Architecture and magnitude of doses received during medical procedures

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Introduction

- Increase in US medical exposures
- Architecture of medical exposures
  - x-ray procedures
  - Nuclear medicine procedures
- Risk, Benefit, Cost
- A lifetime of personal experience
- Summary and Conclusions
Sources of Radiation Exposure to the US Population

- **Radon**: 54%
- Medical X-rays: 11%
- Internal: 11%
- Cosmic: 8%
- Terrestrial: 8%
- Nuclear Medicine: 4%
- Consumer Products: 3%
- Other: <1%

NCRP Report No. 160
Exposure of the Population of the US in 2006

- Space (background) (37 %)
- Radon & thoron (background) (37 %)
- Computed tomography (medical) (24 %)
- Nuclear medicine (medical) (12 %)
- Interventional fluoroscopy (medical) (7 %)
- Conventional radiography / fluoroscopy (medical) (5 %)
- Industrial (<0.1 %)
- Occupational (<0.1 %)
- Consumer (2 %)
- Internal (background) (5 %)
- Terrestrial (background) (3 %)
Architecture of the Radiation Dose Received During Medical X-Ray Procedures

Irradiated tissues receive about the same radiation absorbed dose
Architecture of the Radiation Dose Received from Nuclear Medicine Studies

- Cardiac imaging agent
- Increased use due to limited supply of \( ^{99m}\text{Tc} \)
- Effective dose \( \sim 15\text{mSv} \)

Whole Body Distribution of \( ^{201}\text{TI} \) Chloride
Nonuniform Distribution of Radioactivity in Organs

Enlargements from whole-body autoradiographs of rat tissues following intravenous administration of $^{111}$In-oxine; a: spleen, b: kidney, c: liver and intestinal walls, d: bone marrow in femur, e: inguinal lymph nodes, and f: testes

Nonuniform Distribution of Radioactivity in Tissues

Image of an autoradiographic slide of 0.5-micrometer-thick section of liver (left) and spleen (right) of mice injected intravenously with $^3$H-labeled Microlite (Makrigiorgos et al., J Nucl Med 31, 1358-1363 (1990)).
Variation of Cellular Uptake of $^{210}$Po

Autoradiographic Analysis

The generally nonuniform distribution of radionuclides in tissues has implications for dosimetry and, ultimately, for the biologic response of tissues containing radioactivity. These autoradiographs of a cell population exposed to $^{90}$Y suggest a wide variation in cellular uptake of the tracer.

SEE PAGE 1052

The Official Publication of the Society of Nuclear Medicine, Inc.

Densely Ionizing Radiations Confer Greatest Damage per Unit Absorbed Dose

Fig. 10. Initial positions of the reactive chemical species (e.g., OH, H, $e_{aq}$, etc.) for different Auger emitters. The emitter is located at the midpoint on the surface of a cylindrical DNA segment in liquid water.

Highly Localized Energy Deposition in the Immediate Vicinity of Auger Electron Emitters

Fig. 8. Localized energy deposition around I-125 decay site. The pattern of average energy deposited by the Auger and CK electrons is shown in the top curve. The value at 1 nm is the energy absorbed in a unit density sphere of this radius, centered at the decay site. Energy deposited in 1-nm-thick concentric spherical shells thereafter is indicated as a function of the distance from the decay site. The discontinuities at about 5 and 7 nm are due to the end of the range of major low-energy electron groups. The lower curve, derived from the top one, is the profile of the average absorbed energy density. The sharp drop in the energy density in the first 5 nm illustrates the highly localized nature of the action of the low-energy electrons. Note that 10 eV/(nm)^2 implies a locally absorbed dose of 1 MGy.
Auger Electron Emitters in Nuclear Medicine

Auger electrons/decay

- $^{67}\text{Ga}$ (gallium-67) 5
- $^{99m}\text{Tc}$ (technetium-99m) 4
- $^{111}\text{In}$ (indium-111) 15
- $^{123}\text{I}$ (iodine-123) 15
- $^{125}\text{I}$ (iodine-125) 25
- $^{201}\text{Tl}$ (thallium-201) 37
Distribution of Radioactivity in Nuclear Medicine after Administration

- Distributed among organs and tumors
  - Activity per gram tissue varies widely

- Nonuniformly distributed within tissues at all spatial levels
  - Macroscopic (mm to cm)
  - Multicellular (10 μm to mm)
  - Subcellular (cytoplasm, nucleus, cell surface)
  - Molecular
Medical Radiation Exposures
Risk Analysis, Benefit Analysis, Cost Analysis

- Cost analysis
- Radiation risk analysis
  - Population-based
    - Atomic bomb survivors
- Medical risk vs. benefit analysis
  - Guided by experience with patient populations
  - Consensus management recommendations
  - Ultimately implemented on individual patients by single physician or team
Medical Risks vs. Benefits: A Lifetime of Experience

- Age 10 (1969)
  - Acute abdominal pain for 24 h
  - Taken to ER
  - NO IMAGING.
  - Discharged upon lessening of pain

- Age 16-17 (1975-1976)
  - Migraines with aura
  - Severe mononucleosis (2 months)

- Age 29 (1988)
  - Acute abdominal pain for 24 h
  - remained home, pain resolved
Medical Risks vs. Benefits: A Lifetime of Experience

- **Age 31 (1990)**
  - Business trip to Sweden for 2 weeks.
  - Stayed seated in lab until 5 am on final day to complete project.
  - Awakened at 7 am with **debilitating chest pain and weakness**.
  - Evaluated at hospital - **NO IMAGING**
  - Discharged upon observing reduction in pain.

- **Age 33 (1992)**
  - Chest pain started before bedtime
  - Stabbing chest pain by early am
  - Taken to ER
  - **Limited imaging** – chest x-ray ?, no findings
  - Discharged upon observing reduction in pain.
Medical Risks vs. Benefits: A Lifetime of Experience

- **Age 38 (1997)**
  - Day 0 - Severe abdominal pain > 24 h
    - Taken to ER and discharged *without* imaging
  - Day 1 - Severe abdominal pain continues
    - admitted to hospital
    - administered bolus demerol every 4 hours for pain
    - CT scan with contrast (10 gallons!!!!!!!)
  - Day 2 – Doppler ultrasound
    - *No blood flow through portal vein*
    - *No blood flow through splenic vein*
    - *Partially blocked superior mesenteric vein*
    - Started on iv heparin
Portal Venous System

- Portal vein (PV)
- Splenic vein (SV)
- Renal vein (SV)
- Superior mesenteric vein (SMV)
Portal & Splenic Veins

ANATOMY

Portal vein (PV)

Splenic vein (SV)

MRI

NO radiation absorbed dose

HOWEVER, risk from contrast agent
Age 38 Contrast CT

Absorbed dose = 10-50 mGy
Doppler Ultrasound to Diagnose Portal Vein Thrombosis

NORMAL PV

HOWELL OCCLUDED PV
Medical Risks vs. Benefits: A Lifetime of Experience

- **Age 38 continued (1997)**
  - Day 3 - air-lifted to New England Medical Ctr
    - Marshall Kaplan
    - Lori Olans
    - Ralph Fairchild
  - Day 4 – Magnetic resonance angiogram
  - Day 6 – Xe-133 lung scan for suspected PE
Nuclear Medicine Xe-133 Lung Perfusion Scan

Perfusion Scan: Pulmonary Emboli

Normal Scan

http://www.merck.com/mmhe/sec04/ch046/ch046a.html
My Xenon-133 Lung Scan

- While hospitalized and undergoing heparin therapy, experienced severe headache.
- Various scans including lung scan for PE
- Effective dose = $1 \times 10^{-03}$ mSv/MBq (1100 MBq)
- ~ $1$ mSv

- NEGATIVE for PE!
- Source of headache – scopolamine patch!
- Unnecessary scan?
- Hindsight is 20/20
Nuclear Medicine $^{99m}$Tc Bone Scan for Metastases

Administered activity = 1 GBq

D(Bone surfaces) = 63 mGy

Effective dose = 5.7 mSv

NEGATIVE for metastases.

Image warranted?

Hindsight is 20/20.
Who Gets these Problems?

- Portal vein thrombosis patients
  - Cancer 25%
  - Liver cirrhosis 25%
  - Genetically predisposed 25%
    - Factor V Leiden
    - Protein S, etc.
  - Unknown etiology 25%
    - ???????
    - Migraines linked
    - Mononucleosis linked
Medical Risks vs. Benefits: A Lifetime of Experience

- Age 41-42 (2000-2001)
  - Esophageal hemorrhage
    - Repeated episodes requiring transfusions
    - Octreotide given to reduce portal pressure
    - Wrote grant in ICU – funded !!!!

- Age 42
  - Investigated surgical interventions for eradicating esophageal hemorrhage
Treatment of Portal Hypertension from Venous Occlusive Disease
Splenic Artery Embolization & Splenopneumopexy

Success in several patients.

Medical Risks vs. Benefits: A Lifetime of Experience

- **Age 44 (2003)**
  - Acute abdomen
  - Mesenteric ischemia
  - **Fluoroscopically** guided thrombolytic agents
    - Absorbed dose = 1 Gy ? 3 Gy ? ........
  - Laparoscopy - + for cloudy ascites
  - Laparotomy – identified mild bowel ischemia
  - Post-surgical lung complications
From an individual standpoint, when a CT scan is justified by medical need, the associated risk is small relative to the diagnostic information obtained. However, if it is true that about one third of all CT scans are not justified by medical need, and it appears to be likely, perhaps 20 million adults and, crucially, more than 1 million children per year in the United States are being irradiated unnecessarily.

Brenner & Hall (2007)
Ultrasound as an Alternative to CT?

For example, in a comparison of patients with suspected venous thromboembolism (VTE), US was as sensitive and specific as CT, suggesting that the less expensive imaging technology can be used without compromising patient safety. Literature reviews evaluating patients with deep vein thrombus conclude that US is the most frequently used diagnostic test because of its accuracy and low cost. MR and CT may be used with the known shortfall of limited availability and increased cost.

Surgical treatment of BCS is dependent on a correct diagnosis and classification of the disease.

- 1360 cases

The key to long survival in BCS is prompt diagnosis and treatment by portal decompression.

- 60 cases
Conclusion
Path for the Future

- Teach residents to select the radiologically safest procedure that provides accurate diagnosis
- Teach residents to use radiological procedures as safely as possible
- Use a medical team to assess risk vs. benefit
- Training for radiological procedures
  - Use visual indicators of biological response
  - Develop free web-based Monte Carlo simulations to demonstrate “real-time” 3D dose rate and cumulative dose for all radiological procedures with selectable patient size, kVp, mA, filtration, manufacturer, etc.
  - Incorporate simulation into clinical devices for real time 3D patient specific dose information
Acknowledgments to My Medical Teams

- **Morristown Memorial Hospital**
  - John Dalena, GI

- **New England Medical Center**
  - Marshall Kaplan, GI
  - Lori Olin, GI
  - Ralph Fairchild, Surgery
  - Transplant unit

- **UMDNJ New Jersey Medical School**
  - Stephen Baker, Radiology
  - Kyunghi Cho, CT
  - Marcia Blacksin, CT
  - Leo Wolanski, MRI
  - Lionel Zuckier, Nuclear Medicine
  - Ken Swan, Surgery

- **Overlook Hospital, Summit, NJ**
  - Marvin Lipsky, GI
  - Bonnie Gerhardt, Hematology
  - Mark Mandel, Surgery
  - Clifford Sales, Vascular Surgery
  - Norman Levine, Interventional Radiology
  - ICU team
Radiology Division of Radiation Research
http://njms.umdnj.edu/departments/division_radiation

Ed Azzam  Sonia de Toledo  Bogdan Gerashchenko  Lorenzo Pinto

John Akudugu  Prasad Neti  Manuela Buonnano  Benjamin John

Massimo Pinto  Lionel Zuckier
Kerala, India

- mean 4 mGy y⁻¹
- as high as 70 mGy
Examples of Cumulative Exposures

Cumulative Exposure (mSv)

Age (years)

Monazite
CT
Occupational 10
Jet aircraft
Background
Occupational 1.7
Portomesenteric venous thrombosis in a 73-year-old woman with abdominal pain

Color Doppler - absence of flow at portovenous confluence (white arrow) splenic vein (black arrow)

Contrast CT - filling defects in the portal vein (arrow) with cavernous transformation at the porta hepatis.