Session Moderator:
Randell Kruger, PhD, DABR
Medical Physics Section Head,
Radiology, Marshfield Clinic Health System,
Marshfield, Wisconsin

Session Program:
Imaging Education

CT Lung Cancer Screening Part 1

First Presentation:
- CT Lung Cancer Screening and the Medical Physicist: Background, Findings and Participant Dosimetry Summary of the National Lung Screening Trial (NLST)
  - Presenter: Randell Kruger, PhD, Marshfield Clinic, Marshfield, WI

Second Presentation:
- CT Lung Cancer Screening and the Medical Physicist: A Dosimetry Summary of CT Participants in the National Lung Screening Trial (NLST)
  - Presenter: Choonsik Lee, PhD, National Cancer Institute, Bethesda, MD
CT Lung Cancer Screening Part 1

Learning Objectives
- Review and summarize relevant NLST findings and conclusions
- Understand the scope and scale of the NLST specific to participant dosimetry
- Provide a comprehensive review of NLST participant dosimetry assessments
- Summarize the results of an investigation providing individualized organ dose estimates for NLST participant cohorts

CT Lung Cancer Screening and the Medical Physicist:
Background, Findings and Participant Dosimetry Summary of the National Lung Screening Trial (NLST)

Randell Kruger, PhD, Marshfield Clinic, Marshfield, WI
Introduction and Background

Lung Cancer Statistics (American Cancer Society, ACS)\(^1\)
- Estimated 1.1 billion active smokers in the world
  - About half will die due to the health consequences of smoking
- Excluding skin cancer, lung cancer is the second most common cancer for both men and women in the US
  - 13% of all new cancers
    - 2015 estimated: 221,200 new cases
  - 27% of all cancer deaths
    - 2015 estimated: 158,040 deaths
- Costliest cancer to society (National Institute of Health)
  - Once diagnosed patients require multimodality therapy that is very expensive and complex
  - Direct costs $12 billion
  - Indirect costs $36 billion
- Early-stage lung cancers develop asymptotically
  - Only 8% of stage III and IV tumors were operatively managed in 2014

Lung Cancer Risk (US Preventive Services Task Force, USPSTF)\(^3\)
- Smoking history single most important causative factor
  - 85% of new cases are current or former heavy smokers (30+pack-year)
  - Lifetime risk for a never smoker: 0.2-1.4%, heavy smoker: 18.5-24.4%
- Age is a risk factor, average age at diagnosis is 70

![Percent of New Cases by Age Group](image)

\(^1\)National Cancer Institute SEER 18 2005-2012, All Races, Both Sexes
Introduction and Background

- Lung Cancer Lethality
  - 5-year survival rate of 17.4%
    - Compared to 99.7% for prostate and 90.3% for breast cancers
  - Poor prognosis, 90% with lung cancer die of the disease
    - 75% of patients present with advanced local or metastatic disease
    - Deaths greater than colon, breast, and prostate cancer combined

![Five Year Relative Survival](Image)

*National Cancer Institute SEER 18 2005-2011, All Races, Both Sexes

Introduction and Background

- Lung Cancer Screening – Chronological Review
  - American College of Radiology (ACR)
    - Screening practice registry (2015)
    - Screening center designation (2014)
  - Center for Medicare & Medicaid Services (CMS)
    - Proposed yearly CT screening for selected patients (2014)
  - US Preventive Services Task Force (USPSTF)
    - Final approval for annual CT screening (2013)
  - National Lung Screening Trial (NLST)
    - Findings published 2011-2013, screening 8/02-9/07
NLST Introduction

- NLST introduction
  - Randomized controlled trial funded by the National Cancer Institute, conducted by two organizations
    - Lung Screening Study (LSS)
    - American College of Radiology Imaging Network (ACRIN)
  - Recruited 53,439 asymptomatic participants that were randomly assigned to one of two study groups
  - Chest radiography (CXR)
    - 26,724 participants
    - 73,733 exams acquired
    - 92 chest imaging systems
  - Low Dose Computed Tomography (LDCT)
    - 26,715 participants
    - 75,133 exams acquired
    - 97 multidetector CT scanners

NLST Demographics

- NLST participant demographics
  - Eligibility criteria
    - Smoking history: current or former heavy smokers with at least a 30 pack-years of cigarette smoking (former smokers within last 15 years)
      - 47% of participants had a >50 pack-year smoking history
    - Participants annually screened for three years
      - Compliance rate > 90% for all groups and screening interval
    - Age: 55 to 74
      - Males: 31,523 (59%)
      - Females: 21,916 (41%)
  - Multi-centered trial
    - 33 screening centers
    - Enrollment period: 8/02 - 4/04
    - Screening period: 8/02 - 9/07
    - Event reporting through 12/09
    - Findings published 2011-2013
NLST Demographics

MN and WI provided 19.3% of the NLST participants from three screening centers: Mayo Clinic, University of Minnesota, Marshfield Clinic Health System.

NLST Objectives and Findings

Objective
- Determine whether lung cancer screening using low-dose multidetector helical CT reduces lung cancer-specific mortality relative to a single view chest radiograph in a high-risk cohort

Findings
- Reduction in mortality from lung cancer achieved based on low-dose CT screening
- Demonstrated a 20% reduction in lung-cancer-specific mortality in high-risk patients
NLST Objectives and Findings

- Compared to CXR, low-dose CT had a higher sensitivity and low specificity

<table>
<thead>
<tr>
<th>Interval</th>
<th>Low-dose CT</th>
<th>Chest Radiography</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sensitivity</td>
<td>Specificity</td>
</tr>
<tr>
<td>T₀</td>
<td>93.8</td>
<td>73.4</td>
</tr>
<tr>
<td>T₁</td>
<td>94.4</td>
<td>72.6</td>
</tr>
<tr>
<td>T₂</td>
<td>93.0</td>
<td>83.9</td>
</tr>
</tbody>
</table>

- All-cause mortality was 6.7% lower in the low-dose CT group than the CXR group

NLST CT Summary

- Results published in AJR® Nov 2011, NLST CT Working Group authors
  - Fred Larke, MS
  - Randell Kruger, Ph.D.
  - Chris Cagnon, Ph.D.
  - Michael Flynn, Ph.D.
  - Mike McNitt-Gray, Ph.D.
  - Xizeng Wu, Ph.D.
  - Philip Judy, Ph.D.
  - Dianna Cody, Ph.D.

[Image link to AJR publication]
NLST CT Summary

Summary of 97 CT systems utilized

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Model</th>
<th># Scanners</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Electric Healthcare</td>
<td>LightSpeed Plus 4</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>LightSpeed Discovery 4</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>LightSpeed Qxi 4</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>LightSpeed Ultra 8</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>LightSpeed 16</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>VCT 64</td>
<td>1</td>
</tr>
<tr>
<td>Philips Healthcare</td>
<td>MX8000 (4)</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>MX8000 (16)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Brilliance 64</td>
<td>1</td>
</tr>
<tr>
<td>Siemens Healthcare</td>
<td>Sensation 4 (Volume Zoom)</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Sensation 16</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Emotion 16</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Sensation 64</td>
<td>2</td>
</tr>
<tr>
<td>Toshiba</td>
<td>Aquilion 4</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Aquilion 16</td>
<td>3</td>
</tr>
</tbody>
</table>

NLST CT Summary

CT participant screening parameters

<table>
<thead>
<tr>
<th>NLST Specification</th>
<th>Typical Site Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi detector CT - minimum</td>
<td>4 or 16</td>
</tr>
<tr>
<td>channels</td>
<td></td>
</tr>
<tr>
<td>kVp - 120 to 140</td>
<td>120</td>
</tr>
<tr>
<td>Pitch - 1.25 to 2.00</td>
<td>1.5</td>
</tr>
<tr>
<td>Effective mAs (mAs / pitch)</td>
<td>20 - 40</td>
</tr>
<tr>
<td>Total Scan Time (35 cm) - max</td>
<td>10 - 20 sec</td>
</tr>
</tbody>
</table>
### NLST CT Summary

#### CT participant screening parameters

<table>
<thead>
<tr>
<th>NLST Specification</th>
<th>Typical Site Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi detector CT - minimum 4 channels</td>
<td>4 or 16</td>
</tr>
<tr>
<td>kVp – 120 to 140</td>
<td>120</td>
</tr>
<tr>
<td>Pitch – 1.25 to 2.00</td>
<td>1.5</td>
</tr>
<tr>
<td>Effective mAs (mAs / pitch) – 20 to 60</td>
<td>20 - 40</td>
</tr>
<tr>
<td>Total Scan Time (35 cm) – max 25 sec</td>
<td>10 - 20 sec</td>
</tr>
</tbody>
</table>

### NLST CT Summary

#### ACR lung cancer screening specifications

<table>
<thead>
<tr>
<th>Scan Parameter</th>
<th>Parameter Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT scanner type</td>
<td>multidetector, detector rows ≥ 4</td>
</tr>
<tr>
<td>kV</td>
<td>100 - 140</td>
</tr>
<tr>
<td>Pitch (IEC Definition)</td>
<td>0.7 - 1.5</td>
</tr>
<tr>
<td>Current adjustment</td>
<td>manual or automatic (patient size)</td>
</tr>
<tr>
<td>CTDIvol</td>
<td>CTDIvol(standard size patient) ≤ 3 mGy</td>
</tr>
</tbody>
</table>
NLST CT Summary

- Measured CTDI$_{vol}$ for CTs used in NLST

  ![CTDI$_{vol}$ bar chart]
  
  Average CTDI$_{vol}$ = 3.3 mGy (Std Dev = 1.5 mGy)
  Published in AJR$^5$, November 2011

NLST CXR Participant Dosimetry: Introduction

- Chest radiography participant dose study published
  - AJR$^6$, July 2013

- Study Objective
  - Determine effective dose associated with individual NLST chest x-ray examinations
**NLST CXR Participant Dosimetry: Methods and Materials**

- **CXR Quality Control (QC)**
  - 92 CXR acquisition systems at 33 sites
    - Included film-screen, CR and DR devices
    - Certification requirements were adapted from published ACR standards and consensus among the participating facilities
  - Initial and annual QC activities
    - Focused on verification of output calibration
    - Machine-specific measurements (annually)
      - HVL and radiation output (mR/mAs)

**NLST CXR Participant Dosimetry: Methods and Materials**

- NLST CXR protocol specified the collection of a participant’s acquisition parameters
  - Imaging parameters
    - Tube potential,
    - Current and mAs
    - Exposure time
    - Detector system
  - Participant factors
    - Height and weight
    - Average BMI = 28

![Participant BMI (self-reported height and weight)]
NLST CXR Participant Dosimetry: Methods and Materials

- Monte-Carlo program
  - PCXMC, developed by the Finnish Radiation and Nuclear Safety Authority, Helsinki, Finland
    - PC based special purpose code for diagnostic radiology only dose calculations
    - Hermaphrodite mathematical phantom

- Effective dose assessment methodology
  - Product of exam entrance skin air kerma (ESAK) and the ratio [effective dose per ESAK]
    - Exam ESAK is the product of mAs and average x-ray tube output, measured annually by medical physicist

NLST CXR Participant Dosimetry: Results and Conclusions

- 73,733 CXR examinations performed
- A CXR effective dose assessment was determined based on 66,157 exams
  - Data from 31 sites utilizing 90 CXR systems
  - Data from 26,732 CXR participants utilized
  - Mean Effective Dose (ED): 0.052 mSv

- Variations in tube potential and filtration had a minor influence on assessed ED
  - ED changed <20% at the max/min boundaries
## NLST CXR Participant Dosimetry: Results and Conclusions

### Comparison to other published studies

<table>
<thead>
<tr>
<th>Study or Location</th>
<th>Mean Effective Dose (mSv)</th>
<th>Reference</th>
<th>View</th>
<th>Effective Dose Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dutch National Institute of Public Health (2004)</td>
<td>0.018</td>
<td>11</td>
<td>Posteroanterior</td>
<td>Coefficient of variation, 20%</td>
</tr>
<tr>
<td>National Radiological Protection Board, United Kingdom (1998)</td>
<td>0.017</td>
<td>12</td>
<td>Posteroanterior</td>
<td>Per centile (5th and 95th), 0.006–0.008 mSv</td>
</tr>
<tr>
<td>Nationwide Evaluation of X-ray Tend, chest radiography, United States (1986–1990)</td>
<td>0.025</td>
<td>21</td>
<td>Posteroanterior</td>
<td>SD, 0.004 mSv</td>
</tr>
<tr>
<td>Nationwide Lung Screening Trial, chest radiography, United States (2002–2009)</td>
<td>0.025</td>
<td>26</td>
<td>Posteroanterior</td>
<td>Per centile (5th and 95th), 0.013–0.034 mSv</td>
</tr>
</tbody>
</table>

| UN/CEUR, Japan (2004) | 0.067 | 12 | Not reported | Variation range, 0.01–0.04 mSv |
| UN/CEUR, Switzerland (2002) | 0.067 | 14 | Posteroanterior | Relative error, 15% |
| Taiwan (2005) | 0.056 | 15 | Posteroanterior | Variability |not reported |
| UN/CEUR, Netherlands (2004) | 0.066 | 13 | Not reported | Variation range, 0.01–0.04 mSv |
| UN/CEUR, Finland (2005) | 0.10 | 13 | Not reported | Variation range, 0.01–0.04 mSv |
| UN/CEUR, Norway (2004) | 0.13 | 13 | Not reported | Variation range, 0.01–0.04 mSv |
| UN/CEUR, Sweden (2005) | 0.15 | 13 | Not reported | Variation range, 0.01–0.04 mSv |
| UN/CEUR, Germany (2006) | 0.20 | 13 | Not reported | Variation range, 0.01–0.04 mSv |

**Note:** UN/CEUR = United Nations Scientific Committee on the Effects of Atomic Radiation.

### Questions?

- Cited and significant references: