RECURRENT CT, CUMULATIVE RADIATION EXPOSURE, AND ASSOCIATED RADIATION-INDUCED CANCER RISKS FROM CT OF ADULTS

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Introduction

- United States, 2006 : estimated 62 million CT
  (CT : 15% imaging procedures, 50% collective radiation dose)

  CT scanning: a major source of radiation exposure. Semin Ultrasound CT MR 2002;23:402–410

  In the patients :
  30% > 3 times of CT
  7% > 5 times of CT
  4% > 9 times of CT

  Radiation doses from small-bowel follow-through and abdominopelvic MDCT in Crohn's disease. AJR Am J Roentgenol 2007;189:1015– 1022.

  Specific populations : chronic conditions(Crohn disease, and renal colic) high rates of repeat imaging

- Attention has recently focused on the potential risks of radiation-induced carcinogenesis from diagnostic radiology

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- Current investigation :
  1.Radiation-induced cancer risks :
  particular organs or populations

  2.The emphasis on pediatric patients :
  higher dose for a fixed set of imaging parameters ;
  higher cancer risk per unit dose compared with adult populations

  3. Not been well developed in the United States :
  - individual patient's cumulative exposure
  - patient's associated radiation-induced cancer risk.

- The purpose of this study :
  Cumulative radiation exposure, lifetime attributable risk (LAR) of radiation-induced cancer from CT scanning of adult patients

Materials and Methods

- **Study Design and Setting :**
  - retrospective cohort study
  - 752-bed adult urban tertiary academic medical center and its associated outpatient cancer center.

- **Cohort Selection :**
  - All patients who underwent diagnostic CT from January 1, 2007 ~ December 31, 2007, in any care setting (inpatient, outpatient, or emergency department).

- **Data Collection and Analysis :**
  -Radiology information system (RIS) database :
  21.8-year (May 28, 1986, and March 10, 2008) ,
  excluding interventional CT procedures

  -Sex and date of birth were obtained, and exposure ages were calculated as the difference between each examination completion date and the date of birth.

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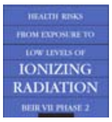
1. CT examination counts :
   elimination : not a unique radiation exposure
   - Abdomen + pelvis codes → single abdomen-pelvis examination
   - Thoracic spine ± chest CT → single code
   - Lumbar spine ± abdominal CT → single code

Table 1

CT Effective Dose Estimates Based on Anatomic Coverage Region

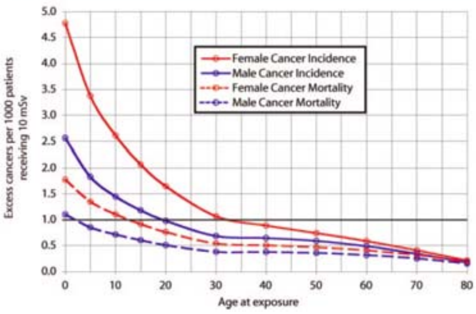
Covered Anatomy	Assigned Effective Dose per CT Examination (mSv)
Head, face	2
Cervical spine, neck	2
Chest, pulmonary embolus, thoracic spine	8
Abdomen alone (no pelvis)	7.5
Pelvis alone (no abdomen)	7.5
Abdomen and pelvis, lumbar spine	15
Extremity	0

2. Risk estimation from effective doses :



Biological Effects of Ionizing Radiation (BEIR) VII methodology

Figure 1



3. Clinical classification of high-risk patients :

- Use billing and electronic order entry data
  → the highest estimated levels of cancer risk from CT exposures (LAR of cancer incidence > 1%)
- Collect all ICD9 (RIS database)
  →radiology study : November 5, 1999~September 9, 2008
- Malignancy history : ICD9 malignant neoplasm categories 140–208
- Metastatic disease : ICD9 categories 197–198

Results

- **Cohort Characteristics :**

Table 2

Patient Demographics in the Cohort

Sex	No. of Patients	Minimum Age (y)	Mean Age (y)	Maximum Age (y)	Standard Deviation
Female	17603	11	56.5	108	17.5
Male	13859	16	57.4	101	17.4
Both	31462	11	56.9	108	17.5

Note.—Cohort of all patients undergoing a diagnostic CT examination in 2007.

Figure 2

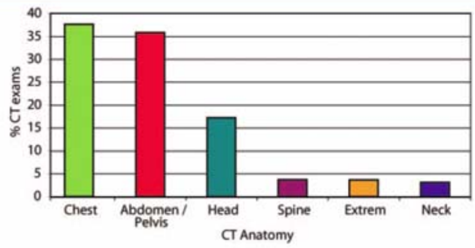


Figure 2: Distribution of anatomic locations for the 190 712 CT examinations captured over the 22-year study period in the cohort of 31 463 patients. *Extrem* = Extremities.

- **Cumulative CT Survey Results :**

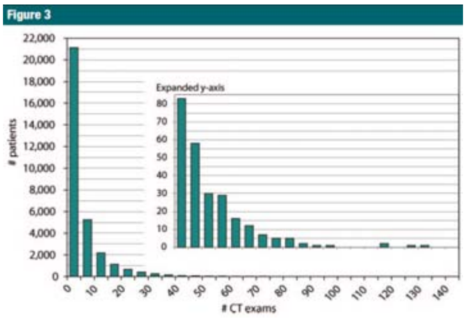
Table 3

Summary Data for the Distributions in Figures 3–5

Parameter	Cumulative CT Examination Count	Cumulative Effective Dose (mSv)	LAR of Cancer Incidence (%)	LAR of Cancer Mortality (%)
Median	3	24	0.13	0.08
Mean	6.1	54.3	0.3	0.2
99th Percentile	38	399	2.7	1.6
Maximum	132	1375	12.0	6.7

- **Cumulative CT Examination Counts :**

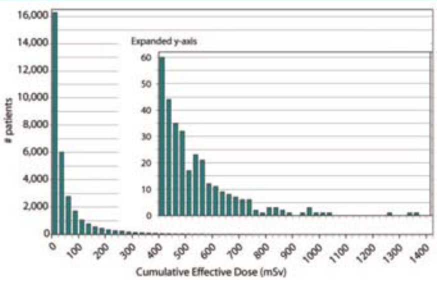
Figure 3



33% ≥ 5 CT examinations ; 5% ≥ 22 examinations ; 1% ≥ 38 examinations.

- **Estimated Cumulative Effective Doses :**

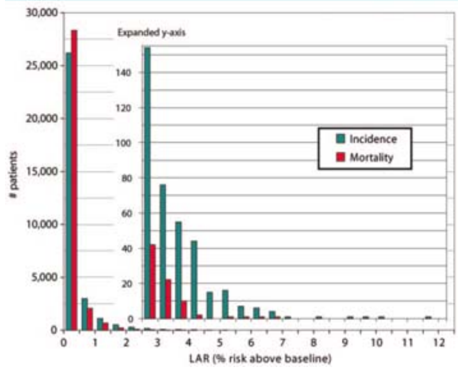
Figure 4



15% ≥ 100 mSv, 4% ≥ 250 mSv, and 1% ≥ 399 mSv

- **Estimated Cumulative Radiation-induced Cancer Risks :**

Figure 5



Cancer incidence :
7% LAR ≥ 1%,
1% LAR ≥ 2.7%

Cancer mortality :
3% LAR ≥ 1%,
1% LAR ≥ 1.6%.

- **Estimated Cumulative Risks to the Cohort (Total 31462):**
  1. BEIR VII :
     baseline cancer incidence of 42% , cancer mortality of 20% (U.S.)
     →baseline cancer rates : 13 214 cancers, 6292 fatal cancers.
  2. Table 3

Summary Data for the Distributions in Figures 3–5

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98 additional radiation-induced cancers, 62 fatal cancers.
(0.7% of expected cancer incidence, 1% of cancer mortality)

4. 315 patients in the top percentile of cumulative LAR :
   LARs : 2.7% ~ 12% above the 42% baseline
   (equates to 6%–22% total expected cancer incidence)

- **Disease Classification in Frequently Imaged Patients :**

Figure 6

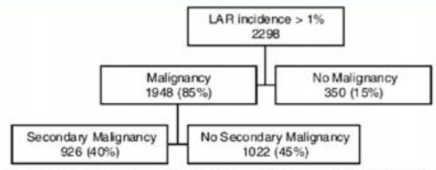
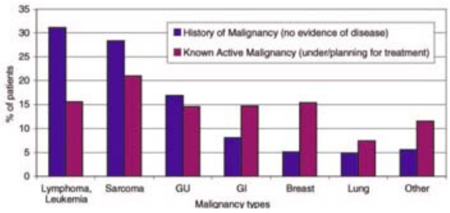


Figure 6: Chart shows classification according to billing ICD9 code for the 2298 patients with an estimated LAR of cancer incidence greater than 1%. Patients with malignancy have an ICD9 code within categories 140–208. Patients with secondary malignancy have an ICD9 code in categories 197–198.

- Since March 2008 : electronic order pertaining to malignancy

1547 (LAR>1%) { 469 (30%) history of malignancy (no evidence of disease)
1078 (70%) known active malignancy (under/planning for treatment)



- 584 cancer patients without evidence of disease, or 25% of the cohort with LAR greater than 1%

- 350 patients (15%) :
  - No malignancy history
  - Estimated LAR > 1%
  - Only 12% had all of their repeat imaging of the same anatomic region

Figure 8

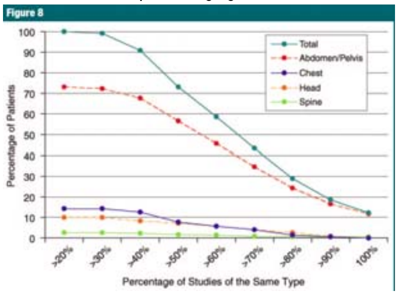


Table 4

Sample Patient Detail in Non-Cancer Patients

Patient No./Sex/Age (y)	LAR Incidence (%)	LAR Mortality (%)	No. of Examinations: Total	Abdomen-Pelvis	Chest	Head	Spine	Abstracted Medical History
1/F/45	9.6	5.3	70	69	0	1	0	Recurrent pyelonephritis, lithotripsy, stone extraction, ulcerative colitis
2/F/49	5.2	3.1	81	27	24	21	1	End-stage renal disease, hemodialysis, lupus
3/F/34	4.4	2.2	35	21	10	1	0	Chronic pancreatitis and Whipple operation, ventral hernias, mesh infections, empyema
4/F/58	3.9	2.5	88	20	20	35	7	Lupus, osteogenesis imperfecta, seizures, stroke
5/F/46	3.8	2.0	28	26	1	1	0	Crohn, hemicolectomy, chronic abdominal pain, heart transplant
6/M/33	3.6	2.0	36	32	2	1	0	Necrotizing pancreatitis, enterocutaneous fistula
7/M/27	2.7	1.4	37	7	22	4	3	Cystic fibrosis, lung transplants
8/F/42	2.5	1.4	38	11	10	12	0	Lupus, asthma, seizures, pulmonary embolus, pulmonary hypertension
9/F/34	2.4	1.3	16	15	1	0	0	Gastric bypass, small bowel obstructions
10/F/24	2.2	1.1	45	2	5	36	0	Acute disseminated encephalomyelitis, ventriculoperitoneal shunt
11/M/54	2.0	1.2	37	19	2	12	0	Renal transplant, hemodialysis, abdominal abscess
12/F/44	1.9	1.1	48	3	21	5	0	Recurrent chest pain, sickle-β thalassemia, emphysema, pulmonary embolus
13/F/55	1.9	1.2	37	11	5	18	1	End-stage renal disease, human immunodeficiency virus, ruptured middle cerebral artery aneurysm
14/F/81	1.7	1.4	40	30	8	0	0	Perforated diverticulitis, congestive heart failure, pulmonary hypertension
15/F/62	1.6	1.1	29	11	10	5	0	Bronchiolitis obliterans organizing pneumonia, perinephric hematoma
16/F/49	1.5	0.9	17	9	1	3	2	Diverticulitis, colectomy, ventral hernia repair, recurrent abdominal pain
17/F/53	1.4	0.9	13	4	0	0	8	Lumbar fusion, back pain
18/F/58	1.4	0.9	18	12	2	1	3	Diverticulitis, trauma
19/F/57	1.3	0.9	19	10	4	4	0	Sarcoidosis, pulmonary hypertension, intraductal papillary mucinous neoplasm
20/F/56	1.2	0.8	24	6	11	2	0	Endocarditis, aortic valve replacement, hepatitis C
21/F/58	1.1	0.7	25	5	9	5	2	Chronic obstructive pulmonary disease, chronic pancreatitis
22/F/31	1.1	0.5	9	5	1	2	0	Flank pain, asthma, migraines
23/F/47	1.1	0.6	21	6	1	12	1	Perforated appendicitis and complications, stroke, ventriculoperioneal shunt
24/M/55	1.1	0.6	19	8	7	2	1	Type A aortic dissection repair
25/M/53	1.0	0.6	36	6	4	19	5	Alcoholic, frequent trauma

Discussion

- High rates of recurrent CT imaging :
  - 33% ≥ 5 CT, 5% ≥ 22 CT
  - 15% cumulative CT effective doses ≥ 100 mSv
  (convincing epidemiologic evidence of increased cancer risk)
  Cancer risks attributable to low doses of ionizing radiation: assessing what we really know. Proc Natl Acad Sci U S A 2003;100: 13761–13766.

- *Brenner DJ, Hall EJ. Computed tomography: an increasing source of radiation exposure. N Engl J Med 2007;357:2277–2284.*
  -1.5%–2.0% of all U.S. population cancers may be caused by CT radiation exposure.
  - BEIR VII : 0.7% of our cohort's lifetime cancers may be caused by CT(includes only past exposures at a single institution, purely adult population)

- **Limitations and Underlying Controversies :**

  1.Cohort setting :
  single adult tertiary care institution
  → may not be generalizable to other institutions
  (different patient mixes, different provider attitudes to CT imaging)

  2. Underestimated cumulative examination counts and doses :
  - no data before 22-year records
  - only diagnostic CT (half of the collective population dose), excluding interventional radiology, nuclear medicine, fluoroscopy, and radiography studies.

3. Dosimetry :
- CT radiation doses : depend on scanner technology and imaging parameters used and may vary with patient size
- No dose adjustment : particular scanner type or date of examination
- Universal dosimetry estimation :
  might alter the shape and scale of the cumulative dose distribution.
- The effects of organ-specific absorbed doses better than effective dose estimates for individual
- Better still would be to capture and archive dose parameters
  → patient-specific dose estimates

- Cancer risk models :

  1.Controversy persists about the response of low-dose radiation
  - BEIR VII , most commonly used linear-no-threshold model

  2.Limitation of the BEIR VII :
  - accuracy of the Life Span Study dosimetry values
  - Japanese v.s. U.S. , differences in baseline cancer rates
  - low doses/ protracted exposures v.s. single acute exposure(LSS), uncertainty of dose and dose rate effectiveness

  3. Without incorporating known diagnoses that might shorten a patient's life
  → Future study : incorporate underlying disease mortality into LAR calculations.

Summary and Recommendations

- Patients who undergo large amounts of recurrent CT :
  measures to control subsequent exposures

  - technical developments (automated tube current modulation, beam filtration, and adaptive collimation)

  - imaging parameter selection (decreasing tube potential, tube current)

  - protocol modifications (reducing duplicate coverage regions, multiple-pass scanning)

  - reduce CT utilization : broadly applicable imaging algorithms, nonionizing imaging alternatives

- The risks of an individual study should be viewed as part of the patient's past (and predicted future) cumulative exposure.

- Educate physicians and inform the risk-benefit decision :

  As a first step :
  Inspection of the CT history

  As a next step :
  The developing real-time decision support tools to identify high-risk patients, provide cumulative exposure and risk estimates

~Thank you~