
<td>Stomach</td>
<td>6.45</td>
<td>0.36</td>
</tr>
</tbody>
</table>

• All others are exposed to scattered radiation:

<table>
<thead>
<tr>
<th>Organs</th>
<th>Max Dose (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colon</td>
<td>2.09</td>
</tr>
<tr>
<td>Ovary</td>
<td>0.42</td>
</tr>
</tbody>
</table>

Can Lung Cancer Screening CT be conducted with lower dose while still providing acceptable image quality for the purpose of lung cancer screening?
PROTOCOL OPTIMIZATION SCAN SETTINGS

To assess LCS-CT image quality at lower doses:

- Decreasing kVp (from 120 to 100)
- Decreasing mA (by increasing SD from 20 to 35)

<table>
<thead>
<tr>
<th>Scan</th>
<th>kVp</th>
<th>SD</th>
<th>Eff mAs</th>
<th>CTDIvol (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>120</td>
<td>20</td>
<td>32</td>
<td>2.2</td>
</tr>
<tr>
<td>2</td>
<td>120</td>
<td>25</td>
<td>21</td>
<td>1.5</td>
</tr>
<tr>
<td>3</td>
<td>120</td>
<td>35</td>
<td>18</td>
<td>0.8</td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>20</td>
<td>50</td>
<td>1.9</td>
</tr>
<tr>
<td>5</td>
<td>100</td>
<td>25</td>
<td>30</td>
<td>1.5</td>
</tr>
<tr>
<td>6</td>
<td>100</td>
<td>35</td>
<td>10</td>
<td>0.7</td>
</tr>
</tbody>
</table>

IMAGE QUALITY ASSESSMENT

2 thoracic radiologists
- Blinded to scan techniques

Graded:
- Sharp reproduction of the lung parenchyma
- Diagnostic confidence in assessing lung nodules
- Diagnostic confidence in assessing lung disease

3-point scale chosen to simplify clinical implementation

1. Unacceptable
2. Borderline acceptable
3. Acceptable
Protocols with Target Noise Levels of 20 or 25 SD were acceptable

Protocols with 35 SD resulted in borderline acceptable scores

Organ doses were measured for the protocols graded with acceptable image quality:

<table>
<thead>
<tr>
<th>Scan</th>
<th>kVp</th>
<th>SD</th>
<th>Eff mAs</th>
<th>CTDI_{vol} (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>120</td>
<td>20</td>
<td>32</td>
<td>2.2</td>
</tr>
<tr>
<td>2</td>
<td>120</td>
<td>25</td>
<td>21</td>
<td>1.5</td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>20</td>
<td>50</td>
<td>1.9</td>
</tr>
<tr>
<td>5</td>
<td>100</td>
<td>25</td>
<td>30</td>
<td>1.5</td>
</tr>
</tbody>
</table>
CONCLUSIONS

- The AAPM Lung Cancer Screening CT Protocol
  - Produced organ doses 3.07 – 4.19 mGy

- Increasing the noise level from 20 to 25 SD
  - Resulted in acceptable image quality
  - Produced organ doses 2.30 – 3.27 mGy (11 - 27% organ dose reduction)

- UF Health implemented these changes to our protocol
- AAPM implemented these changes as well

- Future work: Compare patient doses & image quality for patients scanned with the original & new lower dose protocol
SUMMARY

• Lung cancer is the leading cause of cancer related deaths in the United States and cigarette smoking is the most important risk factor
• NLST is the largest screening trial and shows 20% reduction in mortality
• LDCT is the only recommended screening test to detect early lung cancer
• Be mindful of CT dose variation in protocols across scanners:
  • Appropriate use of CT scanners
  • Comprehensive training for technologists
  • Standardized CT protocols
  • Appropriate scan length
  • Tube current modulation
  • Tube potential
  • Iterative reconstruction

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Lori Gravelle, ARRT
Sondra Garrett, ARRT

Thoracic Imaging
Tan-Lucien Mohammed, MD
Nupur Verma, MD
THANK YOU FOR YOUR ATTENTION

ORGAN DOSE VS PATIENT SIZE

• Organ dosimetry repeated in 10 cadavers
  • Ranging from underweight to obese weight class
• Same:
  • Scanner: Toshiba Aquilion ONE
  • Scan range: Thoracic inlet to bottom of lungs
• Scan parameters modified:
  • Varying levels of mA
  • Filtered backprojection
  • Iterative reconstruction
  • 65, 80, 100, 160 detector channels
Chest organ doses measured in 10 cadavers

Conversion Coefficient

CTDI to organ dose conversion coefficients
**CTDI to organ dose conversion coefficients**

**NLST risks of screening**

- **False Positives:**
  - LDCT had a high false positive rate (96.4%)
    - 18,146 positive tests
    - Only 649 were confirmed to be lung cancer
    - Other 17,497 were benign intrapulmonary lymph nodes or noncalcified granulomas
    - Only 2.5% of positive screens required invasive diagnostic procedures
  - CXR had 94.5% false positive rate
    - 5,043 positive tests
    - Only 279 were confirmed to be lung cancer

- **Overdiagnosis:**
  - Estimated to be at about 10%
    - Results from detection of cancers that never would have become symptomatic

- **Radiation induced cancers:** estimated <1% of cases

- **Incidental findings**
  - 7.5% were clinically significant
    - Coronary artery calcifications, emphysema, pulmonary fibrosis, bronchiectasis, benign tumors

- Psychological stress
CTD_{vol} Specifications

- **American College of Radiology (ACR)**
  - “CTD_{vol} must be ≤ 3 mGy for standard size patient”

- **American Association of Physicists in Medicine (AAPM)**
  - “CTD_{vol} must be ≤ 3 mGy for standard size patient”
  - Other sizes:

<table>
<thead>
<tr>
<th>Approx. Weight (lbs)</th>
<th>Approx. CTD_{vol} (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Patient</td>
<td>110-155</td>
</tr>
<tr>
<td>Average Patient</td>
<td>0.25 - 2.8</td>
</tr>
<tr>
<td>Large Patient</td>
<td>155-200</td>
</tr>
<tr>
<td></td>
<td>0.5 - 4.3</td>
</tr>
<tr>
<td></td>
<td>200-265</td>
</tr>
<tr>
<td></td>
<td>1.0 - 5.6</td>
</tr>
</tbody>
</table>

**IMAGE RECONSTRUCTION**

8 different axial image reconstructions:

- Standard Body Axial (FC18) - 1 mm & 3 mm
- Lung Low Dose (FC55) - 1 mm & 3 mm
- Lung Sharp (FC86) - 1 mm & 3 mm
- Lung High Resolution CT (FC86) - 1 mm & 3 mm

Chief of Thoracic Imaging
- Blinded to reconstruction parameters
- Identified preferred reconstruction for LCS
IMAGE RECONSTRUCTION

Soft Tissue:
- 1-mm image appeared too noisy
- Preferred 3-mm reconstruction

Lung:
- 3-mm image lacked detail
- Better lung detail with 1-mm slices
  - Despite increase in noise
- “High Resolution CT” algorithm looked too noisy
- “Lung Low Dose” algorithm lacked detail

Ideal reconstruction settings:
- 3-mm “Standard Body Axial” algorithm
- 1-mm “Lung Sharp” algorithm

Lung Reporting and Data System (Lung-RADS™)

Standardized system for identification, classification & reporting of lung nodules

- Category 0: Incomplete Additional imaging needed
- Category 1: Negative Continue annual LDCT screening
- Category 2: Benign Continue annual LDCT screening
- Category 3: Probably benign LDCT in 6 months
- Category 4A: Suspicious LDCT in 3 months
  - PET/CT if ≥ 8 mm solid component exists
- Category 4B: Suspicious Chest CT w/wo contrast
  - PET/CT and/or biopsy
Lung Cancer Screening Registry

- First lung cancer screening registry approved by CMS
- Launched in 2015

- Participant responsibilities
  - Furnish data for a twelve month period
  - Provide data for all eligible patients and exams to ACR
  - Submit follow-up information
  - A Facility Administrator should be identified