Use of Medical Imaging Procedures With Ionizing Radiation in Children A Population-Based Study

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Use of Medical Imaging Procedures With Ionizing Radiation in Children

A Population-Based Study

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Objective: To determine population-based rates of the use of diagnostic imaging procedures with ionizing radiation in children, stratified by age and sex.

Design: Retrospective cohort analysis.

Setting: All settings using imaging procedures with ionizing radiation.

Patients: Individuals younger than 18 years, alive, and continuously enrolled in UnitedHealthcare between January 1, 2005, and December 31, 2007, in 5 large US health care markets.

Main Outcome Measures: Number and type of diagnostic imaging procedures using ionizing radiation in children.

Results: A total of 355 088 children were identified; 436 711 imaging procedures using ionizing radiation were performed in 150 930 patients (42.5%). The highest rates of use were in children older than 10 years, with frequent use in infants younger than 2 years as well. Plain radiography accounted for 84.7% of imaging procedures performed. Computed tomographic scans—associated with substantially higher doses of radiation—were commonly used, accounting for 11.9% of all procedures during the study period. Overall, 7.9% of children received at least 1 computed tomographic scan and 3.5% received 2 or more, with computed tomographic scans of the head being the most frequent.

Conclusions: Exposure to ionizing radiation from medical diagnostic imaging procedures may occur frequently among children. Efforts to optimize and ensure appropriate use of these procedures in the pediatric population should be encouraged.

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THE RAPID GROWTH IN USE OF medical diagnostic imaging procedures such as computed tomography (CT) has led to concern about low-dose ionizing radiation exposure in adults.[1-5] Despite widespread discussions about similar hazards for younger patients, contemporary data on the use of such imaging procedures in children are limited. Infants and children are at higher risk for future malignant neoplasms as compared with adults because their developing tissues are more sensitive to radiation and their longer expected life spans allow additional time for the emergence of detrimental effects.[6-10]

Accordingly, we set out to examine patterns of the use of diagnostic imaging procedures with ionizing radiation among children. We used comprehensive inpatient and outpatient claims data sources from UnitedHealthcare, a large health care organization that administers benefits to millions of families across the United States. Because methods for accurately quantifying the effective dose of ionizing radiation exposure[11] (ie, its detrimental biological effect) in children are controversial, we focused primarily on describing the number and types of these procedures being used. As such, our goals were

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the following: (1) to determine overall population-based rates of the use of imaging procedures with ionizing radiation in individuals younger than 18 years; (2) to explore their use across age groups and sex; and (3) to identify the most frequently used procedures.

METHODS

STUDY DESIGN

We conducted an investigator-initiated, retrospective cohort study using exhaustive inpatient and outpatient claims data from UnitedHealthcare. These data were collected between January 1, 2005, and December 31, 2007, from 5 large regional markets: Arizona; Dallas, Texas; Orlando, Florida; South Florida; and Wisconsin. These markets were specifically selected because of their size, the stability of their enrollment population, and the similarity of their insurance products as well as to provide a degree of geographic diversity. The study population included all individuals younger than 18 years at the beginning of the study period who were alive and continuously enrolled in one of the programs administered by UnitedHealthcare during the study period. To obtain a true denominator population, we included all individuals who were continuously enrolled regardless of whether they submitted a claim during the study period. After removing all personal identifiers, data were provided to the investigators for independent analysis and interpretation. The institutional review board of the University of Michigan approved this study protocol and waived the requirement for informed consent.

STUDY OUTCOMES

All claims from hospitals, outpatient facilities, and physician offices that were submitted during the study period were queried for *Current Procedural Terminology* codes that identified imaging procedures using radiation exposure (Radiology Schedule–Diagnostic Imaging and Nuclear Medicine codes 70010-76499 and 78000-79999; and Medicine Schedule–Cardiovascular and Noninvasive Vascular Diagnostic Studies codes 92950-93799 and 93875-94005).[12] Procedures were included regardless of whether they were performed for diagnostic or therapeutic indications (eg, interventional radiological procedures). However, claims related to the specific delivery of radiation for a therapeutic purpose and *not* for imaging (eg, total body irradiation prior to stem cell transplantation) were excluded. In cases where the *Current Procedural Terminology* code for a procedure changed during the study period, all versions of the code were included.

We obtained the following information from each claim: (1) age; (2) sex; (3) the market where the service was performed; and (4) the location of the service (hospital inpatient, hospital outpatient, and physician's office). We categorized these procedures into mutually exclusive categories based on the technology used (plain radiography, CT, fluoroscopy and/or angiography, and nuclear medicine scans) and anatomical area of focus (chest [including cardiac imaging], abdomen, pelvis, extremity, head and neck [including brain imaging], multiple areas [including whole-body scans], and nonspecified). To be as conservative as possible and to avoid the potential of overestimating the number of procedures from duplicate claims, we limited individuals to 1 procedure per day for the same type of technology (eg, CT) performed on the same anatomical area (eg, chest).

STATISTICAL ANALYSIS

We focused on describing the number and types of imaging procedures performed in the study population using simple descriptive statistics. Specifically, we calculated population-based rates of use where the numerators were the cumulative number of imaging procedures performed in an individual and the denominators were the total number of eligible children enrolled throughout the study period. For these analyses, children were categorized based on their age at the beginning of the study period (ages 0 to <2, 2 to <5, 5 to <10, 10 to <15, and 15 to <18 years) and sex. Imaging procedures were then categorized by the type of technology used. All statistical analyses were carried out with the use of SAS version 9.2 statistical software (SAS Institute, Inc, Cary, North Carolina).

RESULTS

DEMOGRAPHIC CHARACTERISTICS

We identified 355 088 children continuously enrolled in a program administered by UnitedHealthcare during the study period. The mean (SD) age was 9.0 (4.9) years, and 181 795 children (51.2%) were boys. The largest proportion of the study population was located in the Dallas market area (124 079 children [34.9%]), while the smallest proportion came from the Orlando market area (45 466 children [12.8%]). Overall, the percentage of subjects who underwent at least 1 diagnostic imaging procedure using ionizing radiation ranged from 39.4% in the Orlando market area to 43.2% in the Dallas market area.

IMAGING PROCEDURE VOLUMES

During the 3-year study period, a total of 436 711 imaging procedures were performed in 150 930 children (42.5%) (**Table 1**), resulting in an annual rate of 410 procedures per 1000 children. During the study period, 89 618 children (25.2%) underwent 2 or more of these procedures, while 56 754 (16.0%) underwent 3 or more. The highest annual rates of use were generally in children aged 10 years and older. Use of these procedures also was generally higher among boys than girls (80 638 [44.4%] vs 70 292 [40.6%], respectively; $P < .001$). Although the overall proportion of patients was smaller, similar patterns of use across age and sex groups were observed in children who underwent at least 2 imaging procedures and those who underwent 3 or more.

Procedure use was stratified by the type of imaging procedure across age and sex groups. Rates varied substantially based on the types of procedures, with 141 480 children (39.8%) receiving at least 1 plain radiographic examination (**Table 2**), 28 107 (7.9%) receiving at least 1 CT scan (**Table 3**), 7492 (2.1%) receiving at least 1 fluoroscopic or angiographic procedure (**Table 4**), and 2607 (0.7%) receiving at least 1 nuclear medicine scan (**Table 5**). Plain radiography also was the most commonly repeated of these procedures: 79 209 children (22.3%) underwent 2 or more of these studies. Similarly, CT scans were frequently repeated, with 12 494 children (3.5%) undergoing 2 or more of these studies. While use of CT was more frequent overall in boys, use in the group aged 15 to 17 years was higher in girls than in boys (93/1000 person-years vs 85/1000 person-years, respectively). Finally, overall patterns of plain radiography and nuclear medicine scans followed those described earlier for all imaging procedures, with use most frequent in infants younger than 2 years and children aged 10 years and older. However, CT scans were used less frequently in young children. In contrast, the largest proportion of

Table 1. Characteristics of Patients Undergoing All Procedures Using Ionizing Radiation

Characteristic	All Patients, No. (%)	Rate of Procedure Use, No./1000 Person-years	Patients, No. (%)		
			≥1 Radiology Procedure	≥2 Radiology Procedures	≥3 Radiology Procedures
All	355 088 (100.0)	410	150 930 (42.5)	89 618 (25.2)	56 754 (16.0)
Age, y					
0 to <2	31 810 (9.0)	337	12 920 (40.6)	6768 (21.3)	3786 (11.9)
2 to <5	51 970 (14.6)	279	18 076 (34.8)	9185 (17.7)	5210 (10.0)
5 to <10	98 358 (27.7)	328	37 149 (37.8)	20 706 (21.1)	12 514 (12.7)
10 to <15	112 238 (31.6)	512	53 918 (48.0)	34 650 (30.9)	23 307 (20.8)
15 to <18	60 712 (17.1)	506	28 867 (47.5)	18 309 (30.2)	11 937 (19.7)
Sex					
Male	181 795 (51.2)	442	80 638 (44.4)	48 709 (26.8)	31 438 (17.3)
Female	173 293 (48.8)	377	70 292 (40.6)	40 919 (23.6)	25 326 (14.6)
Service market					
Arizona	65 943 (18.6)	407	28 429 (43.1)	16 794 (25.5)	10 463 (15.9)
Dallas, Texas	124 079 (34.9)	422	53 639 (43.2)	32 148 (25.9)	20 550 (16.6)
Orlando, Florida	45 466 (12.8)	373	17 907 (39.4)	10 447 (23.0)	6537 (14.4)
South Florida	52 320 (14.7)	414	22 231 (42.5)	13 352 (25.5)	8536 (16.3)
Wisconsin	67 280 (19.0)	412	28 724 (42.7)	16 877 (25.1)	10 668 (15.9)

Table 2. Characteristics of Patients Undergoing Plain Radiography

Characteristic	All Patients, No. (%)	Rate of Plain Radiography Use, No./1000 Person-years	Patients, No. (%)		
			≥1 Plain Radiographic Examination	≥2 Plain Radiographic Examinations	≥3 Plain Radiographic Examinations
All	355 088 (100.0)	347	141 480 (39.8)	79 209 (22.3)	48 215 (13.6)
Age, y					
0 to <2	31 810 (9.0)	289	12 026 (37.8)	5987 (18.8)	3209 (10.1)
2 to <5	51 970 (14.6)	237	16 680 (32.1)	8058 (15.5)	4440 (8.5)
5 to <10	98 358 (27.7)	287	34 891 (35.5)	18 476 (18.8)	10 805 (11.0)
10 to <15	112 238 (31.6)	441	51 232 (45.6)	31 297 (27.9)	20 394 (18.2)
15 to <18	60 712 (17.1)	395	26 651 (43.9)	15 391 (25.4)	9367 (15.4)
Sex					
Male	181 795 (51.2)	379	76 084 (41.9)	43 645 (24.0)	27 316 (15.0)
Female	173 293 (48.8)	313	65 396 (37.7)	35 564 (20.5)	20 899 (12.1)

children undergoing fluoroscopic and/or angiographic studies were younger than 2 years—especially among infant girls.

Overall, plain radiography accounted for 84.7% of the studies that were performed; CT scans were the next most commonly used modality, accounting for 11.9% of imaging procedures, followed by fluoroscopic and/or angiographic studies (2.5%) and then nuclear medicine scans (0.9%). However, this pattern of use varied across different age categories. For example, CT scans were used much more frequently in older groups, increasing to 17.6% of all imaging studies performed in children aged 15 years to younger than 18 years.

Finally, **Table 6** shows specific data on the 10 most frequently used studies for the 4 different categories of imaging procedures. Chest radiography was the most common procedure performed overall, at an annual rate of 68 procedures per 1000 children. This was followed by plain radiography of extremity areas, the spine, and the abdomen. By far, the highest annual rate of use of CT scans involved studies of the head, followed by the abdomen and pelvis. Computed tomographic scans of the abdomen and pelvis, in particular, increased dramatically with age, from 5 procedures performed per 1000 children annually in patients aged 0 to 1 year to 41 procedures per 1000 children in patients aged 15 years to younger than 18 years. The use of fluoroscopic and/or angiographic studies and nuclear medicine scans was infrequent overall.

COMMENT

To our knowledge, we report the first large, population-based study examining the use of diagnostic imaging procedures with low-dose ionizing radiation specifically in a pediatric population. Among 355 088 children across 5 large health care markets in the United States, we found that use of these procedures during a 3-year study period was frequent, with at least 1 of these procedures being performed in 42.5% of children. Importantly, many children underwent more than 1 procedure. Based on these data, the average child in this study population will have

Table 3. Characteristics of Patients Undergoing Computed Tomography

Characteristic	All Patients, No. (%)	Rate of CT Use, No./1000 Person-years	Patients, No. (%)		
			≥1 CT Scan	≥2 CT Scans	≥3 CT Scans
All	355 088 (100.0)	49	28 107 (7.9)	12 494 (3.5)	4015 (1.1)
Age, y					
0 to <2	31 810 (9.0)	27	1675 (5.3)	439 (1.4)	134 (0.4)
2 to <5	51 970 (14.6)	29	2620 (5.0)	906 (1.7)	269 (0.5)
5 to <10	98 358 (27.7)	32	5700 (5.8)	2314 (2.4)	568 (0.6)
10 to <15	112 238 (31.6)	57	10 342 (9.2)	4802 (4.3)	1569 (1.4)
15 to <18	60 712 (17.1)	89	7770 (12.8)	4033 (6.6)	1475 (2.4)
Sex					
Male	181 795 (51.2)	50	15 054 (8.3)	6358 (3.5)	2110 (1.2)
Female	173 293 (48.8)	47	13 053 (7.5)	6136 (3.5)	1905 (1.1)

Abbreviation: CT, computed tomography.

Table 4. Characteristics of Patients Undergoing Fluoroscopy

Characteristic	All Patients, No. (%)	Rate of Fluoroscopy Use, No./1000 Person-years	Patients, No. (%)		
			≥1 Fluoroscopic Study	≥2 Fluoroscopic Studies	≥3 Fluoroscopic Studies
All	355 088 (100.0)	10	7492 (2.1)	1560 (0.4)	666 (0.2)
Age, y					
0 to <2	31 810 (9.0)	19	1137 (3.6)	256 (0.8)	123 (0.4)
2 to <5	51 970 (14.6)	10	1137 (2.2)	239 (0.5)	88 (0.2)
5 to <10	98 358 (27.7)	7	1483 (1.5)	251 (0.3)	107 (0.1)
10 to <15	112 238 (31.6)	8	2006 (1.8)	411 (0.4)	178 (0.2)
15 to <18	60 712 (17.1)	14	1729 (2.8)	403 (0.7)	170 (0.3)
Sex					
Male	181 795 (51.2)	9	3277 (1.8)	750 (0.4)	327 (0.2)
Female	173 293 (48.8)	11	4215 (2.4)	810 (0.5)	339 (0.2)

Table 5. Characteristics of Patients Undergoing Nuclear Medicine Scans

Characteristic	All Patients, No. (%)	Rate of Nuclear Scan Use, No./1000 Person-years	Patients, No. (%)		
			≥1 Nuclear Medicine Scan	≥2 Nuclear Medicine Scans	≥3 Nuclear Medicine Scans
All	355 088 (100.0)	4	2607 (0.7)	933 (0.3)	184 (0.1)
Age, y					
0 to <2	31 810 (9.0)	2	141 (0.4)	38 (0.1)	8 (0.03)
2 to <5	51 970 (14.6)	2	179 (0.3)	68 (0.1)	21 (0.04)
5 to <10	98 358 (27.7)	2	345 (0.4)	120 (0.1)	31 (0.03)
10 to <15	112 238 (31.6)	5	1041 (0.9)	420 (0.4)	67 (0.1)
15 to <18	60 712 (17.1)	7	901 (1.5)	287 (0.5)	57 (0.1)
Sex					
Male	181 795 (51.2)	3	1063 (0.6)	370 (0.2)	77 (0.04)
Female	173 293 (48.8)	4	1544 (0.9)	563 (0.3)	107 (0.1)

received more than 7 procedures by the time he or she reaches age 18 years. While plain radiography—which is associated with much lower levels of radiation exposure—was responsible for most procedures, the use of other types of studies such as CT was not rare.

The National Research Council's *Biological Effects of Ionizing Radiation VII Phase 2* report[13] cautions that there is no lower threshold of exposure to radiation that has been identified as without risk and that repeated exposure increases risk in a linear fashion. Furthermore, studies suggest that the hazards of radiation may be greater in children than in adults.[6-8,14-16] For example, Brenner et al[7] estimated that the risk of fatal malignant neoplasms from radiation exposure with abdominal CT was 8-fold higher in the first year of life as compared with the risk in a 50-year-old adult. This results primarily from children having greater sensitivity to the effects of radiation owing to growing tissues and having a longer life expectancy than adults, allowing more time for the latent effects of radiation to emerge.

Table 6. Most Commonly Performed Procedures by Imaging Modality

Imaging Modality	Anatomical Area or Procedure	Rate of Procedure Use, No./1000 Person-years
Plain radiography	Chest	68
	Hand	35
	Foot	32
	Wrist	30
	Spine	28
	Knee	23
	Ankle	22
	Abdomen	17
	Elbow	13
	Forearm	12
Computed tomography	Head	15
	Abdomen	10
	Pelvis	9
	Maxillofacial area	6
	Spine	3
	Chest	2
	Neck	1
	Skull	1
	Lower extremity	1
	Upper extremity	0.4
Fluoroscopic studies	Upper gastrointestinal tract study	2.4
	Urethrocystography	2.0
	Fluoroscopic evaluation of pharynx and/or esophagus	0.8
	Fluoroscopic guidance for spinal injection	0.6
	Needle localization radiography	0.5
	Left heart catheterization	0.5
	Fluoroscopic guidance for central venous access device placement	0.4
	Urography	0.4
	Barium enema	0.3
	Cardiac electrophysiology procedures	0.1
Nuclear medicine studies	Bone or joint	1.5
	Thyroid	1.2
	Hepatobiliary ductal system	0.4
	Gastric emptying	0.2
	Myocardial perfusion imaging (single-photon emission computed tomography)	0.1
	Ventilation-perfusion scan	0.1
	Gastroesophageal reflux study	0.1
	Intestine imaging (eg, ectopic gastric mucosa, Meckel localization, volvulus)	0.04
	Lung perfusion imaging	0.04
	Brain imaging (single-photon emission computed tomography)	0.04

The risks of radiation exposure in children are not restricted to the development of cancer. For example, repeated head CT that includes imaging of the lens of the eye may increase the risk of later cataract formation. Concern for the possibility of later developmental and other nonmalignant problems has also been raised. More than 3000 children in this study population—1.0% of the subjects—received 2 or more head CTs during the 3-year study period.

A key finding from our analysis was that most imaging procedures performed in this study population were plain radiography, which typically delivers a low dose of radiation in comparison with other techniques. Yet, while the use of CT scans, nuclear medicine scans, and fluoroscopic and/or angiographic procedures was much less common, it was not rare. In particular, CT scans were used in 7.9% of the study population and their use increased dramatically in older groups. As such, the overall contribution of these imaging procedures to the long-term risks of radiation should not be overlooked. This is particularly true since their use appears to be concentrated in a minority of individuals who may undergo repeated studies.

Of the imaging procedures we examined, CT scans may be the most important from the standpoint of radiation exposure. Nationally, the use of CT has rapidly grown over time owing to an increased availability of CT scanners and a lower threshold for ordering these studies in routine clinical practice.[6,17] Although there is evidence that CT volumes in pediatric hospitals have decreased since 2003 relative to the total number of cross-sectional imaging examinations, the absolute trend in use is less clear.[18] If one were to extrapolate our findings to the pediatric population of the United States,[19] 5.8 million children younger than 18 years would be expected to undergo at least 1 CT scan during a 3-year period. Furthermore, nearly 2.6 million would undergo 2 or more CT scans. The average child in this study population received 0.86 CT scans by the time they reached age 18 years. Importantly, these findings extend results recently reported by the congressionally chartered National Council on Radiation Protection and Measurements, which estimated that 8% to 10% of CT scans in the United States are performed in children but did not examine rates of use longitudinally over time within the same child or describe the specific procedures used.[20]

These data reinforce the importance of judicious use of imaging procedures with ionizing radiation, particularly in children. Numerous regulatory groups and publications have highlighted the importance of the concept of ALARA—as low as reasonably achievable—in the application of radiation for imaging procedures.[6] However, recent studies in the literature suggest that this practice is not being used broadly or cohesively in adult imaging.[3,21] We suspect that the same is true for pediatric imaging. For many types of imaging procedures, the development of age- and weight-dose protocols has been lacking, although this may be less of a problem in pediatric hospitals. In the case of CT scans, there is concern that these protocols are not yet widely applied. The Image Gently and Step Lightly programs[22] are important educational campaigns that are enlisting physicians and parents to reduce radiation exposure in children.

Appropriate use of these procedures requires balancing the long-term risks inherent in radiation exposure with the necessity for making clinical decisions at the bedside. Developing better guidelines for these procedures may help guide clinicians struggling to determine the best role for these studies. For example, CT scans have revolutionized the management of head trauma in children. Having either too high or too low a threshold for ordering a CT scan in this clinical situation may be problematic. Several studies have recently examined the use of head CT in this context[23-29] and have derived decision rules for its use based on identifying clinically important traumatic brain injuries, suggesting that CT can be avoided in many children presenting to the emergency department with head trauma.

Several limitations to this study should be noted. First, we used administrative claims data. While this meant that we were able to exhaustively capture information on the use of imaging procedures in the study population, we do not know the clinical context under which these procedures were ordered. We therefore cannot comment on their appropriateness. However, the intent of our study was to examine contemporary use of these procedures—both appropriate and inappropriate. Second, we did not attempt to estimate effective doses of radiation from these imaging procedures. There is a paucity of available data on radiation dosimetry in the pediatric population. Extrapolating effective dose estimates for children from estimates available in the literature could be misleading.[11,22] Instead, we focused on describing the patterns of use across various types of imaging procedures, which we believe adds critical new information for policy makers and health care providers. Third, data in the study population were gathered from 5 specific market areas. While these areas represent large and diverse communities, there may be aspects of these populations that differ from the greater United States as a whole. This could potentially limit the generalizability of these findings to the broader United States. Similarly, these data include only children who were insured and do not represent use in uninsured settings. Fourth, our results likely underestimated the total number of studies performed in children by restricting individuals to 1 procedure per day of the same technology on the same anatomical region and excluding patients who died during the study period. We did this to be as conservative as possible in reporting our findings and to focus explicitly on survivors—the group in whom the long-term risks of radiation are most concerning. Finally, these results represent a snapshot in time. Imaging procedures are constantly evolving and their use has been in flux during recent years.

In conclusion, our study describes patterns of use of diagnostic and therapeutic imaging procedures with ionizing radiation in a large pediatric population. We found that the use of these procedures is common and that studies associated with high doses of radiation are not infrequent and are performed repeatedly in a smaller group of children. These results highlight the importance of generating databased guidelines to aid clinicians in determining the appropriateness of performing imaging procedures in children.

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REFERENCES

1. Brenner DJ, Hall EJ. Computed tomography: an increasing source of radiation exposure. *N Engl J Med*. 2007;357(22):2277-2284.
2. Einstein AJ, Moser KW, Thompson RC, Cerqueira MD, Henzlova MJ. Radiation dose to patients from cardiac diagnostic imaging. *Circulation*. 2007;116(11): 1290-1305.
3. Kim KP, Einstein AJ, Berrington de González A. Coronary artery calcification screening: estimated radiation dose and cancer risk. *Arch Intern Med*. 2009;169(13): 1188-1194.
4. Fazel R, Krumholz HM, Wang Y, et al. Exposure to low-dose ionizing radiation from medical imaging procedures. *N Engl J Med*. 2009;361(9):849-857.
5. Sodickson A, Baeyens PF, Andriole KP, et al. Recurrent CT, cumulative radiation exposure, and associated radiation-induced cancer risks from CT of adults. *Radiology*. 2009;251(1):175-184.
6. Brody AS, Frush DP, Huda W, Brent RL; American Academy of Pediatrics Section on Radiology. Radiation risk to children from computed tomography. *Pediatrics*. 2007;120(3):677-682.
7. Brenner D, Elliston C, Hall E, Berdon W. Estimated risks of radiation-induced fatal cancer from pediatric CT. *AJR Am J Roentgenol*. 2001;176(2):289-296.
8. Hall EJ. Lessons we have learned from our children: cancer risks from diagnostic radiology. *Pediatr Radiol*. 2002;32(10):700-706.
9. Huang B, Law MW, Mak HK, Kwok SP, Khong PL. Pediatric 64-MDCT coronary angiography with ECG-modulated tube current: radiation dose and cancer risk. *AJR Am J Roentgenol*. 2009;193(2):539-544.
10. Preston DL, Ron E, Tokuoka S, et al. Solid cancer incidence in atomic bomb survivors: 1958-1998. *Radiat Res*. 2007;168(1):1-64.
11. International Atomic Energy Agency. Radiation Protection of Patients (RPOP). http://rpop.iaea.org/RPOP/RPoP/Content/InformationFor/HealthProfessionals/1_Radiology/QuantitiesUnits.htm. Accessed November 2, 2010.
12. Beebe MDJ, Espronceda M, Evans DD, Glenn RL. *CPT 2007 Standard Edition: Current Procedural Terminology*. Chicago, IL: American Medical Association; 2006.
13. National Research Council. *Health Risks From Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2*. Washington, DC: National Academies Press; 2006.
14. Chodick G, Ronckers CM, Shalev V, Ron E. Excess lifetime cancer mortality risk attributable to radiation exposure from computed tomography examinations in children. *Isr Med Assoc J*. 2007;9(8):584-587.
15. Modan B, Keinan L, Blumstein T, Sadetzki S. Cancer following cardiac catheterization in childhood. *Int J Epidemiol*. 2000;29(3):424-428.
16. Pierce DA, Shimizu Y, Preston DL, Vaeth M, Mabuchi K. Studies of the mortality of atomic bomb survivors, report 12, part I, cancer: 1950-1990. *Radiat Res*. 1996; 146(1):1-27.
17. Baker LC, Atlas SW, Afendulis CC. Expanded use of imaging technology and the challenge of measuring value. *Health Aff (Millwood)*. 2008;27(6):1467-1478.
18. Townsend BA, Callahan MJ, Zurakowski D, Taylor GA. Has pediatric CT at children's hospitals reached its peak? *AJR Am J Roentgenol*. 2010;194(5):1194-1196.
19. US Census Bureau. 2006-2008 American Community Survey 3-year estimates. http://factfinder.census.gov/servlet/STTable?_bm=y&-geo_id=01000US&-qr_name=ACS_2008_3YR_G00_S0901&-ds_name=ACS_2008_3YR_G00_. Accessed December 9, 2009.
20. National Council on Radiation Protection and Measurements. *Ionizing Radiation Exposure of the Population of the United States: National Council on Radiation Protection and Measurements Report No. 160*. Bethesda, MD: National Council on Radiation Protection and Measurements; 2009.
21. Hausleiter J, Meyer T, Hermann F, et al. Estimated radiation dose associated with cardiac CT angiography. *JAMA*. 2009;301(5):500-507.
22. Alliance for Radiation Safety in Pediatric Imaging. Image Gently. http://www.pedrad.org/associations/5364/ig/. Accessed November 12, 2009.
23. Kuppermann N, Holmes JF, Dayan PS, et al; Pediatric Emergency Care Applied Research Network (PECARN). Identification of children at very low risk of clinically-important brain injuries after head trauma: a prospective cohort study. *Lancet*. 2009;374(9696):1160-1170.
24. Osmond MH, Klassen TP, Wells GA, et al; Pediatric Emergency Research Canada (PERC) Head Injury Study Group. CATCH: a clinical decision rule for the use of computed tomography in children with minor head injury. *CMAJ*. 2010;182 (4):341-348.
25. National Institute for Clinical Excellence. *Head Injury: Triage, Assessment, Investigation and Early Management of Head Injury in Infants, Children and Adults*. London, England: National Collaborating Centre for Acute Care, Royal College of Surgeons of England; 2007.
26. Haydel MJ, Preston CA, Mills TJ, Luber S, Blaudeau E, DeBlieux PM. Indications for computed tomography in patients with minor head injury. *N Engl J Med*. 2000; 343(2):100-105.
27. Ingebrigtsen T, Romner B, Kock-Jensen C; Scandinavian Neurotrauma Committee. Scandinavian guidelines for initial management of minimal, mild, and moderate head injuries. *J Trauma*. 2000;48(4):760-766.
28. Oman JA, Cooper RJ, Holmes JF, et al; NEXUS II Investigators. Performance of a decision rule to predict need for computed tomography among children with blunt head trauma. *Pediatrics*. 2006;117(2):e238-e246.
29. Stein SC, Fabbri A, Servadei F, Glick HA. A critical comparison of clinical decision instruments for computed tomographic scanning in mild closed traumatic brain injury in adolescents and adults. *Ann Emerg Med*. 2009;53(2):180-188.