# Radiation from Medical Imaging: A Hidden Epidemic


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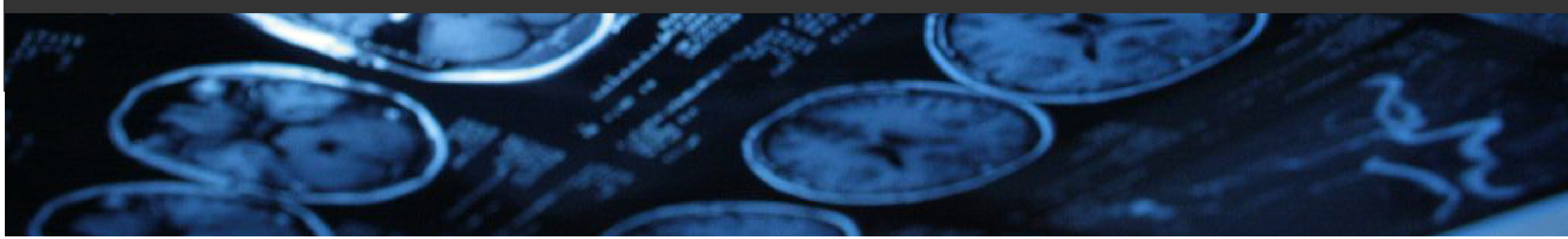


# Diagnostic Imaging

- Improvements in diagnostic imaging have been spectacular
- Many tests are considered among the most important advances in medicine and are an integral part of every day medical care
- CT has become the workhorse of imaging and is integrated into every setting where care is provided
- CT is used extensively in the diagnosis, surveillance and assessment of treatment response in oncology patients.

# Radiation

- Radiation is energy

  High-speed particles and electromagnetic waves

- There are many sources of radiation - some naturally occurring, others are used in science, industry, medicine

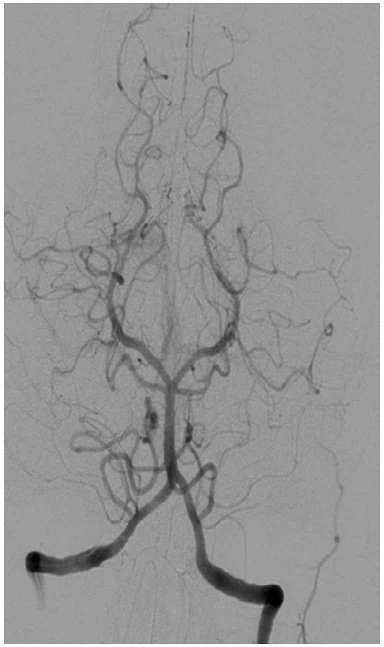
- Ionizing radiation  is one type of radiation– and its effect on cells is know. It can remove tightly bound electrons from their orbits – break chemical bonds – change DNA . Depending on the dose, the impact on cells varies greatly

- Ionizing radiation exposure cannot be eliminated, but to the degree we can minimize exposures we have made decisions to do so - many organizations – ICRP, NCRP, IAEC- are dedicated to this task

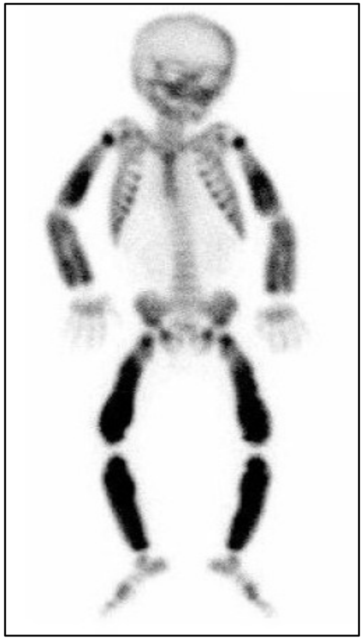
# Radiation from Imaging

Radiographs (x-rays)

Fluroscopy



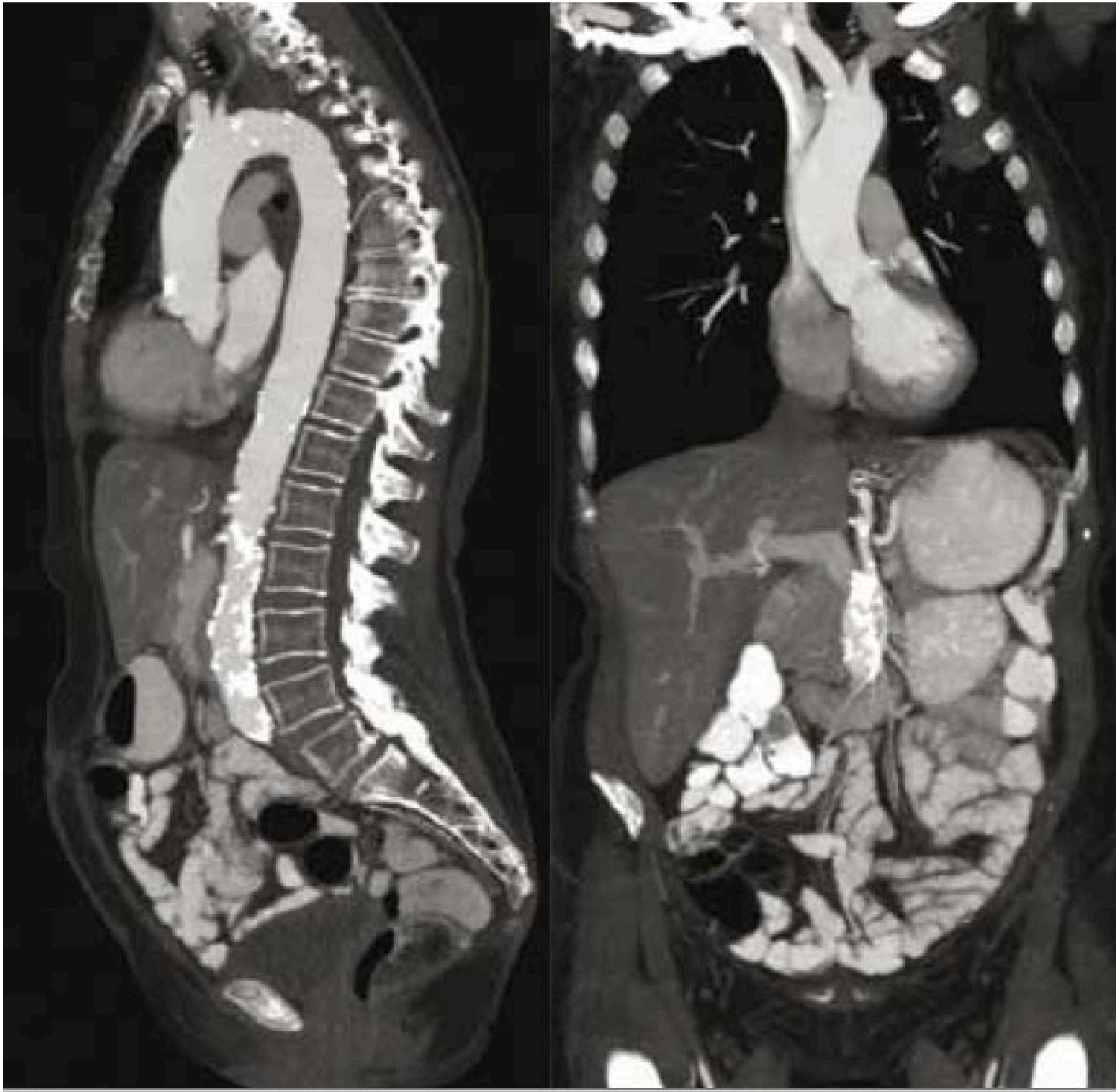
Angiography



Nuclear Medicine

X-Rays

Gamma Rays



# Use of Diagnostic Imaging

- I am a big fan of advanced imaging

- I am not the only one enamored with imaging – everyone is

  Primary care doctors, emergency physicians, every medical

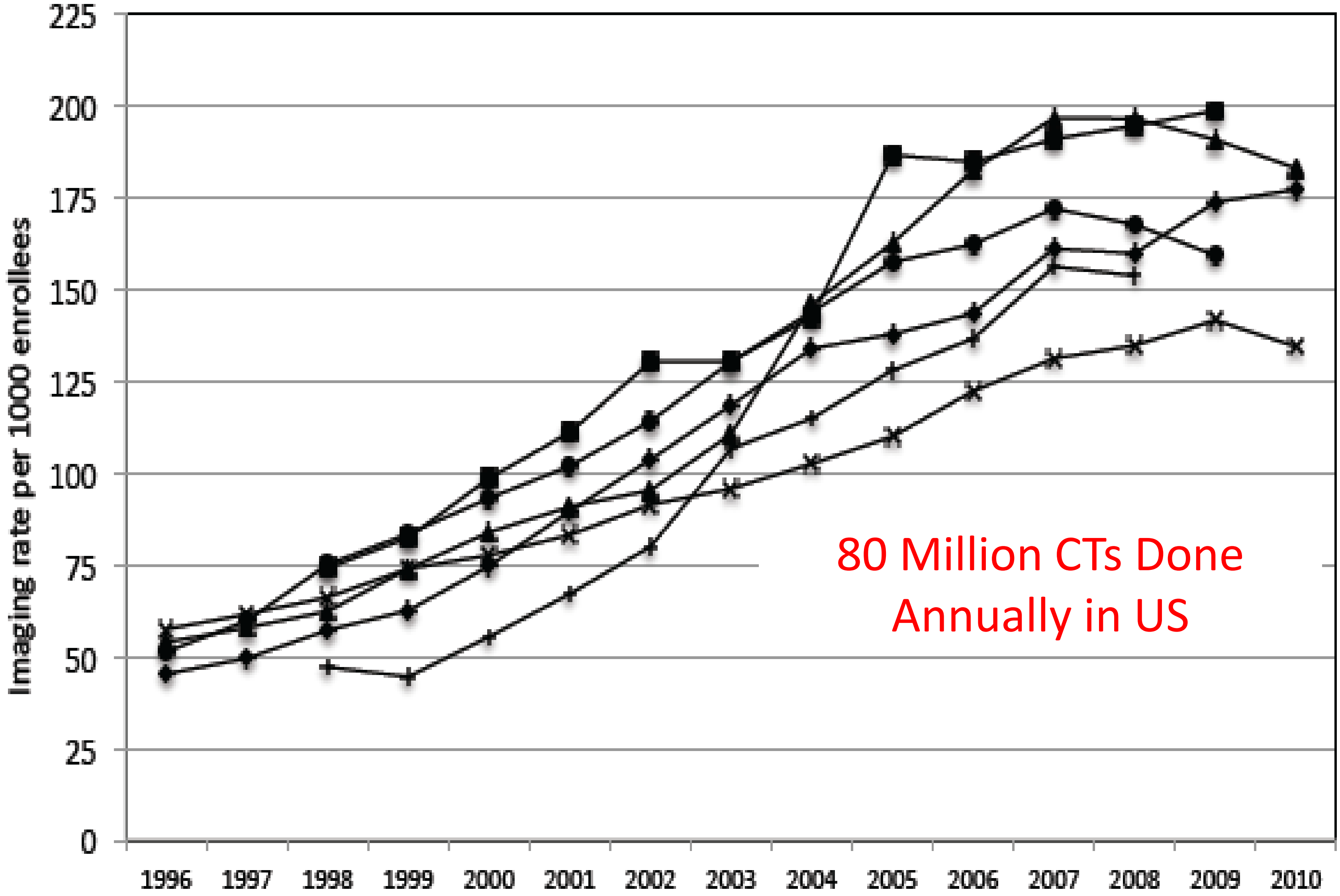
  and surgical specialists, oncologists, radiologists, patients

- And the use of imaging has soared over the last two decades

# How many CT Scans Are Done Annually in the U.S.?

- The equivalent of 1 /100 people get a CT scan/year
- The equivalent of 1 /50 people get a CT scan/year
- The equivalent of 1 /25 people get a CT scan/year
- The equivalent of 1 /10 people get a CT scan/year
- The equivalent of 1 /5 people get a CT scan/year

# Computed Tomography Examinations per 1000 Patients / Year




Smith-Bindman, JAMA, 2012, Trends in Imaging

# Risks and Benefits of CT: It Depends on the Context

- Rapid and accurate diagnoses
- Radiation Exposure – doses are in carcinogenic range
- False positives (fake findings) – common and result in more testing
- Over-diagnosis – leads to unnecessary treatment
- Contrast reactions  - most minor, some major
- Soaring costs – driving calls for comparative effectiveness research

# Risks and Benefits of the Use of CT

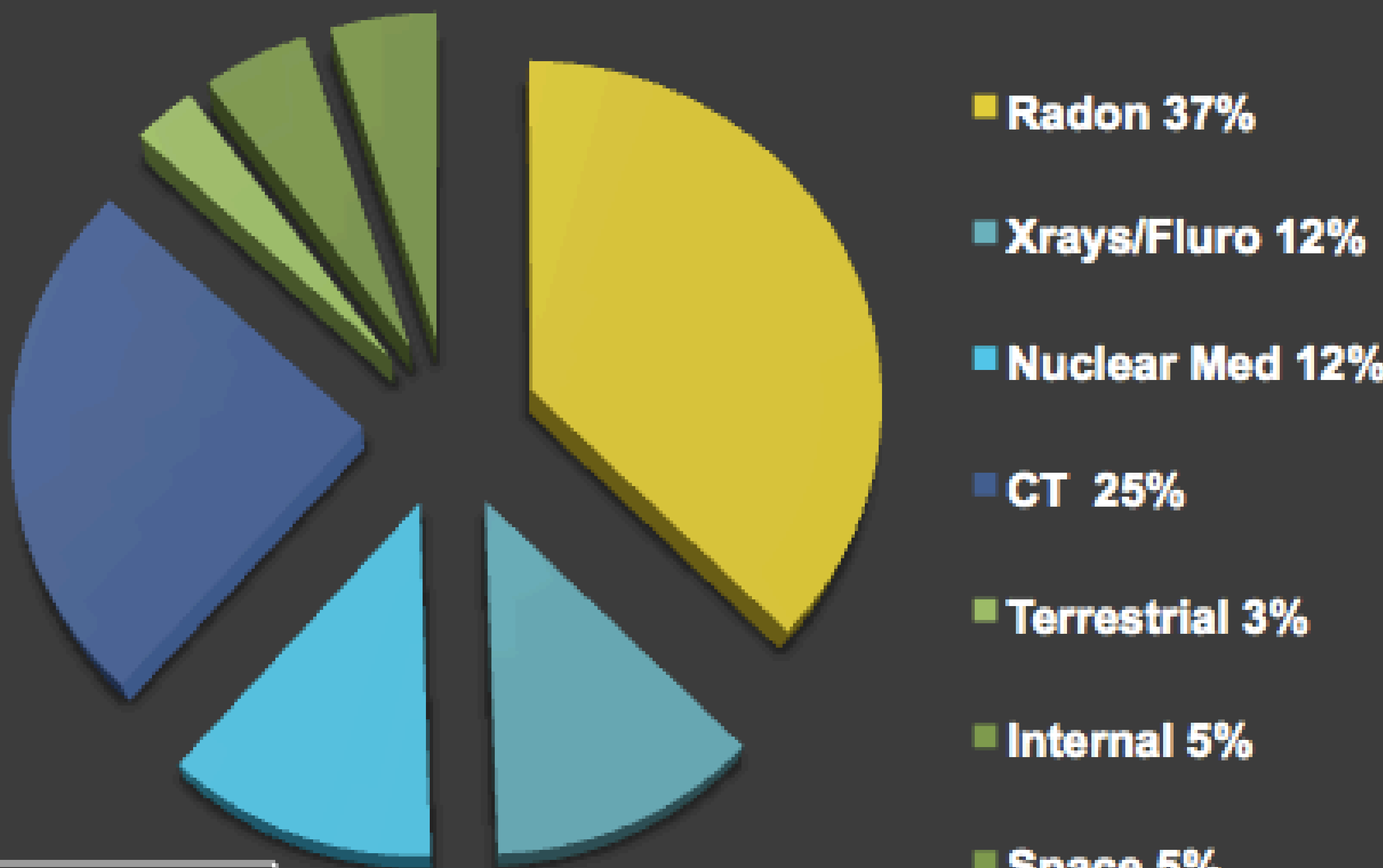
- Every aspect of  health care involve tradeoffs: physical examinations, diagnostic tests, medications, treatments
- The purpose of this talk is not to describe all risks and benefits of medical imaging or CT
- The purpose is to improve your understanding of a single risk associated with CT imaging, radiation , and what I believe is a risk we can and must reduce

# Medical Radiation: An Important Safety Issue

- Most imaging tests use ionizing radiation
  x-rays, CT, nuclear medicine, fluroscopy, angiography (not US /MRI)
- Doses for CT are higher than conventional x-rays ( a lot higher)
- The increase use of CT, and higher dose per scan has resulted in a 600% increase in medical radiation exposure last 20 years
- Further, the doses are far higher than needed for diagnosis and highly variable across institutions

# Sources of Radiation in the U.S.
# 2006 Average Annual Exposure: 6 mSv

National Council on Radiation Protection, 2006




Imaging 3 mSv

# Radiation

- Very high levels can lead to burns, hair loss, immediate harms
- The dose we use in imaging are lower, but can nonetheless damage DNA and the impact can take years or decades to become apparent as cancers
- Substantial evidence on the harmful effects of radiation
- Modeling suggests 2-5% of all cancers come from imaging
- Because risks are delayed, they are harder for patients to comprehend, but no less important as long as a patient has a life expectancy > few years

# Biological Response to Radiation From CT

- Exposure of cells to *therapeutic* radiation triggers a complex network of signal transduction pathways, changes gene expression, protein structure: results in apoptosis, cell cycle arrest, & DNA repair activation
- Nguyen et. Al. asked: Does *diagnostic* CT cause DNA damage?
- Prospective cohort, 67 patients, 2012-2013, underwent cardiac CT
- Biomarkers of DNA damage/ apoptosis measured before and several times after imaging using numerous techniques

Nguyen, JACC Cardiovasc Imaging, 2015

# CT Caused Many Biological Effects

- Mean exposure 30 mSv
- Median DNA damage (lymphocytes) 3%; apoptosis-increased 3 fold
- Genome : significant changes in expression of 39 transcription factors, 33 signaling metabolic pathways, and 17 biological processes involved in regulation of cell cycle and DNA repair ; changes at 1 month
- Genes in DNA repair (DDB2, XRCC4, BAC) sig increased expression
- Measureable change, and a dose response with dose > = 7.5 mSv
- While many damaged cells were repaired, a small percent of cells did not

# BEIR VII Report

- The U.S. National Academies conducted a comprehensive review of the science on the harms of low dose radiation
- They estimated the risk of cancer based on different factors, such as age at exposure, sex , dose levels, and source of exposures
- **They concluded the doses we use routinely use for CT will cause cancer is some patients and that the higher the dose, the greater the risk**
- They explored and fully rejected the horemesis theory because of the absence of any supporting data

# Epidemiology on the Harmful Effects of Low Dose Radiation

- 120,000 survivors of the Atomic bombs
- Patients treated for cancer
- Patients treated for benign conditions
- Patients who received repeated X-rays
- Radiation workers, such as in the nuclear power industry
- Environmental accidents (Chernobyl, Techa River)
- Direct studies of CT (these were not included in BEIR review)

# Japanese Atomic Bomb Survivors: Life Span Study

Preston 2007 , Ozasa 2011, 2012

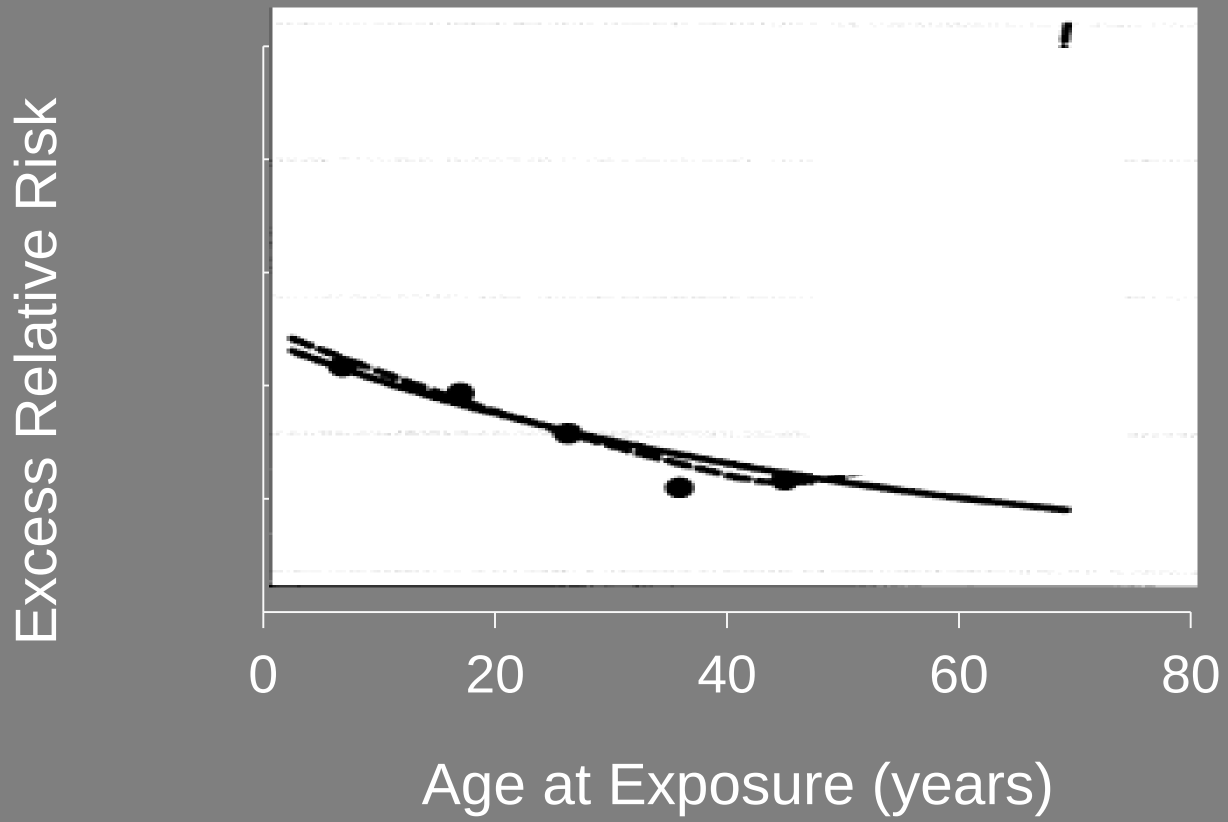
- The median dose of survivors was **40 mSv**
- Radiation doses $\geq$ 10 mSv associated ⇧ with leukemia & solid CA
- 11% of the solid cancers among individuals who received a dose above 5 mGy were associated with their exposure
- Modeling risk from the Japanese survivor data has complexities, but nonetheless many bright scientists on different teams have explored data and arrived at consistent estimates of effects

# Radiation Exposure from CT Scans in Childhood and Risk of Leukemia and Brain Cancer

- 178,604 children in the UK
- Underwent CT between 1985 – 2002, followed until 2008
- 74 leukemias, 135 brain cancers
- Assessed relationship between dose and cancer
- Within 10 years of CT, children who received doses 30 – 50 mSv tripled their risks of brain cancer and leukemia
- 10 – 20% of children receive these doses from 1 CT scan

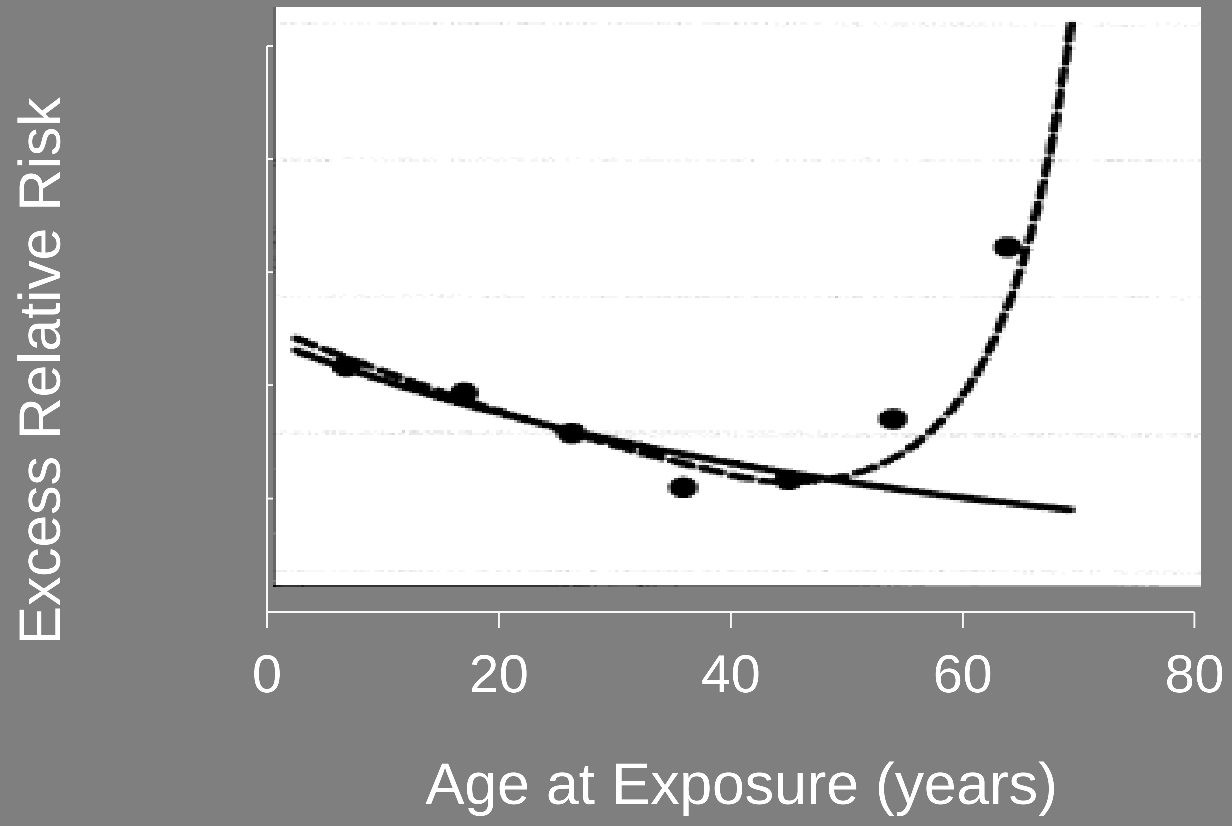
Pearce, Lancet, 2012

# Typical Summary of Cancer Risks by Age at Exposure

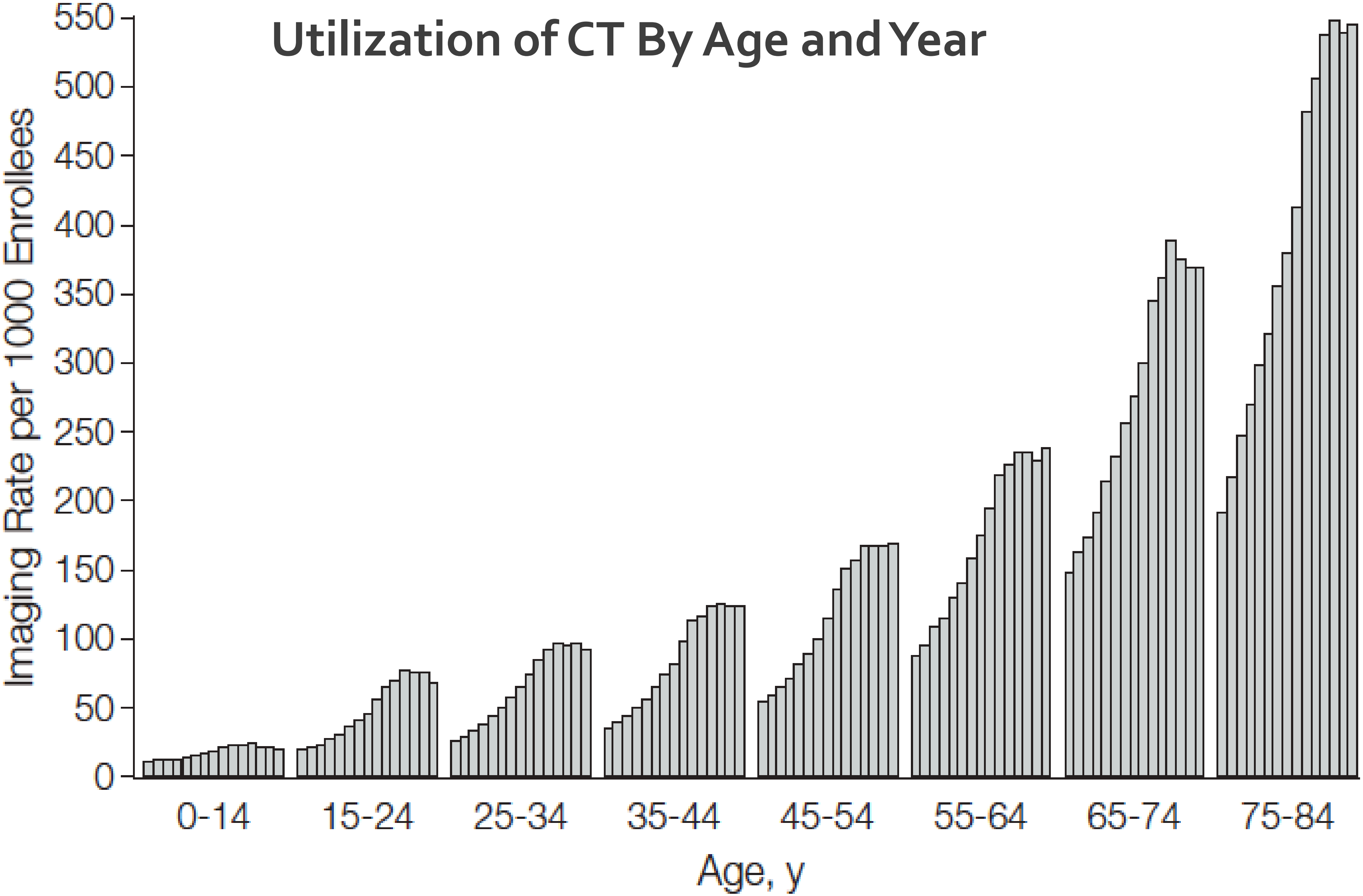


# Cancer Risks Actually Follow a U -Shaped Distribution

Preston 2007, Shuryak 2010



# Utilization of CT By Age and Year




Smith-Bindman, JAMA, 2012, Trends in Imaging

# Quantifying Risks of Ionizing Radiation

- There are many studies that have assessed the risk of radiation
- Studies vary tremendously with respect to the populations and types of exposures, study designs, methods to measure/report
- The data are complex, risks vary by sex, age at exposure and attained age, type of exposure, and many underlying individual risk factors. Confounders vary across studies
- Extrapolating data from the A-bomb survivors is not optimum
- The evidence suggests radiation is carcinogenic in doses used in medical imaging, but there remains uncertainty in magnitude

## Radiation Induced Cancers in Children and Adolescents: NIH Funded Study 2015 – 2019 in Progress

- Mult-institutional study, including KP Northern California, Northwest, Hawaii; Group Health Cooperative, Pediatrics Oncology Group of Ontario, Geisinger Health System, Marshfield Clinic
- Design: Retrospective cohort to evaluate patterns of imaging, cumulative exposure to radiation, and subsequent risk of pediatric cancers from childhood and prenatal exposure.
- Subjects:
  - Children <21 years
  - Pregnant women of all ages
- We will quantify the risk of cancer associated with imaging

# Advantages of our study

- Inclusion of imaging in pregnant women
- Inclusion of all imaging studies (not just CT)
- Accurate assessment of radiation exposure
- More complete assessment of cancer outcomes (we will link to 13 state cancer registries and population based Ontario Registry)
- Better assessment of the indication for scanning
- We will not assess risks of imaging in oncology patients (i.e. patients are censored at cancer diagnosis)

# What Are The Doses For CT
## How much radiation is delivered by Abdominal CT?

- The same as 300 trips to Europe (from Calif.)
- The same as 1000 chest x-rays
- The same as 2500 dental x-rays
- The same as 180,0000 airport scans

# What Are the Doses Used for CT?

- Abdominal CT scanning is the most frequent study
- What is the dose for an abdominal and pelvic CT ?
    - 2 mSv
    - 5 mSv
    - 10 mSv
    - 15 mSv
    - 20 mSv
    - 25 mSv

# What Are the Doses Used for CT?

- I have led many studies assessing CT doses
- We have found that the doses for CT are high and highly variable, varying tremendously for patients imaged for the same reason,
- The doses can vary by up to 200 times across institutions
- The doses are far higher than needed for diagnosis
- To answer the question of dose requires knowing where you are going to be imaged: this does not really make sense

JAMA Internal Medicine 2009; JAMA 2012 , JAMA Pediatrics 2013

# What Are The Doses Used for CT?

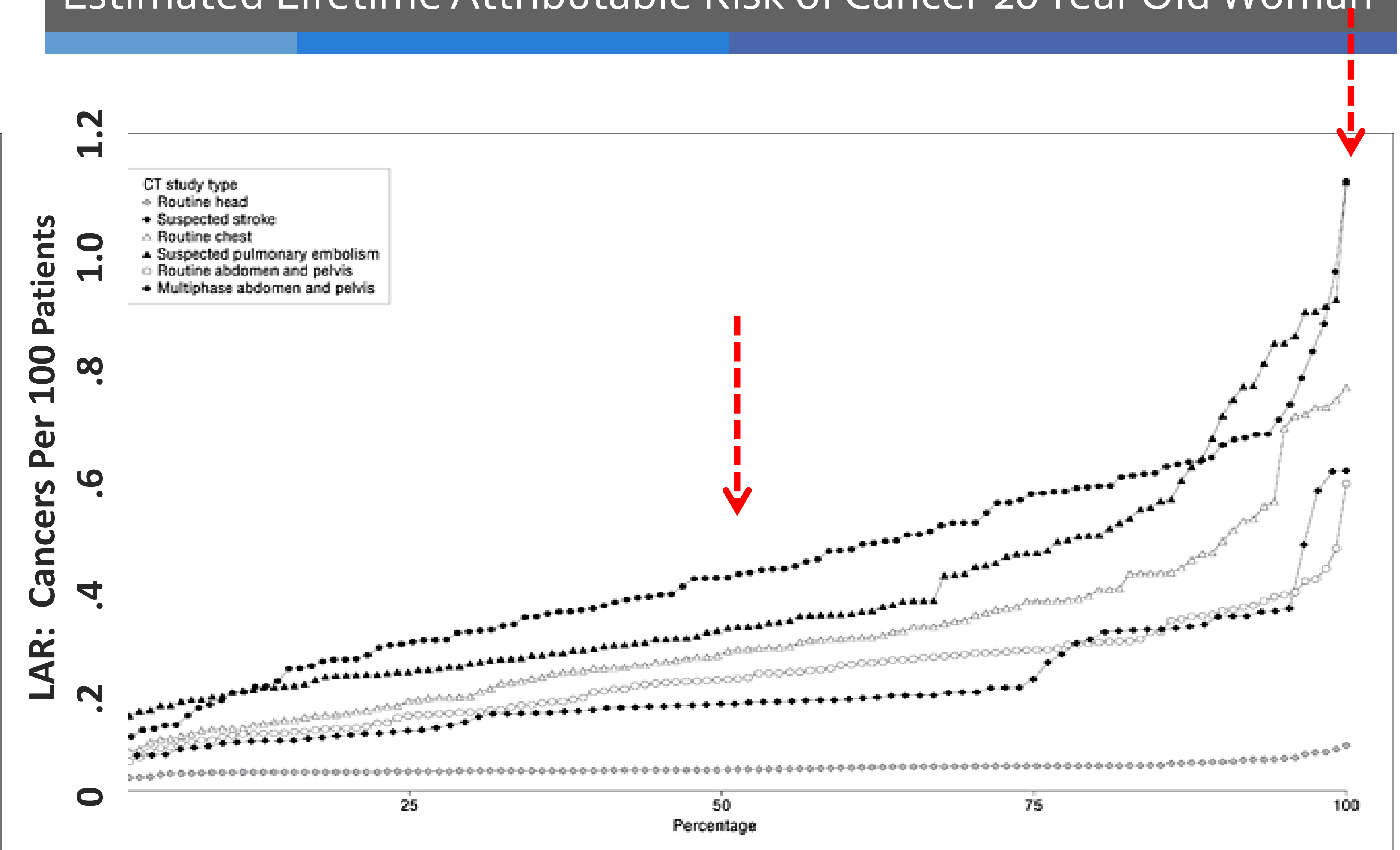
# Large Variation Between Facilities for the Same Indication

JAMA Internal Medicine 2009

| | Effective | Dose | | |
|---|---|---|---|---|
| Head | Site 1 | Site 2 | Site 3 | Site 4 |
| Routine Head | 3 | 2 | 3 | 2 |
| Suspected Stroke | 18 | 15 | 8 | 29 |
| Chest | | | | |
| Routine Chest | 5 | 12 | 11 | 7 |
| Suspected PE | 8 | 21 | 9 | 9 |
| Abdomen | | | | |
| Routine / Pain | 12 | 19 | 20 | 12 |
| Multiphase Suspect AAA | 24 | 35 | 45 | 34 |

# Cancer Risks Are Not Trivial

## Estimated Lifetime Attributable Risk of Cancer 20 Year Old Woman



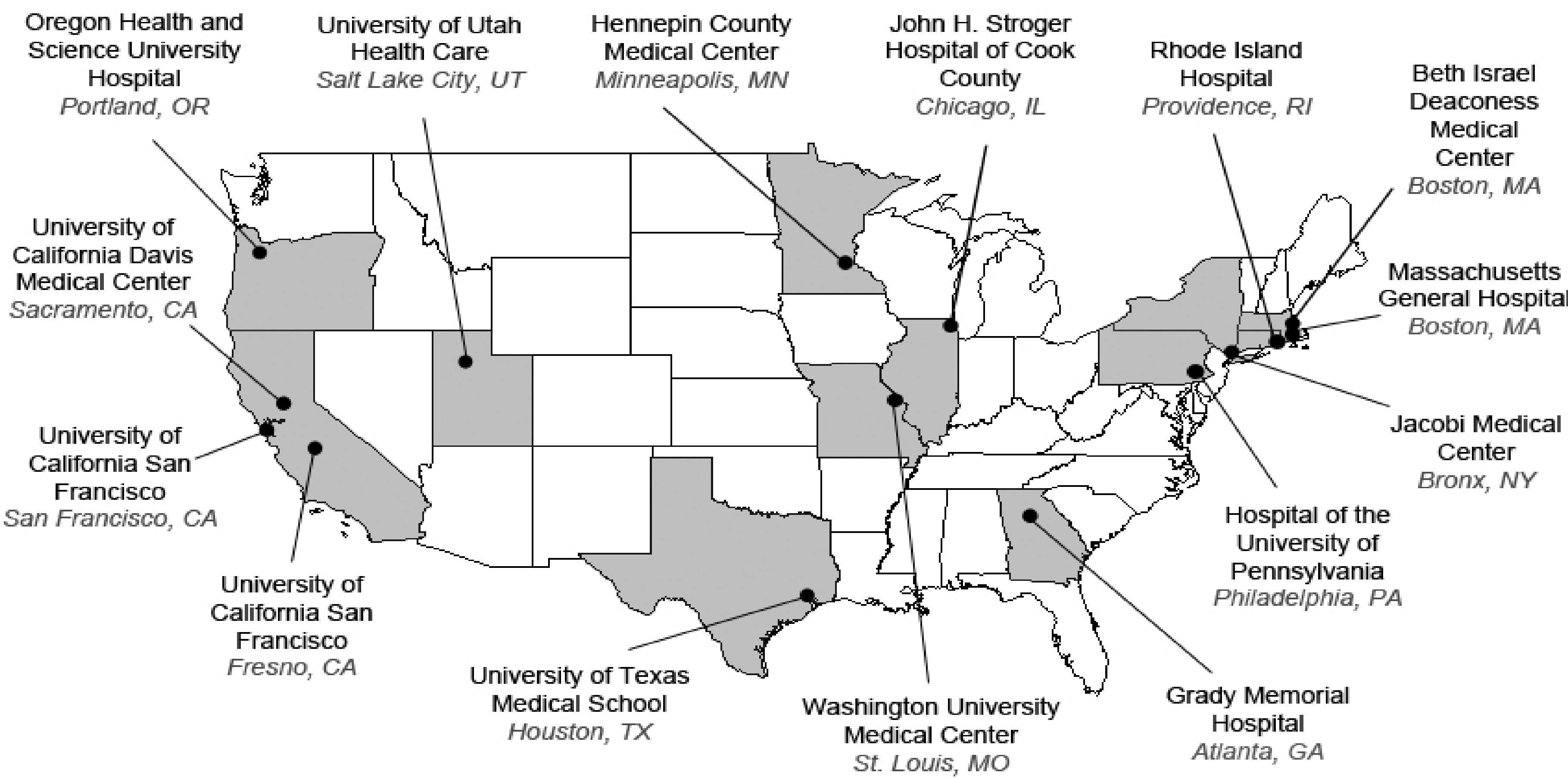
# Imaging of Patients with Suspected Kidney Stones

- Pain from a kidney stone accounts for > 1 million ED visits/yr
- Since the mid 1990s CT has become the primary test
- 15-center study comparing imaging with ultrasound versus CT
- We assessed the radiation doses received by these patients
- We assessed how many patients were imaged using low dose

STONE

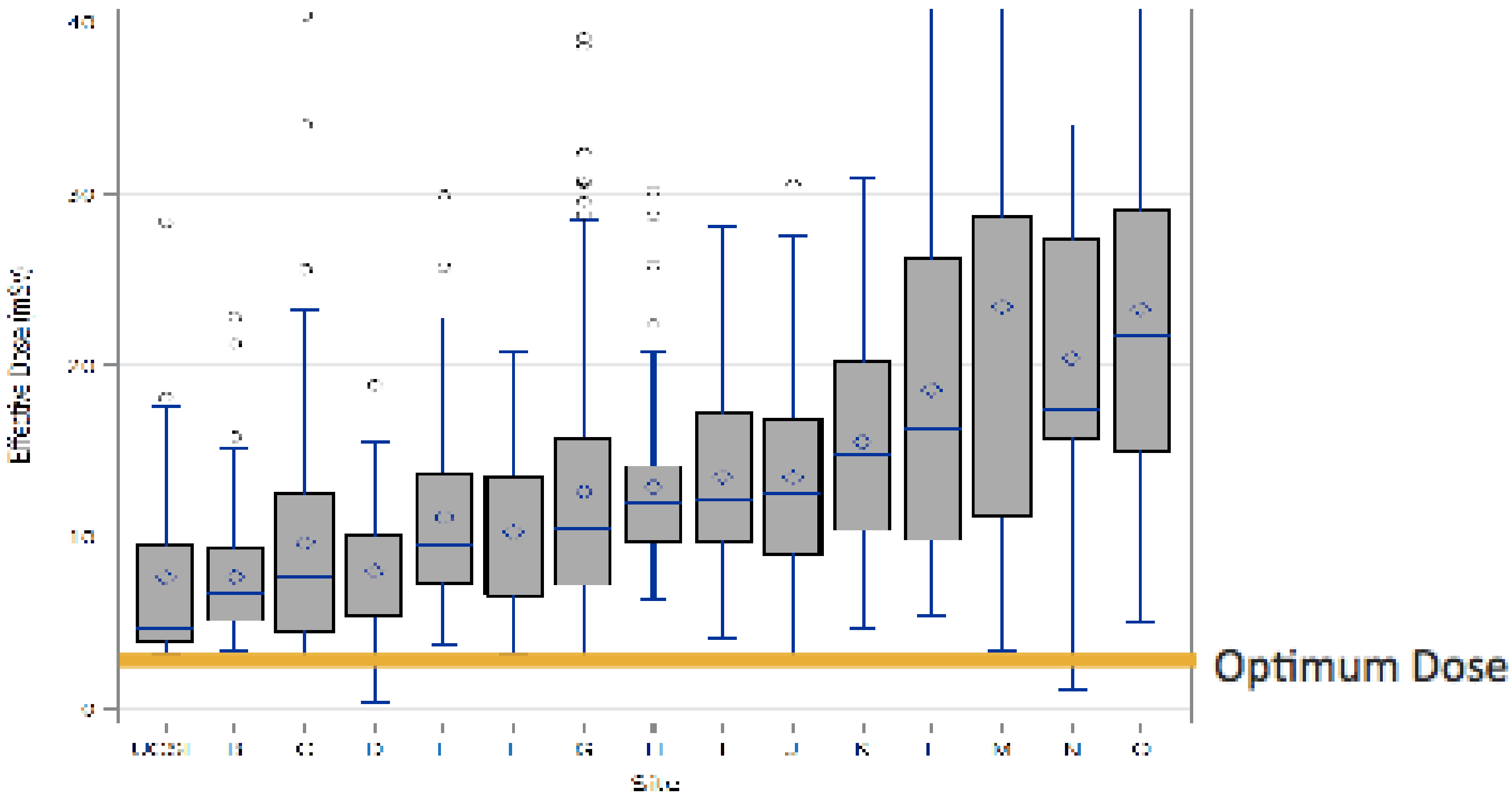
Smith-Bindman, NEJM,2014

# Participating Centers



# CT Radiation Doses in the Stone Trial

STONE




Smith-Bindman, NEJM 2014, JAMA IM, 2015

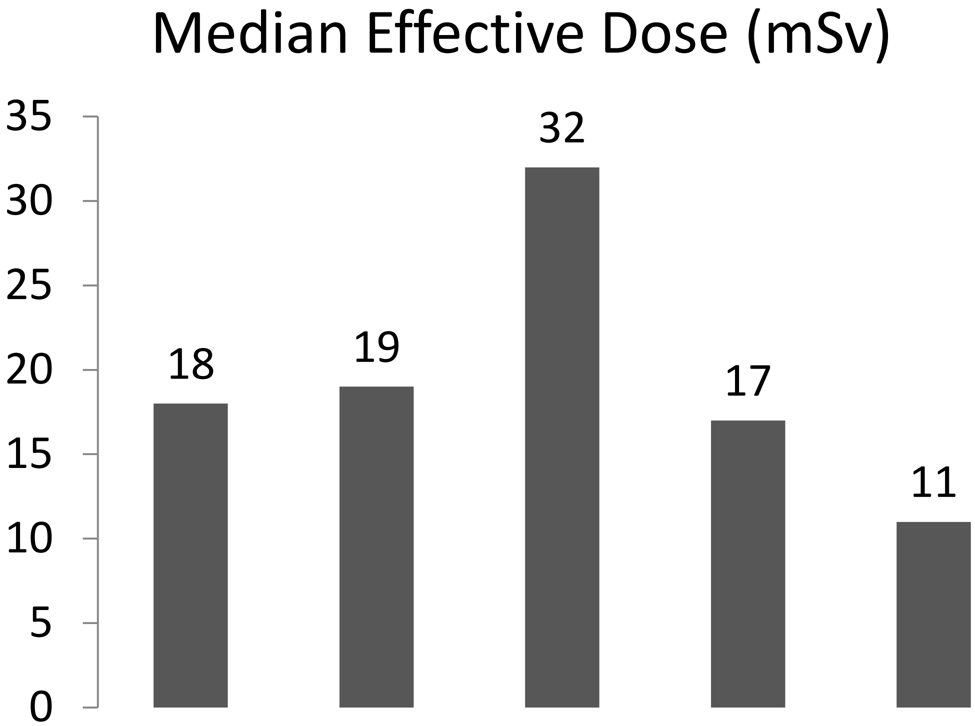
# UCDOSE

- Collaboration across 5 University of California Medical Centers
- Medical physicists, radiologists, technologists, biostatisticians
- Primary goal was to  pool data across campuses, understand performance and use these data to improve practice.
- Comply with California state law requiring reporting of dose in electronic records

# Analysis of Pooled Data

- We found substantial variation in radiation doses
- We explored the the data to understand variation
- While some variation could be explained by patient and scanner factors, most of the variation was due to differences by campus in how they liked to do CT (i.e. personal preferences without clear evidence)

# Chest and Abdomen CT Dose
## Across 5 UC Health Systems

## Two CTs on the Same Patient
## Higher Dose not more diagnostic Better Diagnoses

Low Dose Chest CT
ED 1.5 mSv

Routine Chest CT
ED 15.9 mSv

Smith-Bindman, New Engl J Med 2010

# Using Results to Drive Practice

- We convened an in-person meeting and invited the section heads from neuro, body, and chest; technologists; physicists; researchers to participate

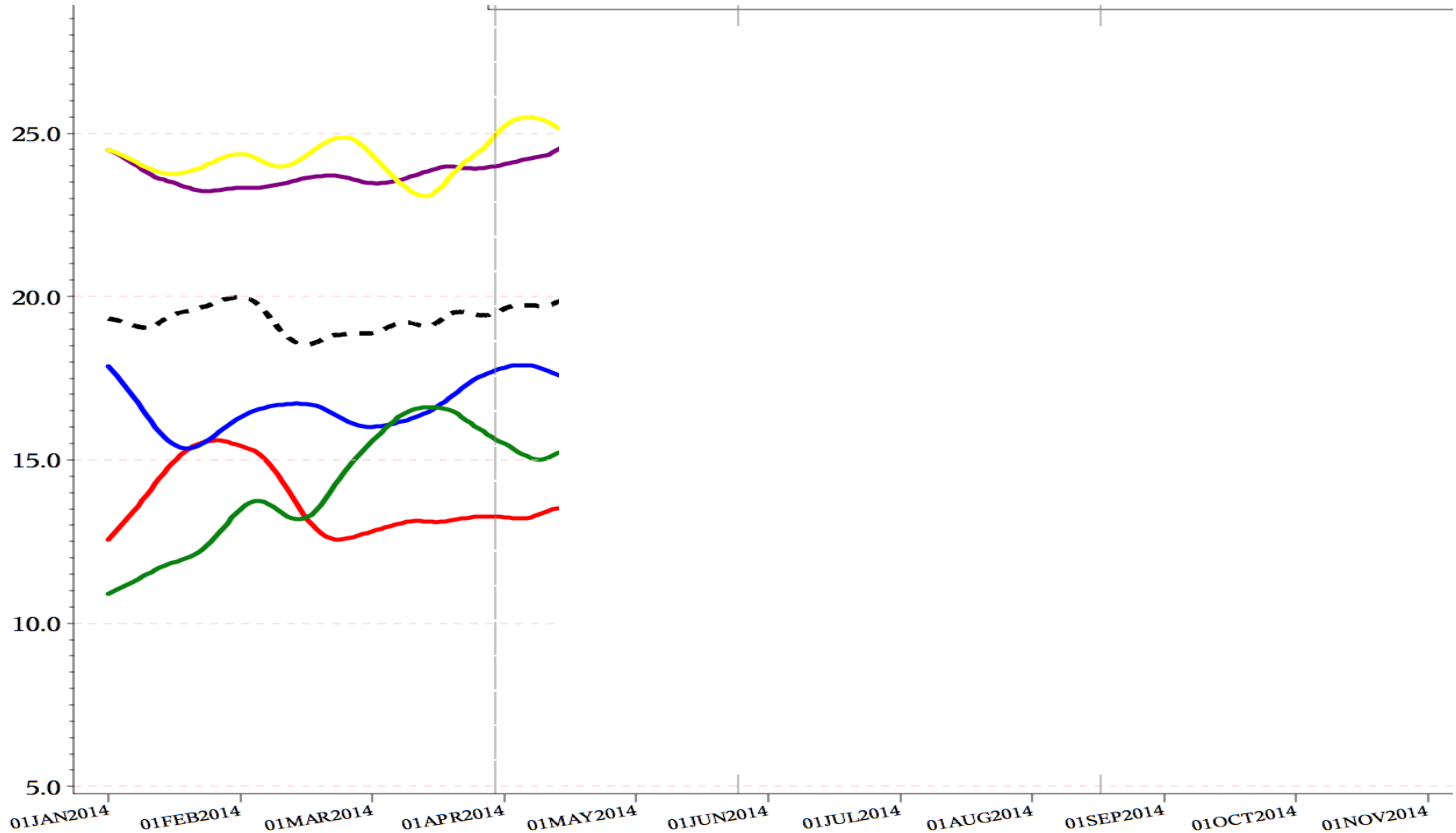
- Each site was provided with their doses ahead of time and Webex calls were had before and after meeting to review results

- Section heads were asked to come prepared to explain, defend, or change practice

- We Identified areas where dose reduction was possible

- Concrete lists of changes to be made were created at meeting

# Abdomen Radiation Doses 2014 (Effective Dose)



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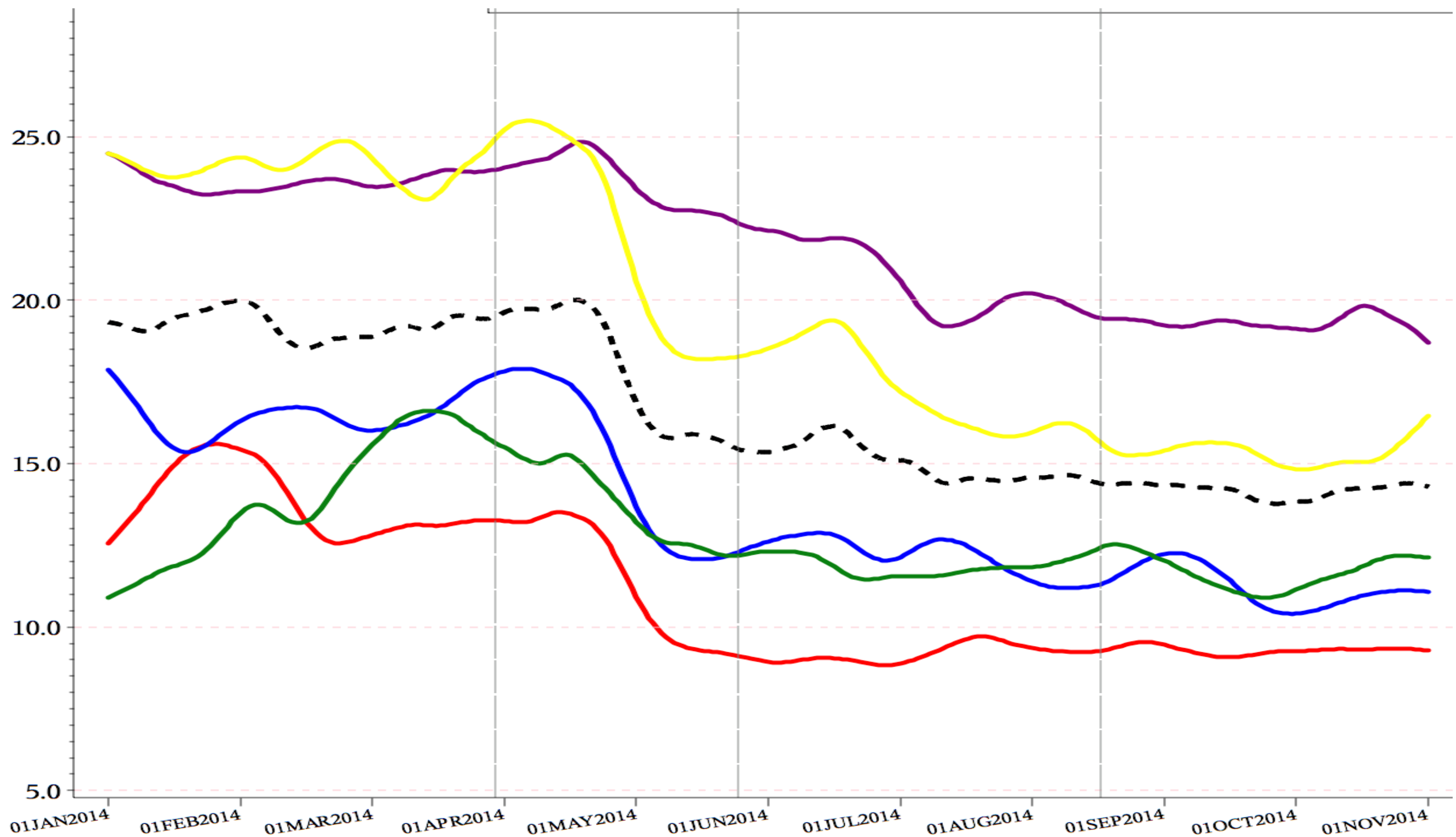


# Computed Tomography (CT): What is the Problem?

- The doses used for CT are far higher than conventional x-rays
- The doses are far higher than needed for diagnosis
- These doses are in the range that they will cause cancer in a small , but significant number of people (we need to quantify this better)
- The doses are highly variable across institutions
- While higher dose can lead to more detailed images, there is no evidence that these lead to more accurate diagnosis
- There are few standards- **benchmarks-** for what is the “right dose”

# Why Are Doses so Variable

- No comprehensive standards or guidelines on CT - there is the sense that everyone should be free to choose
- Guiding principal is that doses should be as low as reasonably achievable -ALARA - but there are few guidelines for what doses are reasonable or achievable
- In the absence of explicit guidelines, practice variation introduces unnecessary harm from excessive radiation
- ALARA does not work
- No organization responsible for collecting or compiling dose data

# Legislative Oversight on Imaging

- The only imaging test with oversight by law is mammography
- National mammography legislation – the Mammography Quality Standard Act – oversees the conduct of mammography in every US facility
- Radiation doses (in addition to many other aspects) are regulated
- The quality of mammography improved profoundly with the passage of the MQSA
- No meaningful oversight exists for CT

# How To Optimize Dose

- Manufacturers are developing hardware / software solutions – but it will take decades to replace current scanners

- Dose monitoring software can help facilities know about their dose and is a good start, but not enough to ensure safety by itself

- Hospitals and imaging facilities must

  **Assess their doses**

  **Compare with benchmarks**

  **Develop strategies to meet benchmarks**

  **Ensure education of staff for QI**

  **Repeat**

# Why Do you Need a Strategy
# What Steps Lead to the Doses Patients Receive

- Test is ordered (ED) with various levels of detail (choices)
- Test is protocoled (by tech, md, other) to call for particular study
- Protocols are preloaded onto CT machine (physicist, tech, manuf)
- Technologist chooses the protocol on the machine to correspond with request
- Technologist tweaks or alters protocol
- Exam reviewed, and possibly repeated or augmented

# What Do We Do at UCSF to Monitor Dose

- We review high doses (by patient) and average doses (for groups of patients) on a monthly basis, by machine, anatomic area , protocol and age group using Radimetrics
- At monthly radiology safety meetings, trainees, attending physicians, technologists review outliers, discuss and investigate
- The technologists review each high dose cases and try to figure out why particular patient's dose are higher than expected – and as a team we brain storm solutions
- We compare the data to benchmarks
- Our doses continue to come down!

# NIH and PCORI : CT DOSE Collaboration

- 5 year study
- Academic and non-academic medical centers, US and non-US
- Expands on previous work
  - Create broader dose benchmarks
  - Understand facility characteristics, change culture,
  - Study what works and what does not to optimize
  - Study design based on using a randomized controlled design
  - Doses are pooled from over 100 institutions

# Collaborating Institutions

- UCSF
- UC Davis
- UC San Diego
- Health Partners Institute

- University of Duisburg-Essen
- Oxford University Hospitals NHS
- University Hospital of Basel
- National Health Services Scotland
- Maastricht University Med Center
- St. Luke's Hospital, Tokyo
- Assuta Health, Israel

**1-40 hospitals / Institution**

- Center for Diagnostic Imaging
- San Francisco Veterans Affairs
- City of Hope
- Henry Ford Health System
- St. Joseph Health System
- Mount Sinai School of Medicine
- Miami Children's Hospital
- Emory Health System
- University of Virginia
- Children's Mercy Hospitals
- Huntsville Hospital System
- Olive View - UCLA
- Einstein Healthcare Network
- Community Health Network
- Maricopa Integrated Health
- East Texas Health Centers

# NIH Aim 1

- RCT to compare Audit vs. Multicomponent Intervention
- Audit – provide sites feedback on how they compare
- Multicomponent Intervention
    - More tailored, site-specific audit feedback
    - Tailored suggestions for lowering doses
    - Meetings with project Change team and hospital-created Implementation Teams
    - Collaborative quality improvement meetings
    - Education on how to created a local quality improvement team and how to do CQI

# NIH Aim 2

- Assess implementation and identify facilitators, barriers, and strategies associated with implementation of dose optimization and sustained dose improvements
- Institutional leaderships views will be assessed
  - Priority to improve radiation safety
  - CT dose optimization
  - Organizational readiness to make changes
  - Care processes and systems associated with successful implementation
- Asses the association between facility factors and dose

# NIH Aim 3

- Broadly expand our work – dissemination and implementation

- Our hope in years 4 and 5 of the project is to allow and encourage all institutions who conduct CT to participate in our registry, and get audit information, and get feedback that we have found to be most effective in our study.

# Current Status of Project

- Registry is established, CT doses are flowing into the registry, > 2 million scans; 20,000 CTs added weekly
- We are finalizing our audit reports
- We are finalizing our multicomponent intervention
- We will begin our feedback in 2016, and assess the relationship between feedback and optimization
- We are hoping to create a publically accessible website of doses/protocols

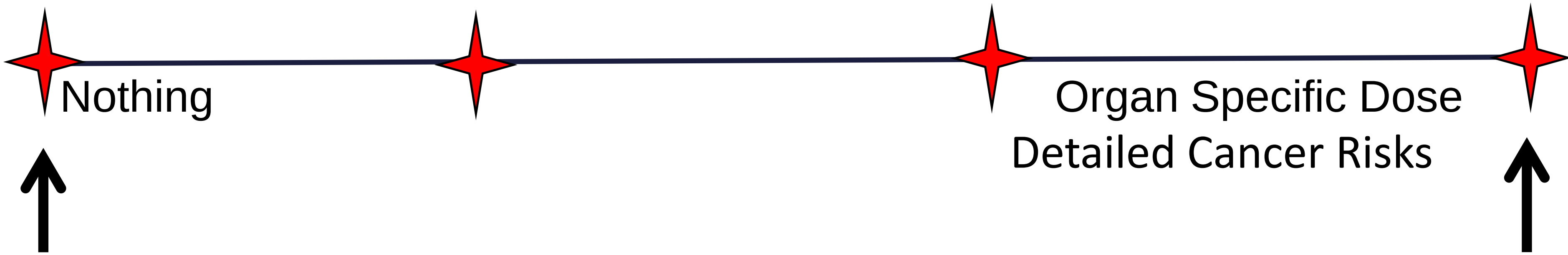
# Does Imaging Radiation Exposure Matter in Cancer Patients

- It depends, and has not been studied
- In a terminal patient, radiation is unlikely to matter
- In a patient who is unlikely to die from their primary cancer (such as a young woman with breast DCIS, man with early stage testicular cancer), repeated imaging (which is common), and doses that are far higher than needed, will add up to measureable dose and risk
- If there is little benefit from surveillance or doses are higher than needed, than only harm can come from the imaging

# Communicating with Patients

- The idea of sharing results directly with patients is not new
- Work is needed to make imaging results and specifically radiation information accessible and understandable
- We just received a small PCORI grant to speak with patients about what they want to know about imaging; how to communicate these results with patients including radiation in a way that educates them without frightening them; and to share these data on a website
- We want to encourage patients and hospitals/providers to Know Your Dose

# What Should Be Communicated about CT Risk / Dose




Comments at US Congressional Hearing on Radiation, 2010

*It is the radiologist job ensure safety– we don't want to frighten patients*
*The risk of radiation injury from a CT scan is virtually non-existent*

Comments from recent Radiology editorial 2015

*We don't know if radiation is harmful or protective, so if we discuss with our patients, we need to tell them both are possible*

**We have a long way to go to improve communication**

# Impact of Reducing the Highest Doses in Children

Miglioretti, JAMA Pediatrics, 2013

- Our study of doses in children ages 15 and younger included a very number of children: 4.8 million patient-years
- Over 10 % of children received doses for  single scan that the UK authors showed tripled their risk of cancer
- We estimate that national use of CT in children in 2010 will result in 9,820 future cancers.
- Reducing the highest outlier doses to the average to the median would prevent 44% of these cancers.

# Summary

- We use a lot of CT scans, and many are not needed
- The Choosing Wisely campaign focuses on all areas, but oncologic imaging comprises a huge proportion of all imaging
- These exams come with both risks and benefits
- The radiation doses we use for CT are too high
- Reducing the doses will only make imaging better
- A lot of work is yet to be done to make imaging safer