Impact of Socioeconomic Status on Ionizing Radiation Exposure From Medical Imaging in Children

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Purpose: To characterize cumulative radiation exposure from diagnostic imaging (CEDI) in pediatric patients and to investigate its relationship to patients' socioeconomic status and comorbid medical conditions.

Methods: A retrospective cohort study of >19,000 pediatric patients seen within the outpatient clinic system of an academic tertiary care urban medical center during the month of January 2006 was conducted to estimate CEDI from all procedures performed within 3 years of the index visit (until January 2009). Socioeconomic status was estimated from census tract geocoding. Comorbid medical conditions were identified from the electronic medical record.

Results: A total of 19,063 patients underwent imaging tests within the index month. The mean age was 8.9 ± 6.3 years. Most had private insurance (56%), with 36% receiving Medicaid and 8% private payers. Our population lived in census tracts in which 27 ± 16% of the population were below the federal poverty level with 62% living in areas in which 20% of residents were living below the poverty level. There were differences in CEDI ($P < .0001$) by age, insurance type, and percentage poverty in the census tract of residence but not among racial groups ($P = .6508$). The association between poverty and CEDI was generally explained by the 26 Elixhauser diagnoses, with the exception of rheumatoid arthritis.

Conclusion: Patients living in areas of greater poverty were exposed over time to more radiation from diagnostic testing than those living in areas with lower percentages of residents living in poverty. This association was explained almost entirely by the presence of disease burden. No direct association was found between socioeconomic status and CEDI.

Key Words: Radiation dose, radiation exposure, exposure to patients and personnel, socioeconomic factor, access to health care, pediatrics

J Am Coll Radiol 2012;9:799-807. Copyright © 2012 American College of Radiology

INTRODUCTION

Although the benefits of radiographic imaging are generally accepted, the side effects of ionizing radiation exposure from CT scans, fluoroscopy, and nuclear medicine studies are receiving more attention. A recent study indicated that approximately 40% of children aged < 18 years in the United States are exposed to at least one ionizing radiation examination over a 3-year period from medical imaging procedures [1]. Studies suggest that radiation exposure may be more hazardous in children because their tissues are still growing and may be more prone to somatic genetic damage. Additionally, children's greater life expectancy provides a longer observation time for adverse events [2-8]. The use of CT has increased rapidly, with an estimated 70 million CT scans performed in 2007 in the United States [9]. Primarily on the basis of epidemiologic data from atomic bomb survivors, it has been estimated that 1.5% to 2% of future cancers in the United States may be attributable to current CT use and that 29,000 cancers may be attributable to the CT scans performed in 2007 [10]. Furthermore, some have estimated that the mortality from radiation exposure is 1 death per 4,000 scans and 1 excess cancer per 1,000 scans [11].

Understanding the factors associated with the utilization of radiologic imaging is important in correcting

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Data from this study were presented at the 2010 annual meeting of the Radiological Society of North America. Dr Freeman's contribution was made possible by National Institutes of Health grant 5 P60 MD000514-06, National Center on Minority Health and Health Disparities Comprehensive Center of Excellence in Health Disparities Research, Bronx Center to Reduce and Eliminate Ethnic and Racial Health Disparities.

0091-2182/12/$36.00 • http://dx.doi.org/10.1016/j.jacr.2012.06.005

possible differences in the delivery of health care services according to patient demographic characteristics (health disparities). Lower socioeconomic status (SES), lack of health insurance, and belonging to a disadvantaged race or ethnicity are associated with increased disease prevalence, decreased access to care, and worse health outcomes across a broad spectrum of diseases [12-16]. In a study of adult patients undergoing myocardial perfusion imaging, those patients without health insurance underwent fewer tests involving radiation and had lower cumulative effective doses than patients with any health insurance [17]. Our objective was to test the association in children between SES and medical radiation exposure and diagnostic imaging utilization in the US health care setting. We hypothesized that because of increased disease burden, lower SES may contribute to an increase in exposure to medical ionizing radiation. Our population was primarily African American and Latino children living in varying degrees of poverty who were followed for 3 years at an urban medical center. We tested our hypothesis by evaluating the associations between cumulative radiation exposure from diagnostic imaging (CEDI) and SES, race, ethnicity, and insurance status, controlling for comorbidities.

METHODS

Data Sources

This was a retrospective cohort study of patients from a tertiary care academic urban medical center with specialized pediatric outpatient, inpatient, and emergency facilities. We accessed our institution's computerized medical record system using Clinical Looking Glass version 3.3 (Montefiore Medical Center, Bronx, New York), an interactive software application, to derive radiation exposure (estimated effective dose), geocoding (census tract of residence), comorbidity reports, demographics, and insurance status. The study was approved by the medical center's Institutional Review Board for the Protection of Human Subjects and was compliant with HIPAA.

Study Population

The population was defined to include all patients aged ≤21 years at the time of an initial visit during January 2006 at any of the institution's 14 outpatient clinic sites, which all use the electronic medical record system. Patient records were reviewed through January 2009 to identify all medical imaging studies performed over this time period. Patients who died during the 3 years of follow-up were excluded to minimize potential bias due to numerous examinations preceding their deaths and the truncation of their observation period. Patients with <3 years of follow-up were also excluded. Age, gender, race, and ethnicity were self-reported by the patient or guardian at registration. Ethnicity was defined as either Hispanic or Latino or non-Hispanic or non-Latino. Insurance information was based on the source of payment recorded for the original outpatient encounter and was subsequently categorized as private insurance, Medicare, Medicaid, or no insurance (self-pay).

SES

The percentage of people living below the poverty level in a census tract has previously been used as a measure of SES [18]. To validate this approach in this cohort, 100 randomly selected addresses geocoded by the Clinical Looking Glass geocoding report were compared with the census tract on the US Census Bureau's geocoding Web site [19]. Eighty-two percent of addresses were assigned the same census tracts by both methods, 10% could not be geocoded by the census Web site, and a small fraction (8%) were assigned different census tracts. To account for the possible nonlinearity of the relationship between census tract percentage of persons living below the poverty level and radiation exposure, percentage poverty categories of 0% to 10%, >10% to 20%, >20% to 30%, >30% to 40%, >40% to 50%, >50% were created. Bronx County has one of the highest poverty rates in the nation (28.3% in 2009), and the study population therefore did not replicate the previously used cutoff of >20%, the federal definition of a poverty area, as the highest poverty group [20].

Examination Utilization and Estimation of Radiation Dose

All diagnostic radiology examinations, nuclear medicine examinations, and cardiac catheterizations were recorded for 3 years from the original outpatient visit date for each patient. These included all procedures performed at multiple imaging facilities, including inpatient, emergency, and outpatient settings. Mean radiation doses were assigned to the common examinations performed in radiology, nuclear medicine, and invasive cardiology on the basis of literature-reported values [21,22] available before the initiation of this cohort. The estimated radiation doses for all examinations for the 3-year period of each patient were then summed, yielding a total estimated cumulative radiation dose in millisieverts. Actual measured radiation exposures vary widely and also tend to be higher than estimated mean calculated exposures [9,22,23].

Comorbidities

Because SES is associated with disease risk, we incorporated comorbidities into our analyses to account for increases in imaging procedures due to increased burden of disease. We determined the presence of each of 26 Elixhauser diagnoses for each patient using International Classification of Diseases, ninth rev., codes for the entire 3-year study period. Elixhauser diagnoses have been shown to be positively associated with mortality and hospital charges [24].

Statistical Analysis

Descriptive statistics are presented as mean ± SD for continuous variables and as relative frequencies for categorical variables. Multiple linear regression analysis with a monitored backward variable elimination procedure was used to derive models of the relationship between cumulative radiation exposure and patient characteristics, with estimated cumulative radiation dose as the dependent variable. Because the distribution of estimated cumulative radiation was not normal, transformations of scale were attempted to better approximate assumptions of normally distributed error terms. However, with most patients receiving very low doses or no radiation, and because the data set was sufficiently large, errors were reasonably normal, and thus assumptions of the multiple linear regression analyses were not violated. Bivariate analyses between CEDI and demographics and insurance were performed using Kruskal-Wallis tests for categorical or short-scale ordinal variables or Wilcoxon's rank-sum tests for dichotomous variables. Variables significantly associated with CEDI were included in multivariate models. Primary analyses included CEDI as the dependent variable and age and its effect on poverty and its effect on diagnosis as independent variables. Sensitivity analyses were performed for the entire data set, with CEDI as the dependent variable and the following independent variables: age, gender, ethnicity, race, census tract percentage poverty as either a continuous or a categorical variable, insurance categories, and diagnosis, as well as within insurance group. Variables retained in final models were those significant at $P < .05$. Analyses were performed using SAS version 9.1.2 (SAS Institute Inc, Cary, North Carolina).

RESULTS

A total of 19,063 patients had outpatient visits between January 1 and January 31, 2006, and were followed for 3 years. Distributions of children from infancy to 21 years by demographic characteristics and insurance type are shown in Table 1. The mean age was 8.9 ± 6.3, with 34% aged < 5 years. The most prevalent racial groups were African American (33.1%) and multiracial (14.9%); 36.4% of the population was of Hispanic eth-

Table 1. Distribution of demographic characteristics and insurance in children and adolescents aged 0 to 21 years by poverty and CEDI (n = 19,063)

	Frequency Distribution		Poverty Rate of Living Environment		3-Year CEDI (mSv)	
Variable	n	%	Mean ± SD	Difference: *P* Value	Mean ± SD	Difference: *P* Value
Age (y)				<.0001		<.0001
<5	6,458	33.88	0.27 ± 0.16		0.50 ± 8.73	
5-9	4,449	23.34	0.27 ± 0.16		0.38 ± 4.00	
10-15	4,244	22.26	0.27 ± 0.16		0.76 ± 7.66	
16-21	3,911	20.52	0.28 ± 0.16		1.61 ± 11.14	
Gender				.0064		.5132
Male	9,212	48.33	0.27 ± 0.16		0.80 ± 8.65	
Female	9,847	51.67	0.27 ± 0.16		0.72 ± 7.89	
Race				<.0001		.6508
American Indian	91	0.48	0.32 ± 0.14		0.99 ± 5.48	
Asian	324	1.70	0.23 ± 0.16		1.45 ± 20.39	
African American	6,303	33.06	0.28 ± 0.16		0.80 ± 8.76	
Multiracial	2,839	14.89	0.31 ± 0.15		1.23 ± 11.60	
Pacific Islander	11	0.06	0.29 ± 0.12		0.14 ± 0.28	
White	1,946	10.21	0.20 ± 0.16		0.57 ± 6.05	
Ethnicity				<.0001		.8353
Hispanic	6,874	36.37	0.31 ± 0.15		1.03 ± 8.30	
Insurance				<.0001		<.0001
Medicaid	6,825	35.80	0.32 ± 0.14		1.06 ± 9.63	
Medicare	61	0.32	0.34 ± 0.13		2.15 ± 6.83	
None	1,496	7.85	0.27 ± 0.17		0.29 ± 2.31	
Private	10,680	56.03	0.24 ± 0.16		0.62 ± 7.84	
Percentage poverty				—		<.0001
<10%	3,909	20.76	—		0.44 ± 3.85	
10%-<20%	3,207	17.03	—		0.83 ± 9.43	
20%-<30%	3,637	19.32	—		1.00 ± 11.31	
30%-<40%	3,311	17.58	—		0.69 ± 6.64	
40%-<50%	3,356	17.82	—		0.75 ± 6.61	
≥50%	1,409	7.48	—		1.11 ± 11.90	
Total	19,063	100.00	0.27 ± 0.16	—	0.76 ± 8.27	—

Note: CEDI = cumulative radiation exposure from diagnostic imaging.

nicity. Most children were covered under private insurance (56%), with an additional 36% receiving Medicaid. Across census tracts, 27 ± 16% of children from this population lived in poverty, with 62% living in areas in which >20% of residents were living below the poverty level.

Descriptive statistics for percentage poverty and CEDI stratified by demographic characteristics and insurance type are also shown in Table 1. Differences in mean levels of poverty were significant for age, with both the very young and the oldest children more likely to be living in higher poverty areas, and for sex, with female patients more likely to live in higher poverty areas. Percentage poverty differed by race, with Native Americans, African Americans, and Pacific Islanders more likely to live in higher poverty areas than Asians or Caucasians, and by ethnicity, with Hispanics more likely to live in higher poverty areas ($P < .0001$). As expected, children receiving Medicaid were more likely to live in higher poverty areas than those with either no or private insurance and were more likely to be Native American ($P = .0016$), African American ($P < .0001$), or Hispanic ($P < .0001$) (data not shown). With regard to CEDI, 82.5% of children received no ionizing radiation, and <1% received >10 mSv. Differences among age groups with regard to CEDI were significant, with those aged 16 to 21 years having notably higher levels of cumulative radiation exposure than younger children ($P < .0001$). Differences among insurance types were significant, with those on Medicaid or Medicare receiving significantly more radiation than those with private or no insurance ($P < .0001$). There were no significant differences by gender, race, or ethnicity.

The distribution of children with one or more Elixhauser diagnosis is shown in Table 2. For each diagnosis, descriptive statistics for percentage poverty and CEDI are presented, along with corresponding P values indicating the significance of the difference between those with and without the diagnosis. The most prevalent diagnosis was chronic pulmonary disease, affecting more than one-fourth of all children. Other diagnoses affecting >2% of children included deficiency anemia, fluid and electrolyte disorders, and depression. More than one-third of children had at least one Elixhauser diagnosis. In bivariate analyses, Elixhauser diagnoses more prevalent in higher poverty areas included chronic pulmonary disease, hemiplegia or paraplegia, complicated hypertension, other neurologic disorders, fluid and electrolyte disorders, deficiency anemia, drug abuse, psychoses, and depression; having at least one diagnosis was associated with living in areas of significantly greater poverty. For Elixhauser diagnoses with sufficient sample sizes for analysis ($n > 10$), children with the diagnoses were exposed to significantly greater CEDI than those without the diagnoses. CEDI was notably greater for such diagnoses as myocardial infarction, metastatic solid tumor, lymphoma, and blood loss anemia.

Table 3 presents the results of multiple linear regression models to determine the effect of percentage poverty of living environment on CEDI, controlling for diagnosis. Each model accounted for age and how age modified the effect of poverty on CEDI, as well as diagnosis and how poverty modified the effect of diagnosis on CEDI. Given the two interaction terms in each initial model, analyses of interaction terms were reviewed to determine if sample sizes within subgroups were sufficient to consider results reliable (ie, >10 subjects in each subgroup dichotomized at the median). After controlling for diagnosis and age, poverty was not significantly associated with CEDI, with the exception of rheumatoid arthritis. For this diagnosis only, the interaction between poverty and diagnosis was significantly associated with CEDI ($P < .0001$), indicating that children with rheumatoid arthritis living in greater poverty areas had much higher than expected CEDI compared with those with rheumatoid arthritis living in areas of lesser poverty and those without the disease. The interaction between poverty and disease was significant for moderate to severe liver disease; in examining these results more closely, there was a significant difference in CEDI between those living in greater poverty areas and those without moderate or severe liver disease. These findings are illustrated in Figs. 1 and 2. Sensitivity analyses supported all findings.

DISCUSSION

From our multiracial and ethnic population in which the majority of children lived in areas with >20% of residents living below the poverty level, those living in areas of greater poverty had higher levels of cumulative ionizing radiation exposure. However, analyses that controlled for age and diagnosis attributed this finding primarily to burden of disease. Our results are consistent with those of prior studies, which demonstrated an association between lower SES and greater disease burden [25,26]. We found that more than one-third of children had at least one Elixhauser diagnosis, and those affected lived in notably poorer environments. Contrary to expectations regarding barriers to accessing health care by poorer patients, our analyses showed that mean levels of CEDI in general did not differ between children living in census tracts with greater vs lower poverty after controlling for diagnosis and age.

There was only one diagnosis, rheumatoid arthritis, for which poverty was associated with CEDI. For children with this diagnosis living in areas of ≥10% poverty, mean CEDI was more than twice that of those living in areas of <10% poverty; for children without this diagnosis, the difference in mean CEDI was not as pronounced. Only one study examined the relationship between SES and juvenile rheumatoid arthritis and indicated that children in families with higher incomes

Table 2. Distribution of demographic characteristics, insurance, and diagnoses in children and adolescents aged 0 to 21 years by poverty and CEDI (n = 19,063)

	Frequency Distribution		Percentage Poverty of Living Environment		3-year CEDI (mSv)	
Diagnosis	**n**	**%**	**Mean ± SD**	***P***	**Mean ± SD**	***P***
Myocardial infarction	2	0.01	0.48 ± 0.02	—	160.50 ± 163.30	—
Congestive heart failure	18	0.10	0.33 ± 0.14	.0927	21.83 ± 65.20	<.0001
Peripheral vascular disorders	16	0.09	0.32 ± 0.14	.2200	4.57 ± 8.62	<.0001
Cerebrovascular disease	42	0.23	0.28 ± 0.16	.5802	7.75 ± 13.69	<.0001
Dementia	4	0.02	0.15 ± 0.06	—	0.03 ± 0.05	—
Chronic pulmonary disease	4,883	27.14	0.29 ± 0.16	<.0001	0.99 ± 7.30	<.0001
Peptic ulcer disease	11	0.06	0.26 ± 0.16	.8851	4.73 ± 6.79	<.0001
Mild liver disease	76	0.42	0.29 ± 0.15	.2032	2.54 ± 5.84	<.0001
Diabetes without complications	178	0.99	0.28 ± 0.16	.4105	1.83 ± 6.47	<.0001
Hemiplegia or paraplegia	157	0.87	0.31 ± 0.18	.0114	4.84 ± 12.96	<.0001
Moderate or severe liver disease	176	0.98	0.28 ± 0.15	.1308	5.47 ± 10.34	<.0001
Metastatic solid tumor	14	0.08	0.29 ± 0.14	.6689	140.70 ± 139.80	<.0001
Valvular disease	130	0.72	0.29 ± 0.15	.1740	1.96 ± 5.55	<.0001
Pulmonary circulation disorders	12	0.07	0.26 ± 0.16	.8165	15.79 ± 23.96	<.0001
Complicated hypertension	124	0.69	0.32 ± 0.17	.0016	12.62 ± 46.89	<.0001
Other neurologic disorders	324	1.80	0.29 ± 0.15	.0495	5.37 ± 25.98	<.0001
Hypothyroidism	163	0.91	0.29 ± 0.17	.1315	2.89 ± 8.43	<.0001
Lymphoma	20	0.11	0.32 ± 0.16	.1242	110.10 ± 118.30	<.0001
Rheumatoid arthritis collagen vascular disease	63	0.35	0.29 ± 0.15	.2577	9.59 ± 36.07	<.0001
Coagulopathy	102	0.57	0.30 ± 0.17	.1569	15.59 ± 45.26	<.0001
Fluid and electrolyte disorders	621	3.45	0.28 ± 0.15	.0207	4.62 ± 21.45	<.0001
Blood loss anemia	13	0.07	0.29 ± 0.16	.6691	32.21 ± 74.25	<.0001
Deficiency anemia	976	5.42	0.31 ± 0.16	<.0001	3.44 ± 22.68	<.0001
Drug abuse	49	0.27	0.32 ± 0.13	.0082	10.10 ± 40.38	<.0001
Psychoses	267	1.48	0.30 ± 0.14	.0004	1.56 ± 6.33	<.0001
Depression	471	2.62	0.32 ± 0.14	<.0001	2.38 ± 8.31	<.0001
Elixhauser diagnoses				<.0001		<.0001
None	12,237	64.19	0.26 ± 0.16		0.24 ± 2.40	
Any	6,826	35.81	0.29 ± 0.16		1.69 ± 13.38	
Total	19,063	100.00	0.27 ± 0.16		0.76 ± 8.27	

Note: CEDI = cumulative radiation exposure from diagnostic imaging.

were more likely to have the diagnosis; however, the investigators did not examine effects of imaging and treatment [27]. This finding warrants further investigation focusing on this population of patients with juvenile rheumatoid arthritis. The current data concern limited variables pertaining to the whole population of patients studied. Prospective detailed analysis of this clinic population may shed light on the finding.

In a 2011 report, the use of ionizing radiation was generally higher among boys than girls aged < 15 years and increased dramatically in older children [1]. Although consistent with what we observed, these results were limited to children with private insurance. With regard to differences among racial groups, the results of our study differed from those of Einstein et al [17] in that they found that white patients had higher cumulative effective doses of ionizing radiation, whereas we found no differences. Consistent with our findings, those investigators also found that patients without health insurance had lower cumulative effective doses than patients with any health insurance [17]. Two previous studies have investigated the relationship between SES and diminished access to ionizing medical imaging in large populations. A Canadian study found that the highest income quintile was more likely than the lowest income quintile to receive nearly all radiologic examinations [28]. However, a Taiwanese study found that lower SES was associated with a higher rate of CT utilization [29]. It is important to note that both of these studies were performed in systems with different health care and insurance systems than was analyzed in this study. Neither of these studies reported cumulative radiation exposure estimates. In a study paralleling our cohort of children but with adult patients, we similarly reported that radiation

Table 3. Multivariate associations between 3-year CEDI and percentage of people living below the poverty level in a census tract and presence or absence of Elixhauser diagnoses*

	P Value		
Diagnosis	CEDI vs % Poverty	CEDI vs Diagnosis	CEDI vs Interaction of Poverty and Diagnosis†
Myocardial infarction	‡	‡	‡
Congestive heart failure	.1343	.3336	‡
Peripheral vascular disorders	.1810	.0708	.2246
Cerebrovascular disease	.1843	.0002	.1377
Dementia	‡	‡	‡
Chronic pulmonary disease	.2103	.2169	.8995
Peptic ulcer disease	.1848	.4233	.0770
Mild liver disease	.1862	.3902	.7732
Diabetes without complications	.1815	.2230	.4070
Hemiplegia or paraplegia	.1433	.0042	.9009
Moderate or severe liver disease†	.2134	<.0001	.0010
Metastatic solid tumor	.1080	<.0001	‡
Valvular disease	.1803	.7370	.7507
Pulmonary circulation disorders	.1770	<.0001	‡
Complicated hypertension	.2293	<.0001	.2597
Other neurologic disorders	.1704	<.0001	.3107
Hypothyroidism	.1897	.0332	.3831
Lymphoma	.0642	<.0001	‡
Rheumatoid arthritis collagen vascular disease†	.2150	.7748	<.0001
Coagulopathy	.1677	<.0001	.5313
Fluid and electrolyte disorders	.0789	.0001	.0542
Blood loss anemia	.2740	<.0001	‡
Deficiency anemia	.1473	<.0001	.0987
Drug abuse	.2432	.0369	‡
Psychoses	.1704	.1825	.2129
Depression	.1861	.1485	.6620
Any Elixhauser diagnoses	.0297	<.0001	.2266

Note: CEDI = cumulative radiation exposure from diagnostic imaging.
*For all analyses, the interaction between age and poverty was significant ($P < .05$), indicating that older children living in greater poverty have much higher levels of CEDI than older children living in less poverty, relative to what is observed in younger children.
†$P < .05$ indicates that the interaction between poverty and diagnosis was significant and that poverty was a significant effect modifier of the relationship between diagnosis and CEDI: (1) those without moderate or severe liver disease living in higher poverty areas had significantly greater CEDI than those without the disease who lived in lower poverty areas (the difference in CEDI between those living in higher vs lower poverty areas among those with the diagnosis was not significant), and (2) among those with rheumatoid arthritis, CEDI was significantly greater in those living in higher poverty areas than those living in lower poverty areas (among those without rheumatoid arthritis, the difference in CEDI between those living in higher vs lower poverty areas was not significant).
‡Too few (<10) patients in one or more of the subsets stratified by poverty and diagnosis group.

exposure was directly related to comorbidities rather than SES [30].

Several studies have discussed diminished imaging utilization in mammography, bone densitometry, and cardiac catheterization as they relate to lower SES in adults [31-36]. The international consistency of these findings, including countries with socialized health care, indicates that insurance is not the only factor limiting access to radiologic imaging. We have shown no differences in race or ethnicity with regard to CEDI, and for only 1 of the 26 Elixhauser diagnoses, juvenile rheumatoid arthritis, was there an association between poverty and CEDI. We did demonstrate that those children enrolled in Medicaid or Medicare received significantly more radiation than those with private or no insurance. Patients with Medicaid or Medicare will be those who are poor and have Elixhauser diagnoses. They will be enrolled to obtain required services. Those without insurance (<10% of the sample) have no means of payment and would not be expected to have ready access to health care services regardless of their medical comorbidities. It is also possible that this 10% represents those who were not located within the catchment area throughout the study period and were not able to benefit from social services afforded to those enrolled in Medicare or Medicaid.

In a review from 2009, it was reported that for every 4,000 CT scans, there would be one excess death from radiation-induced malignancy [11]. Although imaging

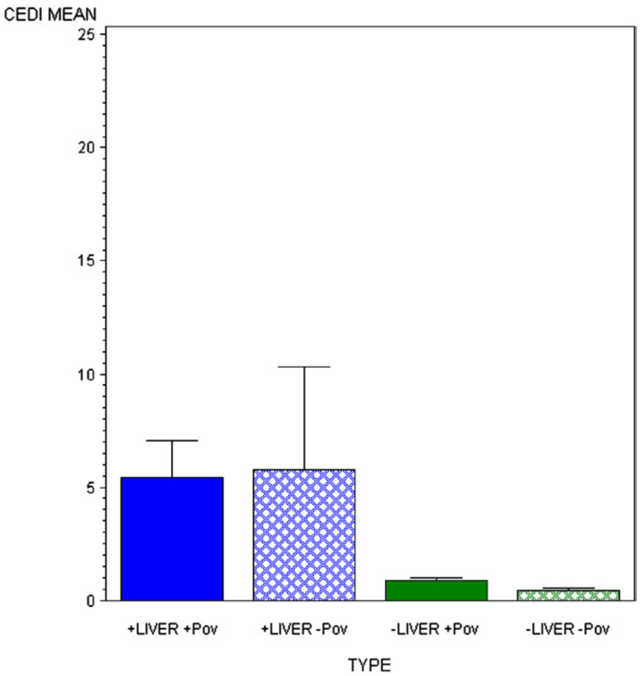

Fig 1. Chart demonstrating the interaction between moderate or severe liver disease, poverty, and CEDI. Those without moderate or severe liver disease living in higher poverty areas had significantly greater CEDI than those without the disease who lived in lower poverty areas (the difference in CEDI between those living in higher vs lower poverty areas among those with the diagnosis was not significant).

data have not supported a causal relationship with cancer, evidence from Japanese populations demonstrate a dose-response relationship [3]. The authors estimated that in 15 developed countries between 0.6% and 1.8% of all malignancies occurred as a result of diagnostic medical radiation, on the basis of the estimate that CEDI > 50 mSv was considered high [11]. Thus, we agree that physicians caring for such patients must seek to limit radiation exposure whenever possible to lessen the lifetime risk for malignancy [37]. In children and adolescents aged 5 to 21 years diagnosed with osteosarcoma, excess cancer incidence and excess mortality decreased dramatically with age, with rates for those aged 15 to 21 years $\leq$15% of values for children aged 5 to 10 years [38]. For the 34 children in our sample diagnosed with metastatic solid tumors or lymphoma as well as for children with other diagnoses, we agree with the need to minimize patient exposure to ionizing radiation associated with medical imaging, with specific attention paid to young children, in considering the advantages of such imaging.

Although the assertion cited above that a significant number of cancers are caused by medical radiation has been questioned [39,40], the need to minimize unnecessary ionizing radiation has been widely accepted. The "American College of Radiology White Paper on Radiation Dose in Medicine" cites research indicating a significant cancer increase at radiation levels > 50 mSv and notes that it would not be uncommon for patients receiving multiple CT scans to have an estimated exposure above this level [24]. Because of these concerns, the International Commission on Radiological Protection [41] has recommended that occupational effective radiation doses be limited to an effective dose of 100 mSv over 5 years, with a maximum of 50 mSv in any year. Assuming that we limit the effective dose to 60 mSv over the 3 years of follow-up, it is estimated that 34 children (0.18%) had CEDI values exceeding this threshold, 4 of whom had no Elixhauser diagnoses.

Limitations of the study include the inaccuracy of census tract geocoding and the inability to approximate the SES of individual patients. Insurance status captured at the index visit may have changed over the 3 years. Also, a single hospital system's imaging facilities may lead to potential underestimation of cumulative radiation exposure. Although it is possible that subjects obtained imaging services outside of the net cast by the Clinical Looking Glass software, the true magnitude is unknown. The medical center provides primary care to two-thirds of the poorest children living in the Bronx and subspecialty care to nearly all of these children. The majority of outpatient

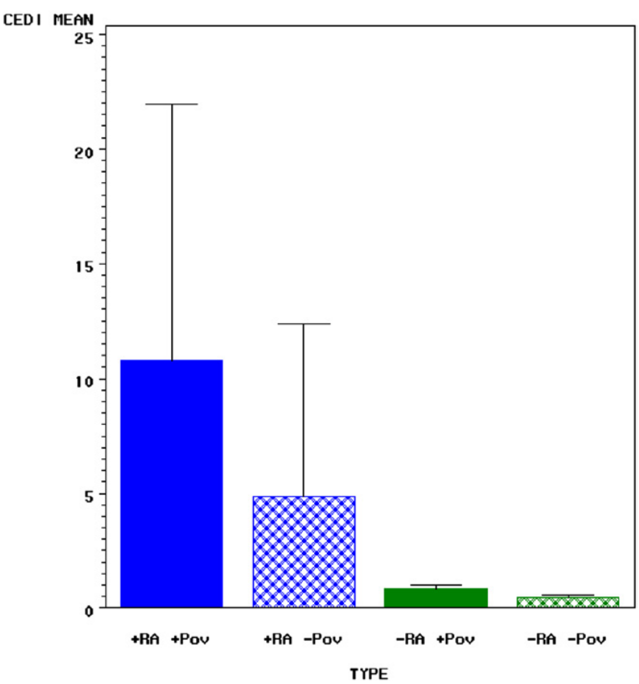

Fig 2. Chart demonstrating the interaction between rheumatoid arthritis, poverty, and CEDI. Among those with rheumatoid arthritis, CEDI was significantly greater in those living in higher poverty areas than those living in lower poverty areas (among those without rheumatoid arthritis, the difference in CEDI between those living in higher vs lower poverty areas was not significant).

encounters that generate imaging requests via the electronic medical record automatically generate scheduling requests within the radiology information system, which spans 4 inpatient sites and 5 outpatient imaging centers. We are currently designing prospective analyses of the subsets of the cohort within each Elixhauser diagnosis group. This prospective methodology will allow us to more accurately account for these confounders.

Estimated doses rather than actual doses were used, which would tend to underestimate true findings; however, uniform correction would likely not alter results. Information regarding the use of shielding and whether scans were repeated was unavailable. Factors unique to our institution or its patient population, such as its greater proportion of African Americans and smaller proportion of Caucasians, limit generalizability further. Additionally, children could have received imaging at other institutions, which would serve to underestimate the CEDI values reported here. Although we accounted for greater use of ionizing radiation due to increased morbidity by incorporating Elixhauser diagnoses in analyses, we may have omitted other diagnoses associated with increased radiation.

CONCLUSIONS

Although medical imaging provides valuable information at the appropriate settings, many tests can only be done using ionizing radiation. Exposure to ionizing radiation at levels from diagnostic testing is associated with an increased risk for forming solid tumors, and this risk is particularly notable in young children and those with cancer [38]. This study confirms previous work showing that patients of lower SES have greater disease burden. Contrary to expectations with regard to barriers to care, patients in this cohort living in areas with greater concentrations of persons living in poverty had higher levels of CEDI than those living in areas with lower concentrations. This association was explained by the presence of disease burden. We found no direct association between SES and CEDI. Our study demonstrates that poorer children have increased burden of disease and as a consequence receive more CEDI. Although disparities in disease burden resulting from poverty are unlikely to change rapidly, awareness of higher overall potential radiation exposure from diagnostic testing and conscious efforts to utilize nonionizinig alternatives may be used to reduce consequences of imaging in a poorer and sicker pediatric population.

TAKE-HOME POINTS

- Disease burden increases as census tract poverty percentage increases.
- Total accumulated ionizing radiation from diagnostic imaging increases with disease burden.
- Controlling for SES, disease burden accounted for all differences in ionizing radiation exposure.

REFERENCES

1. Dorfman AL, Fazel R, Einstein AJ, et al. Use of medical imaging procedures with ionizing radiation in children: a population-based study. Arch Pediatr Adolesc Med 2011;165:458-64.
2. Brenner DJ, Elliston CD, Hall EJ, Berdon WE. Estimated risks of radiation-induced fatal cancer from pediatric CT. AJR Am J Roentgenol 2001; 176:289-96.
3. Section on Radiology. Brody AS, Frush DP, Huda W, Brent RL, Radiation risk to children from computed tomography. Pediatrics 2007;120: 677-82.
4. Hall EJ. Lessons we have learned from our children: cancer risks from diagnostic radiology. Pediatr Radiol 2002;32:700-6.
5. Chodick G, Bekiroglu N, Hauptmann M, et al. Risk of cataract after exposure to low doses of ionizing radiation: a 20-year prospective cohort study among US radiologic technologists. Am J Epidemiol 2008;168: 620-31.
6. Modan B, Keinan L, Blumstein T, Sadetzki S. Cancer following cardiac catheterization in childhood. Int J Epidemiol 2000;29:424-8.
7. 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;146:1-27.
8. Sadetzki S, Chetrit A, Freedman L, Stovall M, Modan B, Novikov I. Long-term follow-up for brain tumor development after childhood exposure to ionizing radiation for tinea capitis. Radiat Res 2005;163:424-32.
9. Smith-Bindman R, Lipson J, Marcus R, et al. Radiation dose associated with common computed tomography examinations and the associated lifetime attributable risk of cancer. Arch Intern Med 2009;169:2078-86.
10. Brenner DJ, Hall EJ. Computed tomography—an increasing source of radiation exposure. N Engl J Med 2007;357:2277-84.
11. Berrington de Gonzalez A, Mahesh M, Kim KP, et al. Projected cancer risks from computed tomographic scans performed in the United States in 2007. Arch Intern Med 2009;169:2071-7.
12. Baker DW, Sudano JJ, Durazo-Arvizu R, Feinglass J, Witt WP, Thompson J. Health insurance coverage and the risk of decline in overall health and death among the near elderly 1992-2002. Med Care 2006;44:277-82.
13. Dalstra J, Kunst A, Borrell C, et al. Socioeconomic differences in the prevalence of common chronic diseases: an overview of eight European countries. Int J Epidemiol 2005;34:316-26.
14. Krieger N, Chen JT, Waterman PD, Soobader MJ, Subramanian SV, Carson R. Geocoding and monitoring of US socioeconomic inequalities in mortality and cancer incidence: does the choice of area-based measure and geographic level matter? The Public Health Disparities Geocoding Project. Am J Epidemiol 2002;156:471-82.
15. Sudano JJ, Baker DW. Explaining US racial/ethnic disparities in health declines and mortality in late middle age: the roles of socioeconomic status, health behaviors, and health insurance. Soc Sci Med 2006;62:909-22.
16. Seligman HK, Chattopadhyay A, Vittinghoff E, Bindman AB. Racial and ethnic differences in receipt of primary care services between Medicaid fee-for-service and managed care plans. J Ambul Care Manage 2007;30: 264-73.
17. Einstein AJ, Weiner SD, Bernheim A, et al. Multiple testing, cumulative radiation dose, and clinical indications in patients undergoing myocardial perfusion imaging. JAMA 2010;304:2137-44.
18. Krieger N, Chen JT, Waterman PD, Rehkopf DH, Subramanian SV. Painting a truer picture of US socioeconomic and racial/ethnic health inequalities: the Public Health Disparities Geocoding Project. Am J Public Health 2005;95:312-23.
19. US Census Bureau. American fact finder: advanced geography search. Available at: http://factfinder.census.gov/servlet/AGSGeoAddressServlet?_

lang=en&_programYear=50&_treeId=420. Accessed November, 15 2009.

20. US Census Bureau. Bronx County, New York. Available at: http://quickfacts.census.gov/qfd/states/36/36005.html. Accessed July 24, 2011.

21. Mettler FA Jr, Huda W, Yoshizumi TT, Mahesh M. Effective doses in radiology and diagnostic nuclear medicine: a catalog. Radiology 2008; 248:254-63.

22. Stein EG, Haramati LB, Bellin E, et al. Radiation exposure from medical imaging in patients with chronic and recurrent conditions. J Am Coll Radiol 2010;7:351-9.

23. Amis ES Jr, Butler PF, Applegate KE, et al. American College of Radiology white paper on radiation dose in medicine. J Am Coll Radiol 2007; 4:272-84.

24. Elixhauser A, Steiner C, Harris DR, Coffey RM. Comorbidity measures for use with administrative data. Med Care 1998;36:8-27.

25. Newacheck PW, Hung YY, Park MJ, Brindis CD, Irwin CE Jr. Disparities in adolescent health and health care: does socioeconomic status matter? Health Serv Res 2003;38:1235-52.

26. Gulliford MC, Mahabir D, Rocke B. Diabetes-related inequalities in health status and financial barriers to health care access in a population-based study. Diabet Med 2004;21:45-51.

27. Nielsen HE, Dorup J, Herlin T, Larsen K, Nielsen S, Pedersen FK. Epidemiology of juvenile chronic arthritis: risk dependent on sibship, parental income, and housing. J Rheumatol 1999;26:1600-5.

28. Demeter S, Reed M, Lix L, MacWilliam L, Leslie WD. Socioeconomic status and the utilization of diagnostic imaging in an urban setting. CMAJ 2005;173:1173-7.

29. Kung PT, Tsai WC, Hu HY. Disease patterns and socioeconomic status associated with utilization of computed tomography in Taiwan 1997-2003. J Formos Med Assoc 2008;107:145-55.

30. Strauchler D, Freeman K, Miller T. The impact of socioeconomic status and comorbid medical conditions on ionizing radiation exposure from diagnostic medical imaging in adults. JACR 2012;9:58-63.

31. Schueler KM, Chu PW, Smith-Bindman R. Factors associated with mammography utilization: a systematic quantitative review of the literature. J Womens Health (Larchmt) 2008;17:1477-98.

32. Chagpar AB, Polk HC Jr, McMasters KM. Racial trends in mammography rates: a population-based study. Surgery 2008;144:467-72.

33. Demeter S, Leslie WD, Lix L, MacWilliam L, Finlayson GS, Reed M. The effect of socioeconomic status on bone density testing in a public health-care system. Osteoporos Int 2007;18:153-8.

34. Griffiths S, Fone D, Borg A. Bone densitometry: the influence of deprivation on access to care. Public Health 2005;119:870-4.

35. Neuner JM, Zhang X, Sparapani R, Laud PW, Nattinger AB. Racial and socioeconomic disparities in bone density testing before and after hip fracture. J Gen Intern Med 2007;22:1239-45.

36. Alter DA, Naylor CD, Austin P, Tu JV. Effects of socioeconomic status on access to invasive cardiac procedures and on mortality after acute myocardial infarction. N Engl J Med 1999;341:1359-67.

37. Sidhu M, Goske MJ, Connolly B, et al. Image Gently, Step Lightly: promoting radiation safety in pediatric interventional radiology. AJR Am J Roentgenol 2010;195:W299-301.

38. Kaste SC, Waszilycsak GL, McCarville MB, Daw NC. Estimation of potential excess cancer incidence in pediatric 201Tl imaging. AJR Am J Roentgenol 2010;194:245-9.

39. Cohen BL. Test of the linear-no threshold theory: rationale for procedures. Dose Response 2005;3:369-90.

40. Tubiana M, Feinendegen LE, Yang C, Kaminski JM. The linear no-threshold relationship is inconsistent with radiation biologic and experimental data. Radiology 2009;251:13-22.

41. Wrixon AD. New ICRP recommendations. J Radiol Prot 2008;28:161-8.