Patient Radiation Exposures with Mammographic Imaging

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Overview

• Updates
• How breast dose is calculated
• Radiation units
• Risk vs Benefit
• Dose Indexes
• New Technology

Updates - NRCP

• Average dose to the population
  • 760mRem
  • 7.6mSv
• Large increase in medical radiation
  • CT
Updates

- Increase in accreditation (MRI, CT, Nuclear Medicine) – 2012
- Qualified personnel
- Quality control procedures
- MQSA – or – Accreditation requirements for modalities (CT, Rad Therapy)
- Radiation Accidents
  - CT and Therapy

Where is this going?

- Increased government oversight/standards
  - California CT Regulations
- Reducing # of procedures (determining standard of care)
- Patient Awareness
  - Increase in # of concerned patients requesting information

Determining Dose

“How much dose am I getting?”
3 Steps

1. How much radiation is entering the patient
2. How much dose is the glandular tissue receiving
3. What is the whole body dose/risk to the patient

1. Entrance Exposure
   - Exposure (ionized particles in air) is measured in ‘Roentgen’

[Diagram: Entrance Exposure]

Measured directly with test equipment - accurate

950mRoentgen
2. Inside the Body

- Dose to the organ
  - Rads or Gray (Gy) (1 Gy = 100 Rads)
  - Energy deposited by the x-rays

2. Inside the body

- Where do the x-rays go?
  - Absorbed, scattered, penetrate?
- Where is the absorbed energy being deposited?
  - Dose to critical organs
- Computer simulations (Monte Carlo)

Simulations

Simulate different x-ray energies
Breast compositions, thicknesses
Model

• “Cristy”

Inside the body

• ‘Rando’ phantom

• Used to verify computer simulations

• Given an entrance exposure – you can convert it to a mean glandular dose

<table>
<thead>
<tr>
<th>Model</th>
<th>X ray Tube Voltage (kVp)</th>
<th>Wd</th>
<th>Target Eff.</th>
<th>Conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>58 32 26 25 24 24 24 29</td>
<td>20</td>
<td>180 270 250 240 230 220 210 200</td>
<td>170</td>
</tr>
<tr>
<td>19</td>
<td>58 32 26 25 24 24 24 29</td>
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<td>170</td>
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<td>170</td>
</tr>
</tbody>
</table>
2. Glandular Dose

- ‘Average dose’ to the glandular tissue
  - Not on a per-patient basis
  - “Average” patient
    - 50/50 (glandular/adipose)
    - 4.2cm compressed breast

2. Glandular Dose

- 950mRoentgen x

2. Glandular Dose - Errors

- One size doesn’t fit all
  - 50/50 4.2 cm breasts
  - Glandular tissue distribution
  - Average glandular dose
    - Superior glandular tissue will receive more dose
  - Different views not considered
3. Whole Body Dose

- Convert organ dose(s) to an entire body irradiation.
- Organ sensitivity to radiation

180 mRad

Organ Sensitivities (Wt)

<table>
<thead>
<tr>
<th>Organ</th>
<th>Wt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breast tissue</td>
<td>0.12</td>
</tr>
<tr>
<td>Lung</td>
<td>0.12</td>
</tr>
<tr>
<td>Colon</td>
<td>0.12</td>
</tr>
<tr>
<td>Spleen</td>
<td>0.04</td>
</tr>
<tr>
<td>Stomach</td>
<td>0.12</td>
</tr>
<tr>
<td>Bladder</td>
<td>0.04</td>
</tr>
<tr>
<td>Liver</td>
<td>0.04</td>
</tr>
<tr>
<td>Esophagus</td>
<td>0.04</td>
</tr>
<tr>
<td>Skin</td>
<td>0.01</td>
</tr>
<tr>
<td>Intestinal glands</td>
<td>0.01</td>
</tr>
<tr>
<td>Brain</td>
<td>0.01</td>
</tr>
</tbody>
</table>

3. Whole Body Dose

- Organ sensitivity to radiation
  - Breast tissue weighting factor (0.12)
  - 180 mRad x 0.12

180 mRad

21.6 mRem (effective dose)

REM is used whenever biological effects are considered
Organ Sensitivities (Wt)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone marrow (red)</td>
<td>0.12</td>
<td>0.13</td>
<td>0.12</td>
</tr>
<tr>
<td>Lung</td>
<td>0.12</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>Brain</td>
<td>0.14</td>
<td>0.16</td>
<td>0.13</td>
</tr>
<tr>
<td>Thyroid</td>
<td>0.03</td>
<td>0.05</td>
<td>0.04</td>
</tr>
<tr>
<td>Other thoracic tissues</td>
<td>0.02</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>Pericardium</td>
<td>0.10</td>
<td>0.08</td>
<td>0.13</td>
</tr>
</tbody>
</table>

Same Radiation = Different dose

3. Whole Body Dose

- 21.6 mRem (whole body) per view (0.0216 Rem)
- R/L breasts are considered ‘one organ’
- 2 views (CC & MLO) (~40mRem total)

1Sv = 100 Rem

“how much dose am I getting?”

- 3 to 6 values
- 1 Rad (skin dose) or 1 Roentgen entering the patient
- 180 mRrad or 1.8 mGy for mean glandular dose
- 40 mRem or 0.4 mSv of effective (whole body) dose

Average Patient = 4.2cm
“how much dose am I getting?”

- Averages & lots of ‘estimations’
- Unfortunately, it’s difficult to give patients specific numbers...
  - Pt. Size
  - Glandular composition
  - Glandular distribution (high/low)
  - CC/MLO views
  - kVp, mAs

Are mammograms harmful?

What’s the risk?

3. Whole Body Dose

- Risk of getting cancer from partial body exposures is unknown
  - Low doses (diagnostic)
  - Risks are low (Radiation is a weak carcinogen)
  - Need large #s for statistical significance
- Roundabout method
  - Whole body dose
3. Whole Body Dose Risk Estimates

- Risk data is based on whole body exposures
  - Hiroshima / Nagasaki
  - Chernobyl

3. Risk Estimates

- BEIR VII – Biological Effects of Ionizing Radiation 7: “Health Risks from Exposure to Low Levels of Ionizing Radiation”

- Men: 0.08% chance per Rem of getting cancer
  - 0.04% chance of dying from cancer
- Women: 0.13% chance per Rem of getting cancer
  - 0.06% chance of dying of cancer

- Age dependent

Risk

- 21.6 mRem (whole body – for CC view L&R)
- Screening (CC & MLO) (~43.2 mRem total)
- 0.0432 Rem x 0.13% /Rem
- 0.0056% chance of getting cancer from 1 screening mammo visit
Risk Perspective

- Risk of getting breast cancer = 12.5%
  - 1 in 8
- Additional risk of getting breast cancer from mammography radiation
  - 0.0056%
  - 1 in 17800

Remember - These are estimates

- Glandular dose values are taken from a 'reference' patient (Rando, Cristy)
- Tissue weighting factors (0.12) and risk of cancer values taken from high dose events with high energy isotopes
  - Taken as a population.
  - Not supposed to be used for individual risk.
  - Genetic factors? Sensitivities?
  - Truly random or peanut butter?

Controversy

- Is mammography necessary?
- Are we giving patients cancer?
Mammography Screening

- Screening an asymptomatic population
  - FDA approved, ACS recommended
  - High risk women under 40
  - Women over 40 annually
  - 30 Million women/year

- 99% of the screening population will not have breast cancer at the time of the exam.
  - “Low” incidence (diagnostic yield)
    - 4-7 cancers detected per 1000 women screened
    - Maintain doses as low as possible

Risk vs Benefit

- Risks due to diagnostic x-rays are extrapolated from higher dose events and mathematical models
- For every 100,000 women screened annually from ages 40 to 69
  - 18 Additional breast cancer cases due to mammography radiation
  - Takes into account latency time
  - Risk of cancer is age dependent

If we believe these #s..

- 18 additional cancers per 100,000
- For 30 million women –
  - 5,400 cancers caused by radiation?!

  Remember: these are mathematical simulations
  - and -
  Risk percentages are low

Risk vs Benefit

- Randomized large scale trials suggest a reduction of mortality between 20-40%
- For every 100,000 women screened annually with mammography
  - 16,131 will get breast cancer, 3,273 deaths
  - Benefit: 525 to 1059 (20-40% of 3,273) fewer deaths from screening with mammography

And Other Breast Imaging Procedures (2004)

Benefits

- 525 fewer deaths per 100,000 (20% reduction)
- 157,500 women saved by mammography (if everyone were screened)
Common Comparisons

- Other radiographic procedures
  - Abdomen X-ray (100 mRem)
  - CT abd. Series (1000 mRem)
  - Pet scan (1400 mRem)
  - Mammography = 40 mRem

Common Comparisons

- Natural Background radiation
  - 250 mRem (Los Angeles)
    - 2 months of living in LA
  - 1180 mRem (Denver)
    - 12 days in Denver
  - Mammography 40 mRem

Common Comparisons

- Radiation Worker Allowed Doses
  - 5000 mRem per year
  - Pregnant Radiation worker
    - 500 mRem Fetal Dose
  - Mammography = 40 mRem
Other risks

- Driving: 1 death/18 million miles driven
- Screening series = 250 miles driven

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Effective Dose</th>
<th>Effective Dose</th>
<th>Equivalent to Number of Highway Miles Driven</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest Radiograph</td>
<td>$3.2 \times 10^3$</td>
<td>3.2</td>
<td>23</td>
</tr>
<tr>
<td>Skull Exam</td>
<td>$5.5 \times 10^4$</td>
<td>15</td>
<td>104</td>
</tr>
<tr>
<td>Breast Exam</td>
<td>$5.4 \times 10^4$</td>
<td>54</td>
<td>357</td>
</tr>
<tr>
<td>Bone Scan</td>
<td>$6.4 \times 10^3$</td>
<td>440</td>
<td>1200</td>
</tr>
</tbody>
</table>

< 1 tank of gas

Quick Review

- “How much dose am I getting?”
  - We can’t give a specific number
  - Doses reported are estimated values
  - Mammography machines must comply with MQSA standards for dose but are based on ‘averages’ (size, glandular content)
    - However an individual’s dose may be higher or lower
  - Risk associated with the exams is very low
  - Benefit outweighs the risk when guidelines are followed

Dose Reduction Strategies

- Improve contrast between tissue types
  - Difference between Ca. and normal breast
- Improve resolution
  - Microcalcifications
  - Spiculated lesions
- Maintain a reasonable patient dose
  - Normal population (asymptomatic)
- We don’t want to sacrifice any of these
Compression

- Reduces breast thickness
  - 2-8 cm
- Reduces scatter
- Lower kVp to penetrate
- Improved contrast
- Reduces dose
  - Lower mAs needed
  - 3x decrease or more

Doses

<table>
<thead>
<tr>
<th>Compressed Breast</th>
<th>Entrance Exposure</th>
<th>Mean Glandular Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 cm</td>
<td>260 mR</td>
<td>0.69 mGy</td>
</tr>
<tr>
<td>4 cm</td>
<td>1080 mR</td>
<td>1.79 mGy</td>
</tr>
<tr>
<td>6 cm</td>
<td>1450 mR</td>
<td>2.37 mGy</td>
</tr>
</tbody>
</table>

These values will vary by technical factors and equipment used.

Automatic Exposure Control

- Tech selectable settings (GE)
  - Low dose
    - Increases kVp or higher energy anode/filter
    - May reduce contrast
Other Factors

- Film/Screen selections (speed index)
- Faster film – lower doses
- Processor factors
  - Chemistry type, concentration, temperature
  - Longer immersion time – faster speed, lower doses

Digital Systems

- Variable contrast and brightness
  - Window/leveling
  - Lower repeated exams

Digital: Not always a lower dose exam

- Lower repeats means:
  - Less dose to a population of patients
- Average dose per exam remains about the same as (film/screen)
  - System dependent (CR vs flat panel detectors)
  - Recent trend to reduce dose (manufacturer)
Digital Systems

- Higher energies could be used to help reduce dose
- Window/level to regain the contrast
- Tungsten tube systems. (Hologic/Siemens)

Digital Systems

- “Noise limited”
- Noise is fixed after the exposure*
- The amount of noise is related to the exposure
- Quantum limited (more quanta – less noise)

Pipeline..

- Sectra (slot scanning) mammography
- Slot scanning reduces scatter (improved contrast)
- Increase kVp – reduce dose
- Avg patient (30-32 kVp)
- Longer exposure times

Not FDA Approved
Dose index

Newer digital systems

- Dose Indices
  - Number corresponding to detector dose
  - Guideline for proper exposure – not patient dose
  - Hologic systems (300-600)
    - Higher values = more detector dose

Dose Index

- 28kVp, 100mAs
  - EI=300

- 28kVp, 200mAs
  - EI=600

For the same pt: 2x the dose = 2x the EI
Dose Index – not patient dose

- 28kVp, 100mAs
  - EI=500
- 28kVp, 100mAs
  - EI=300

Dose Reporting

- Mean glandular dose
  - Rando, Cristy
- Entrance exposures
  
  Should be transferred to PACS

AAPM TG 116

- Standards for dose reporting
  - Air Kerma (Dose) at the detector
  - Predefined target value
- Deviation Index (DI) ranging from -9 to +9
  - How much you are off from the target value
  - Logarithmic value 10 log (actual / target)
    
    We didn’t make it simple..
AAPM TG 116: Example

- Standards for dose reporting
  - Target value defined (0.1 mGy)
  - Let's say 28 kVp, 100 mA as gets you the target value
  - If you shoot at 28 kVp, 200 mA as 0.2 mGy @ det.
- Deviation Index
  - $10 \log (0.2/0.1) = 3$

We didn't make it simple.

New Technology

- Digital Tomosynthesis
  - During compression, 10-20 lower dose images are acquired as tube arcs over the breast
  - 30-50 degree arc
  - Reconstructed images show less overlying tissue
  - Potential for improving mammography specificity and reducing callbacks
- Not FDA Approved (4/2010)
  - Several vendors have clinical trials underway

New Technology

- 2D mammogram
  - Suspicious mass
- Images courtesy of Hologic inc.
  - Pending FDA Approval

Well circumscribed lesion indicates a cyst
Doses with tomosynthesis

- Most likely be higher compared to a conventional mammogram
- Vendors attempting to make systems comply with MQSA regulations (3mGy/tomo)
  - Each projection has less mAs
  - Higher energy beams

Summary

- Dose calculations are approximations
- Doses in mammography are small relative to other exams
- Risks are very low compared to other everyday activities
- Mammography saves lives
- Dose reduction technologies
- Dose index

Thanks!