CT Radiation Dose: Current status and future strategies

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I consider the radiologist’s responsibility with (radiation) dose to be the same as any physician’s with (medication) dose.

Over (or under) dosing is a medical error.
Current Concerns

- Are CT doses high?
- Is this a problem?
- Strategies to control medical radiation
Current Concerns

• Are CT doses high?
• Is this a problem?
• Strategies to control medical radiation
Low-level Radiation

< 100-150 mSv
Background Radiation

3.0-3.5 mSv per year
Measures of CT Dose

- Physical measurements
  - e.g. anthropomorphic phantoms
- Monte Carlo
- DLP method
- Published estimations

**Exam Description: CT BRAIN**

<table>
<thead>
<tr>
<th>Series</th>
<th>Type</th>
<th>Scan Range (mm)</th>
<th>CTDIvol (mGy)</th>
<th>DLP (mGy·cm)</th>
<th>Phantom cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Scout</td>
<td>-</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>2</td>
<td>Axial</td>
<td>131.000–5106.525</td>
<td>13.57</td>
<td>193.46</td>
<td>Head 16</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>193.46</td>
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</table>

Total Exam DLP: 193.46
<table>
<thead>
<tr>
<th>Examination</th>
<th>Average Effective Dose (mSv)</th>
<th>Values Reported in Literature (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skull</td>
<td>0.1</td>
<td>0.03–0.22</td>
</tr>
<tr>
<td>Cervical spine</td>
<td>0.2</td>
<td>0.07–0.3</td>
</tr>
<tr>
<td>Thoracic spine</td>
<td>1.0</td>
<td>0.6–1.4</td>
</tr>
<tr>
<td>Lumbar spine</td>
<td>1.5</td>
<td>0.5–1.8</td>
</tr>
<tr>
<td>Posteroanterior and lateral study of chest</td>
<td>0.1</td>
<td>0.05–0.24</td>
</tr>
<tr>
<td>Posteroanterior study of chest</td>
<td>0.02</td>
<td>0.007–0.050</td>
</tr>
<tr>
<td>Mammography</td>
<td>0.4</td>
<td>0.10–0.60</td>
</tr>
<tr>
<td>Abdomen</td>
<td>0.7</td>
<td>0.04–1.1</td>
</tr>
<tr>
<td>Pelvis</td>
<td>0.6</td>
<td>0.2–1.2</td>
</tr>
<tr>
<td>Hip</td>
<td>0.7</td>
<td>0.18–2.71</td>
</tr>
<tr>
<td>Shoulder</td>
<td>0.01</td>
<td>. .</td>
</tr>
<tr>
<td>Knee</td>
<td>0.005</td>
<td>. .</td>
</tr>
<tr>
<td>Other extremities</td>
<td>0.001</td>
<td>0.0002–0.1</td>
</tr>
<tr>
<td>Dual x-ray absorptiometry (without CT)</td>
<td>0.001</td>
<td>0.001–0.035</td>
</tr>
<tr>
<td>Dual x-ray absorptiometry (with CT)</td>
<td>0.04</td>
<td>0.003–0.06</td>
</tr>
<tr>
<td>Intravenous urography</td>
<td>3</td>
<td>0.7–3.7</td>
</tr>
<tr>
<td>Upper gastrointestinal series</td>
<td>6*</td>
<td>1.5–12</td>
</tr>
<tr>
<td>Small-bowel series</td>
<td>5</td>
<td>3.0–7.8</td>
</tr>
<tr>
<td>Barium enema</td>
<td>8*</td>
<td>2.0–18.0</td>
</tr>
<tr>
<td>Endoscopic retrograde cholangiopancreatography</td>
<td>4.0</td>
<td>. .</td>
</tr>
</tbody>
</table>

* Includes fluoroscopy.
<table>
<thead>
<tr>
<th>Examination</th>
<th>Average Effective Dose (mSv)</th>
<th>Values Reported in Literature (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>2</td>
<td>0.9–4.0</td>
</tr>
<tr>
<td>Neck</td>
<td>3</td>
<td>.</td>
</tr>
<tr>
<td>Chest</td>
<td>7</td>
<td>4.0–18.0</td>
</tr>
<tr>
<td>Chest for pulmonary embolism</td>
<td>15</td>
<td>13–40</td>
</tr>
<tr>
<td>Abdomen</td>
<td>8</td>
<td>3.5–25</td>
</tr>
<tr>
<td>Pelvis</td>
<td>6</td>
<td>3.3–10</td>
</tr>
<tr>
<td>Three-phase liver study</td>
<td>15</td>
<td>.</td>
</tr>
<tr>
<td>Spine</td>
<td>6</td>
<td>1.5–10</td>
</tr>
<tr>
<td>Coronary angiography</td>
<td>16</td>
<td>5.0–32</td>
</tr>
<tr>
<td>Calcium scoring</td>
<td>3</td>
<td>1.0–12</td>
</tr>
<tr>
<td>Virtual colonoscopy</td>
<td>10</td>
<td>4.0–13.2</td>
</tr>
</tbody>
</table>

Mettler, Huda, Yoshizumi, Mahesh. Radiology. 2008; 248; 254-263
Typical Medical Radiation Doses: 5 year-old (mSv)

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Dose (mSv)</th>
<th>CXR Equivalents</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-view ankle</td>
<td>0.0015</td>
<td>1/14&lt;sup&gt;th&lt;/sup&gt;</td>
</tr>
<tr>
<td>2-view chest</td>
<td>0.02</td>
<td>1</td>
</tr>
<tr>
<td>Tc-99m radionuclide gastric emptying</td>
<td>0.06</td>
<td>3</td>
</tr>
<tr>
<td>Tc-99m radionuclide cystogram</td>
<td>0.18</td>
<td>9</td>
</tr>
<tr>
<td>Tc-99m radionuclide bone scan</td>
<td>6.2</td>
<td>310</td>
</tr>
<tr>
<td>FDG PET</td>
<td>15.3</td>
<td>765</td>
</tr>
<tr>
<td>Fluoroscopic cystogram</td>
<td>&lt;0.33</td>
<td>16</td>
</tr>
<tr>
<td>Chest CT</td>
<td>up to 3</td>
<td>150</td>
</tr>
<tr>
<td>Abdomen CT</td>
<td>up to 5</td>
<td>250</td>
</tr>
</tbody>
</table>
Can Be High Dose: 64-Slice MDCT

<table>
<thead>
<tr>
<th></th>
<th>ED (mSv)</th>
<th>SD (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest with modulation</td>
<td>3.05</td>
<td>0.14</td>
</tr>
<tr>
<td>Chest w/o modulation</td>
<td>3.05</td>
<td>0.14</td>
</tr>
<tr>
<td>Chest Extreme</td>
<td>42.95</td>
<td>0.55</td>
</tr>
<tr>
<td>Abdomen with modulation</td>
<td>7.32</td>
<td>0.33</td>
</tr>
<tr>
<td>Abdomen w/o modulation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abdomen Extreme</td>
<td>118.9</td>
<td>1.85</td>
</tr>
</tbody>
</table>
How much do we understand about CT radiation dose?
### TABLE 3
Dose Estimates for One CT Scan versus One Chest Radiograph

<table>
<thead>
<tr>
<th>Respondent Group</th>
<th>CT ≤ CR</th>
<th>CT &gt; CR</th>
<th>CT ≥ 10 × CR</th>
<th>CT ≥ 500 × CR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CR</td>
<td>&lt; 10 × CR</td>
<td>&lt; 100 × CR</td>
<td>CT = 100–250 × CR*</td>
</tr>
<tr>
<td>Patients (n = 67)</td>
<td>19 (28)</td>
<td>43 (64)</td>
<td>5 (7)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>ED Physicians</td>
<td>3 (7)</td>
<td>20 (44)</td>
<td>10 (22)</td>
<td>10 (22)</td>
</tr>
<tr>
<td>(n = 45)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radiologists</td>
<td>2 (5)</td>
<td>22 (56)</td>
<td>6 (15)</td>
<td>5 (13)</td>
</tr>
<tr>
<td>(n = 39)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note.—Data are the number of respondents. Numbers in parentheses are percentages. $\chi^2$ test result, 67.04; $P < .001$. CR = chest radiograph.

* Accurate range.

**Under estimation by 75% of MDs!**

Lee et al. Radiology. 2004; 231:393-398
Current Concerns

• Are CT doses high?
• Is this a problem?
• Strategies to control medical radiation
CT: Patterns of Use

- 30 - 65 million examinations in U.S.
- U.S. : 25 - 60% of world total
- Up to 11% of CT exams are pediatric
  - 4-7 million pediatric CTs
- 17% of these in children 0-5 years old
Multidetector CT: U.S.

• 65,000,000 examinations per year
• If 50% involve two phases ....
• 97,500,000 “dose events” per year
• 2002 US population: 281,000,000
• 1 CT for every 3.5 people
• Conservative: 1 CT for 9.6 people
Fig. 1. Data from IMV Benchmark Report (IMV 2006). CT.
Pediatric Procedure Volumes

Computed Tomography
- 37% CAGR
- Source: AMR, 2006. As referred by Pediatrician

Magnetic Resonance
- 30% CAGR
- Source: AMR, 2006. As referred by Pediatrician

Positron Emission Tomography
- 38% CAGR
- Source: AMR, 2006. As referred by Pediatrician

Conventional X-Ray
- 5% CAGR
- Source: AMR, 2006. As referred by Pediatrician

Privileged & Confidential GE Healthcare, David Dobson
Scope of CT Radiation

All Medical X-Ray Imaging Modalities

- CT: 5% frequency of use but contributes 40%-67% of medical radiation

Chest: 41%
Skeleton: 29%
Abdomen: 5%
Head: 6%
GI Tract: 5%
CT: 5%
Angio/Interventional: 1%
Other: 8%

Mettler et al J Radiol Prot. 2000; 20:353-359
(old) Estimated Annual Radiation Exposure

- Background: 81.2%
- Medical: 15%
- Consumer Products: 0.8%
- Other: 0.3%

Kimball’s Biology; NCRP
MEDICAL RADIATION EXPOSURE IN THE U.S. IN 2006: PRELIMINARY RESULTS OF NCRP 6-2
Fred A. Mettler, Jr.,* Bruce R. Thomadsen,† Mythreyi Bhargavan,‡ Debbie B. Gilley,§ Joel E. Gray,¶ Jill A. Lipoti,∥ John McCrohan,¶ Terry T. Yoshizumi,¶ and Mahadevappa Mahesh**

Abstract—Medical radiation exposure of the U.S. population has not been systematically evaluated for almost 25 y. In 1982, the per capita dose was estimated to be 0.64 mSv and the collective dose 124,000 person-Sv. The preliminary estimates of the NCRP Scientific Committee 6-2 medical subgroup are that, in 2006, the per capita dose from medical exposure (not including dental or radiology) had increased almost 60% to about 1.0 mSv and the collective dose had increased over 700% to about 900,000 person-Sv. The largest contributions and increases have come primarily from CT scanning and nuclear medicine. The 62 million CT procedures accounted for 15% of the total number procedures (excluding dental) and over half of the collective dose. Nuclear medicine accounted for about 4% of all procedures but 26% of the total collective dose. Medical radiation exposure is now approximately equal to natural background radiation.

INTRODUCTION

The last comprehensive report on ionizing radiation exposure of the U.S. population from all sources was published by the National Council on Radiation Protection and Measurements (NCRP) in 1987 (NCRP 1987). This was followed by another report in 1989 (NCRP 1989) that included supporting data relative to medical exposure. Both of those reports included data only up through 1982. In the fall of 2006, the NCRP established a scientific committee (SC 6-2) to review the current state of knowledge and prepare a new report on the magnitude of all sources of radiation exposure to the U.S. population. A medical subgroup was included as part of the committee to specifically examine the changes that had occurred over the last 25 y.

Specific tasks of the medical subgroup included estimating the current number and types of medical procedures using ionizing radiation and evaluating the effective dose per procedure as well as annual per capita effective dose and annual collective effective dose. Additional tasks included evaluating past and potential future trends. Modalities or applications to be examined included standard radiography and fluoroscopy, interventional procedures (including cardiology), mammography, computed tomography (CT), dental, nuclear medicine, and radiotherapy. The information gained was intended for use by individuals, manufacturers, practitioners, and regulators. The preliminary results of the work of the NCRP 6–2 medical subgroup are presented here. NCRP will publish a full report on exposure of the U.S. population to ionizing radiation. Readers are encouraged to obtain a copy of this report from NCRP.

MATERIALS AND METHODS

Data were derived from both primary and secondary sources. The primary sources on national utilization included Medicare claims data for about 40 million subscribers during 2004 as well as commercially available benchmarking reports for various modalities from IMV (Information Means Value) Limited (IMV 2004, 2005, 2006). The IMV reports cover both hospital and non-hospital sites and the surveys typically obtained responses from one-half to two-thirds of all imaging sites in the U.S.

Fig. 5. Comparison of per capita dose to the U.S. population from various sources in 1980 and the preliminary estimate for 2006.

Why?
Driving CT Use…

- We drive use
- Industry drives use
- Non-radiologists drive use
- Media drives use
- Public drives use
Isn’t it easier just to get a CT?
ED Imaging
“But I thought that the ED was different than the clinic…. and we should order more [CTs]”

resident, June 4th, 2008
Get Scanned!

EARLY DETECTION OF HEART DISEASE AND CANCER CAN MEAN A CURE!

Where: St. James Baptist Church
1305 W. Club Blvd., Durham, NC
When: Monday, April 23rd Beginning at 7:00 a.m.

Appointments Are Required.
Call 727-799-2000 or toll free 1-87-R-U-AT-RISK
(1-877-828-7475)

No Needles, No Preparation, No Removal of Clothing.

What Is A Heart Scan?
A painless, high-speed X-ray of the coronary arteries that measures the amount of calcium in cholesterol-laden deposits. In most people, the greater the calcium deposit, the higher the risk of obstructive coronary artery disease. A heart scan is recommended for men over 40 and postmenopausal women.

What Is A Lung Scan?
A painless, high-speed X-ray of the lungs that can identify cancerous tumors when they are small enough to be cured. CT lung scanning is four times more sensitive in detecting lung cancer than conventional chest X-rays.

What Is An Abdominal/Pelvic Scan?
A painless, high-speed X-ray capable of seeing tumors in the kidneys, pancreas, liver or adrenal glands; gallstones, intestinal masses, kidney stones or cysts, liver cysts, cirrhosis of the liver, ovarian cysts in women and prostate enlargement in men.

CATscan 2000

All tests are reviewed by a board certified Radiologist. Results are completely confidential and mailed in 2-3 weeks. Abnormal results are copied to your primary care physician. Any one test: $195 per test. Have any two tests and receive $50.00 off the third test. May be covered by your insurance.
Dr. Oz

Love Your Heart

Even the loyal viewers of The Oprah Show have never seen Oprah quite like this: she places her heart as seen in the new 64-slice CT scanner.

"Though CT scanners have been around for years, the new 64-slice CT scanner's technology actually allows doctors and patients to watch their heart beating. If you think about it, the CAT scan takes a picture of the body without actually seeing the heart beating. You need a scanner that can take pictures so fast it can catch the heart in a beat. Those new scanners can take almost 200 pictures a second so they can get your heart at so many different angles that you capture it."

"Before the invention of this new CT scanner, Dr. Oz says, doctors relied on calcium scores to determine hardening of the arteries. However, this was a highly inaccurate science. "What makes this technology so cool," Dr. Oz says, "is you can actually see the calcium which is just a symptom."

Curious about the state of her own heart, Oprah decided to get one of these heart scans. What does Dr. Andrew Rosenson, who performed her scan, think of Oprah's heart?

"Your heart is perfect," Dr. Andy says. "You have the heart of a 19-year-old."
There are Two Types of Bio Effects

Dose dependent:
- severity depends on dose
- there is a threshold
- burns, hair loss

This is a *deterministic* effect
Radiation-induced temporary hair loss as a radiation damage only occurring in patients who had the combination of MDCT and DSA

Yasuhisa Imamishi
Atsushi Fukui
Hirotoshi Niimi
Daikichi Itoh
Kyoko Nozaki
Shun'etsu Nakaji
Kumiko Ishizuka
Hirotoshi Tabata
Yu Furuya
Masahiko Uzura
Hideto Takahama
Suzuo Hashizume
Shiro Arima
Yasuo Nakajima

Abstract As imaging technologies become increasingly advanced, it is possible to obtain detailed morphological information as well as functional imaging data. In some imaging technologies, the radiation dose increases with the ability to obtain better images or more detailed information. We encountered three cases of temporary bandage-shaped hair loss, which was caused by perfusion studies of the head by multi-detector row computed tomography (MDCT) for evaluation of cerebral blood flow in patients with vascular disorders. In all three patients with loss, two angiograph had been performed. A serial CT examination suggested the possibility of exposure from angio image formed by the fusion of perfusion images. The head with MDCT porcine role in this shape-shaped hair loss should be aware that multiplier effect of radiation from multiple images may result in other types of radiations.

Keywords Hair loss - Perfusion study by N - Complication of radiation - Skin - Effects of irradiation on
There are Two Types of Bio Effects

Non dose dependent:

- *severity* is independent of dose
- *risk* of event occurring is dependent on dose
- there is “no threshold”
- cancer, genetic mutations

This is a *stochastic* effect
CT scans in children linked to cancer later

By Steve Sternberg
USA TODAY

Each year, about 1.6 million children in the USA get CT scans to the head and abdomen — and about 1,500 of those will die later in life of radiation-induced cancer, according to research out today.

What's more, CT or computed tomography scans given to kids are typically calibrated for adults, so children absorb two to six times the radiation needed to produce clear images, a second study shows. These doses are "way bigger than the sorts of doses that people at Three Mile Island were getting."

David Brenner of Columbia University says, "Most people got a tenth or a hundredth of the dose of a CT."

Both studies appear in February's American Journal of Roentgenology, the nation's leading radiology journal. The first, by Brenner and colleagues, is the first to estimate the risks of "radiation-induced fatal cancer" from pediatric CT scans. Until a decade ago, CT scans took too long to perform on children without giving them anesthesia to keep them still. Today's scanners spiral around the patient in seconds, providing cross sections, or "slices," of anatomy.

Doctors use CT scans on children to search for cancers and ailments such as appendicitis and kidney stones.

"There's a huge number of people who don't just receive one scan," says Fred Mettler of the University of New Mexico, noting that CT scans are used for diagnosis and to plan and evaluate treatment. "The breast dose from a CT scan of the chest is somewhere between 10 and 20 mammograms. You'd want to think long and hard about giving your young daughter 10 to 20 mammograms unless she really needs it."

Mettler recently published a study showing that 11% of the CT scans at his center are done on children younger than 15, and they get 70% of the total radiation dose given to patients. Children have more rapidly dividing cells than adults, which are more susceptible to radiation damage. Children also will live long enough for cancers to develop.

Researchers led by Lane Donnelly at Cincinnati's Children's Hospital found that children often get radiation doses six times higher than necessary, cutting the adult dose in half would yield a clear image and cut the risk a like amount, Brenner says. "Radiologists genuinely believe the risks are small," he says, "I suspect they've never been confronted with numbers like this."
Is it safe?
Low-Level Radiation Risk: Four Perspectives

• We don’t know
• Data indicate low-level harmful
• Data indicate low-level not harmful
• Data indicate low-level helpful
  – Concept of hormesis
- 100 mSv exposure
- 1:100 cancer incidence
- Background 43:100

Figure 2. In a lifetime, approximately 42 (solid circles) of 100 people will be diagnosed with cancer from causes unrelated to radiation. The calculations in this report suggest approximately one cancer (star) in 100 people could result from a single exposure 100 mSv of low-LET radiation.

http://dels.nas.edu/dels/rpt_briefs/beir_vii_final.pdf
Estimating Risk of Cancer Associated With Radiation Exposure From 64-Slice Computed Tomography Coronary Angiography

Andrea J. Einstein, MD, MPH
Mohan J. Ramiah, MD, PhD
Sandeep J. Popescu, MD

**Context**
Computed tomography coronary angiography (CTCA) has become a common diagnostic test, yet little is known about the long-term associated cancer risk. The recent FDA guidelines for the use of radiation exposure for CTCA studies 

**Objectives**
To determine the cancer incidence associated with radiation exposure from a 64-slice CTCA study and to evaluate the influence of age, sex, and scan protocol on cancer risk.

**Design, Setting, and Patients**
Organ doses from 64-slice CTCA to standardized phantom (computational model) male and female patients were estimated using Monte Carlo simulation methods, using standard voxel CT protocols. Age- and sex-specific LARs of individual cancers were estimated using the approach of BEIR VII and summed to obtain whole-body LARs.

**Main Outcome Measures**
Whole-body and organ LARs of cancer incidence.

**Results**
Organs doses ranged from 42 to 91 mSv for the lungs and 50 to 80 mSv for the female breast. Lifetime cancer risk estimates for standard cardiac CT scans varied from 1 in 143 for a 20-year-old woman to 1 in 326 for an 80-year-old man. Use of simulating electrocardiographically controlled tube current modulation (ECTM) decreased these risk estimates to 1 in 219 and 1 in 5017, respectively. Estimated cancer risks using ECTM for a 60-year-old woman and a 60-year-old man were 1 in 715 and 1 in 1141, respectively. A combined scan of the heart and aorta had highest LARs, up to 1 in 114 for a 20-year-old woman.

**Conclusions**
These estimates derived from simulation models suggest that use of 64-slice CTCA is associated with a nonnegligible LAR of cancer. This risk varies markedly and is considerably greater for women, younger patients, and for combined cardiac and aortic scans.

JAMA. 2007;298(2):317-323

www.jama.com
Pediatric Fatal Cancer Risk

- Estimated
- Debated
- May be zero
- May be 1 in 500 – 10,000 risk from single CT
The Hidden Costs of CT Bioeffects

Christoph I. Lee, MD, Howard P. Forman, MD, MBA

With the rapidly increasing use of computed tomography (CT) in the clinical setting, diagnostic radiology continues to solidify its integral role in the diagnosis, management, and treatment of diseases. In terms of the economic gain from the rapidly increasing utilization of CT, the future seemed all too promising for radiologists just a few years ago. However, there are hidden costs associated with the boom in CT to patients, the U.S. health care system, and the profession of radiology that should be monitored for both economic and ethical reasons.

The cost of medical imaging, fueled increasingly by CT, to the U.S. health care system now surpasses that of pharmaceutical drugs, with little regulation. While the U.S. population is growing at a rate of less than 1% per year, the use of CT is growing at a rate of 10% per year, with a total of more than 60 million computed tomographic scans performed in 2006 [1]. Given the extraordinary boom in medical imaging, the field of radiology has increasingly become a target for expenditure cuts in recent years. The Deficit Reduction Act of 2005, for instance, has already had a huge economic impact on practitioners.

Decreasing reimbursements for technical fees for hospitals and imaging centers, decreasing reimbursement for professional fees for radiologists, and increased insurance premiums for all patients.

Although the topics of CT radiation dose and possible increased radiation-related cancer risks have been heavily debated over the past few years in the radiology community, it is an extremely relevant topic with regard to the economics of CT. In economics, incomplete information refers to a situation in which a market participant lacks necessary information important for decision making. Although patients and physicians consider the potential benefits of CT without consideration of the related risks, the tendency would be for overutilization of this modality in the clinical setting.

Although a minority within the radiology community may disagree, current literature suggests that effective doses from computed tomographic scans are within a range associated with a statistically significant increase in solid cancer risk and cancer mortality. Several studies have supported an increased lifetime cancer risk in the pediatric population as well as increased risk in adults. As a result, the Pediatric Radiation Monitoring System has already instituted strict criteria governing who may order tests involving ionizing radiation and requiring by law that physicians be educated on the risks of computed tomographic examinations.

In our previously published study at one major academic medical center, only 9% of emergency medicine physicians and 3% of patients were aware of a possible increased cancer risk associated with the diagnostic computed tomographic scans they ordered or consented to having performed [8]. Nearly all of our sample of patients seen in the emergency room with mild to moderate pain in the abdomen, pelvis, or flank were not provided information regarding the radiation dose and possible risks associated with diagnostic computed tomographic scans before their acquisition.

The lack of information to patients and our physician colleagues regarding the radiation effects of CT is contributing to a growing economic burden involving CT reimbursements from relatively fixed national health care expenditures. For the market to be more efficient, one must first have a better understanding of all the costs involved.

Lee CI, Foreman HP. The hidden costs of CT bioeffects. (2007) JACR 5:78-79
Excessive CT Scans May Be Dangerous

If you or a family member has been injured, contact a personal injury attorney today. Just fill out InjuryBoard.com's on-line questionnaire and have a personal injury lawyer review your potential personal injury claim - free of charge.

The American College of Radiology does not condone preventative use of CT scans. It released an official statement indicating that no evidence has shown preventative CT scans to be effective or cost-efficient.

Critics of CT scans are quick to point out that most life-threatening illnesses are in advanced stages before their symptoms even show up in a CT scan. They are especially critical of "mobile" CT scan units that travel from location to location. These machines are smaller than the normal CT scan machine, are much slower, and often produce blurry images. Poor image quality can cause anxiety because patients may think they have a medical problem when in fact it is just a blurred image.
Radiation Risks in Children: No Debate

- Tissues are more radiosensitive
- Longer lifetime to manifest radiation-induced injury (cancer, cataracts)
- Each exam (dose) is cumulative
- Same settings: higher dose for children
Adhere to ALARA principle
Current Concerns

• Are CT doses high?
• Is this a problem?
• Strategies to control medical radiation
Radiation Dose Reduction Strategies for CT

• Judicious use of CT
  - avoid unnecessary exams
  - consider alternate modalities
  - focus exams: limit coverage

• Adjust scan techniques
Judicious use of CT: this is extremely complicated

On June 26 and 27, 2008, the World Health Organization (WHO) convened a panel of experts from 20 countries to determine priority needs for ensuring radiation safety in healthcare settings and the expected role of WHO to assist countries in meeting those needs. NCRP's Executive Director, Dr. David A. Schauer, summarized preliminary findings related to medical exposure of the U.S. population, and he served as rapporteur for the meeting.

Representatives from Belgium, Japan, Sweden and the United States reported that ~20 to 50% of diagnostic imaging procedures performed in those countries are not medically "justified" (i.e., they do not meet the relevant referral guidelines or appropriateness criteria).
Radiation Dose Reduction Strategies for CT

• Judicious use of CT

• Adjust scan parameters
  - scan indication
  - scan region/organ system
  - adjust individual parameters
  - simplify scanning
Radiation Dose Reduction Strategies for CT

- Judicious use of CT

- Adjust scan parameters
  - scan indication
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Radiation Dose Reduction Strategies for CT

- Judicious use of CT

- Adjust scan parameters
  - scan indication
  - scan region/organ system
  - adjust individual parameters
  - simplify scanning
Radiation Control: Adjustable CT Parameters

- Tube Current (mA)
- Gantry cycle time (0.5 –1.0 seconds)
- Kilovoltage (kVp)
- Pitch
15 mAs
Conventional and Reduced Radiation Dose of 16-MDCT for Detection of Nephrolithiasis and Ureterolithiasis

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OBJECTIVE. Our purpose was to prospectively compare the reader compatibility and acceptability of a range of reduced-dose 16-MDCT images with standard-dose 16-MDCT images for the detection of nephroureterolithiasis using a dose reduction simulation technique.

SUBJECTS AND METHODS. The study was HIPAA compliant and institutional review board approved. Fifty consecutive patients with suspected nephrolithiasis were recruited to undergo conventional renal stone unenhanced 16-MDCT with at least 160 mA. Noise was then artificially introduced to simulate levels of 70, 100, and 130 mA. Three blinded independent readers interpreted the original and simulated-dose scans for the location and number of renal and ureteral calculi and secondary signs of obstruction using a 5-point confidence scale.

RESULTS. Reader acceptability of scans was inversely related to noise. There was no significant reduction in readers’ confidence in detection or exclusion of renal collecting system calculi with simulated reduction of mA of 70, 100, and 130 compared with the standard-dose study. However, for ureteral calcifications, there was a decrease in confidence for the detection or exclusion of ureterolithiasis at an mA of 70 (35 mAs).

CONCLUSION. An mA as low as 70 (35 mAs) is acceptable for evaluation of nephrolithiasis. However, the evaluation of ureterolithiasis is compromised with an mA of 70.

CT has been used extensively for the examination of patients with suspected urinary obstruction from ureterolithiasis and for the detection of nephrolithiasis. In many practices, CT has virtually replaced conventional radiography for these indications [1-4]. For [8, 9]. However, to our knowledge, it is not known what minimum dose is required for adequate stone detection using 16-MDCT.

Our purpose was to prospectively compare the reader acceptability and confidence of a range of reduced-dose 16-MDCT images with standard-dose 16-MDCT images for
Fig. 2—Effect of noise addition: simulated tube current reduction in 44-year-old obese woman with ileal occlusion.

A. Axial enhanced CT image obtained with 300 mA through lower aspect of ileum shows single right ileal calculus (arrow).

B. With noise addition to simulate tube current of 70 mA, this stone is still evident.

C. Axial CT image at level of cecum shows peritoneal calcification (encircled).

D and E. With simulated tube currents of 150 mA (D) and 70 mA (E), the peritoneal calcification becomes less evident. At simulated tube current of 70 mA (E), increased noise could be mistaken for internal calcification (arrow).
3D Nodule Simulation

Real

Simulated
Simulated Sarcoma Metastases
Results: area under ROC
--- preliminary analysis

Reader 1

Reader 2

Reader 3

TPF vs. FPF graphs for different conditions:
- Original mA, Az = 0.94 (0.02)
- Leveled mA, Az = 0.97 (0.02)
- 50 per, Az = 0.89 (0.03)
- 75 per, Az = 0.95 (0.02)

- Original mA, Az = 0.95 (0.03)
- Leveled mA, Az = 0.97 (0.03)
- 50 per, Az = 0.93 (0.03)
- 75 per, Az = 0.90 (0.04)

- Original mA, Az = 0.92 (0.03)
- Leveled mA, Az = 0.89 (0.04)
- 50 per, Az = 0.92 (0.03)
- 75 per, Az = 0.92 (0.03)
Radiation Dose Reduction Strategies for CT

- Judicious use of CT

- Adjust scan parameters
  - scan indication
  - scan region/organ system
  - adjust individual parameters
  - simplify scanning
Color Coding for KIDS
Weight-Based Pediatric Protocols

Selecting a Pediatric Anatomical Region brings up color selector.
Tube Current Modulation (ATCM)

Angular \((x, y)\)  

Z-axis

Pediatric Chest MDCT Using Tube Current Modulation: Effect on Radiation Dose with Breast Shielding

OBJECTIVE. The purpose of our study was to assess the effect on radiation dose and image noise during pediatric chest 16-MDCT using automatic tube current modulation and bismuth breast shields.

MATERIALS AND METHODS. Age-based chest 16-MDCT was performed on an anthropomorphic phantom representing a 5-year-old child. Two scans were obtained in each of four sequences: first, without a shield; second, with a 2-ply bismuth shield; third, using automatic tube current modulation with a scout image obtained after placement of the shield; and fourth, using automatic tube current modulation with a scout image obtained before placement of the shield. Metal oxide semiconductor field effect transistor technology was used to measure the radiation dose in 20 organ locations. Effective dose was estimated using the console dose-length product. Noise was measured by recording the SD of Hounsfield units in identical regions of interest.

RESULTS. The bismuth breast shield reduced the dose to the breast by 26%. Shielding and automatic tube current modulation reduced the breast dose by 52%. Multiple organ doses were lowest when the shield was placed after the scout radiograph had been obtained. When the shield was placed after the scout image was obtained, the mean noise in the range of shielding increased from 11.4 to 13.1 H (superior mediastinum) and from 10.0 to 12.8 H (heart) \((p < 0.01)\). Increased noise, however, was near the target noise index (measured in SD of Hounsfield units) of 12.0 H (SD). Using automatic tube current modulation, the effective dose was reduced by 35% when the shield was placed after the scout and by 20% when the shield was present in the scout.

CONCLUSION. The greatest dose reduction is achieved by placing the shield after obtaining the scout image to avoid Auto mA compensation due to density of shield. With this technique, image noise increased but remained close to the target noise index.

An estimated 57 million CT examinations were performed in the United States in 2000 [1]. It is also estimated that approximately one quarter of pediatric CT examinations are performed on children under 5 years of age [2,3]. Because of the possibility of malignancy, CT is one of the most widely used medical imaging modalities in pediatrics. However, pediatric CT is associated with an increased risk of second malignancy in the form of childhood leukemia and other pediatric malignancies [4-6]. It is therefore imperative that we strive to reduce the radiation doses to this vulnerable population [7].

Keywords: CT, CT technology, MDCT, pediatric chest CT, phantoms, radiation dose reduction, shielding

DOI:10.2214/AJR.07.2717

The bismuth material for this study was provided by F & L Medical Products.

D. P. Frush received unrestricted research support from GE Healthcare.

Received February 6, 2007; accepted after revision July 22, 2007.

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How Are We Doing?
Pediatric Body MDCT: A 5-Year Follow-Up Survey of Scanning Parameters Used by Pediatric Radiologists

Michael E. Arch
Donald P. Frush

OBJECTIVE. The purpose of this study was to evaluate how pediatric body MDCT scanning parameters (i.e., the principal determinants of radiation dose) have changed since a prior survey conducted in 2001.

MATERIALS AND METHODS. The survey used in this study consisted of 27 questions addressing practice setting, equipment, and scanning parameters including kilovoltage, tube current, and pitch. Members of the Society for Pediatric Radiology (SPR) received an email with a link to the Web-based survey. Respondents were asked to complete only one survey to represent their practice and indicate the number of pediatric radiologists they represent.

RESULTS. Sixty-three responses representing 337 pediatric radiologists were received. Eighty-five percent of respondents practice in a university or children’s hospital. Ninety percent report performing a peak kilovoltage setting of higher than 120 kVp for routine chest or abdomen scans. These values range from 120 kVp to 140 kVp for chest CT and from 120 kVp to 140 kVp for abdomen CT with a mean of 130 kVp. Weight-based adjustments in tube current are used by 98% of respondents. Tube current tends to increase with a patient’s age or weight, with most pediatric body imaging examinations being performed with a tube current of less than 150 mA. The mean tube current used across all age groups decreased between 31 and 61 mAs (p < 0.001) with the largest percentage decreases in patients in the 0-4 years age group.

CONCLUSION. Since 2001, the peak kilovoltage and tube current settings, two principal parameters determining radiation dose, used by SPR members have decreased significantly for pediatric body MDCT. It is a reasonable assumption that these changes are due to efforts to decrease awareness of the risks of radiation.

Before 2002, an estimated 71 million annual pediatric CT examinations were performed in the United States [1]. Since 2002, CT examinations have increasingly been performed in the pediatric population. For example, chest and abdominal examinations of children have increased out of proportion to the frequency of visits to the emergency department in a recent 5-year period [2, 3]. The justification for this increasing use has been questioned in light of the potential risks of radiation exposure to children [4]. Increasing use becomes more problematic if the ALARA (as low as reasonably achievable) principle is not followed and techniques are not appropriately adjusted, especially to the size of the child [4-6]. In community practice, the lack of adjustments was reported by Paterson et al. [7, 8]. As a follow-up to these data, Hellingsworth et al. [9] surveyed members of the Society for Pediatric Radiology (SPR) and found a greater use of age-adjusted body CT examinations. Although assessing the impact of dose reduction strategies to minimize the risks of radiation has been emphasized [10, 11], CT radiation awareness continues to be an important issue [3, 12]. To our knowledge, no comparable survey assessing routine pediatric MDCT examination parameters has been performed since 2001. Our purpose was to assess current pediatric body MDCT practice, emphasizing parameters that determine radiation dose, and compare this with practice as surveyed in 2001 [8].

Materials and Methods

The Web-based survey consisted of questions related to pediatric body MDCT. Institutional review board exemption was obtained because the survey results remained anonymous. This Web-based
SPR Survey 2001 vs 2006: kVp

Fig. 2—Peak kilovoltage routinely used for pediatric chest MDCT. Amount used has decreased from 2001 [8] to 2006, with 100% of those indicating a value in 2006 survey selecting 120 kVp or less (p < 0.001).

Fig. 3—Peak kilovoltage routinely used for pediatric abdominal MDCT. Amount used has decreased from 2001 [8] to 2006, with 100% of those indicating a value in 2006 survey selecting 120 kVp or less (p < 0.001).
SPR Survey 2001 vs 2006: mA

**Figure 8**—Mean tube current used by members of Society for Pediatric Radiology for pediatric chest MDCT over several age ranges compared with 2001 [8]. Mean tube current used decreased between 32 and 61 mA for each age range.

**Figure 9**—Mean tube current used by members of Society for Pediatric Radiology for pediatric abdominal MDCT over several age ranges compared with 2001 [8]. Mean tube current decreased between 31 and 55 for each age range.
Guidelines for Pediatric CT

The Alliance for Radiation Safety in Pediatric Imaging

Let’s image gently when we care for kids! The image gently Campaign is an initiative of the Alliance for Radiation Safety in Pediatric Imaging. The campaign goal is to change practice by increasing awareness of the opportunities to lower radiation dose in the imaging of children.

ONE SIZE DOES NOT FIT ALL...

There's no question: CT helps us save kids’ lives!

But, when we image, radiation matters.
* Children are more sensitive to radiation
* What we do now, lasts their lifetimes

So, when we image, let’s image gently
* More is often not better
* When CT is the right thing to do:
  * Child size the kid up and mA
  * One scan (single phase) is often enough
  * Scan only the indicated area

Let’s image gently....
Take Home Points

• Imaging is helpful
• Radiation is necessary
• Wise to consider any radiation a risk
• There are many ways to be safe
• Radiologists are consultants