Curr Radiol Rep (2015) 3:78
DOI 10.1007/s40134-014-0078-4

Trends of CT Utilization in North America Over the Last Decade

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Published online: 11 November 2014

Abstract Given the improvements in technology and usefulness of CT for diagnosis and therapeutic-planning, the growth in CT utilization is not surprising. Current estimates are that more than 85 million CT scans are performed annually (Prochaska G, Latest IMV CT survey shows hospitals seek to improve productivity to manage increased outpatient and emergency CT procedure volume). However, this increasing trend has prompted increased publicity and concern over the risks of radiation exposure (Cedars-Sinai investigated for significant radiation overdoses of 206 patients, LA Times October 10, 2009; Radiation Concerns Rise with Patient's Exposure, The New York Times June 12, 2012). Recent research has focused on which patient populations are "at risk" for high radiation exposure and what efforts can be undertaken to decrease this risk.

Keywords CT utilization · Radiation exposure · Medical imaging

This article is part of the Topical Collection on *Radiation Exposure and Reduction*.

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Introduction

Over the last decade, reports of increasing utilization of medical imaging and the potential adverse effects of ionizing radiation have appeared in the lay press [2–5]. Medical radiation is now the primary source of radiation exposure in the United States [6] and prior research based on atomic bomb survivors, occupational exposure, and cohort studies of individuals exposed to medical imaging have suggested that radiation doses in the range of medical imaging 10–100 mSv result in increased risk of radiation-induced malignancy [7–9]. This has prompted many physicians and physicists to study the overall trends in the use of medical imaging, including computed tomography (CT), focusing on which populations of patients are experiencing this increased radiation exposure and the effects of the radiation exposure, in an effort to reduce inappropriate exposure where possible and where most impactful. From this work, it is suggested that with increased radiation-sensitivity and greater life expectancies, young healthy adults and children are at the greatest risk of radiation-induced malignancy [10].

These studies have further fueled efforts to decrease radiation dose by promoting the reduction in unnecessary imaging, shifting cases to nonionizing radiation imaging modalities such as magnetic resonance imaging (MRI) or ultrasound, and reducing CT dose through technical improvements such as modulation of the X-ray beam and iterative reconstruction. This report will summarize the research efforts over the past decade that have attempted to measure the trend of CT utilization, identify those patient populations who are at highest risk, quantify the risk, and describe what is being done to moderate unnecessary radiation exposure.

Overall Trend of CT

Several studies have demonstrated an increasing trend in the use of CT imaging, and associated radiation exposure, over the last decade [7, 11, 12]. Smith-Bindman et al. demonstrated an 8 % annual increase in CT examination volume among patients enrolled in one of 6 HMOs, resulting in a doubling of the mean per capita effective dose over a 15-year period [13]. Further, the proportion of patients receiving high (>20–50 mSv) and very high exposure (>50 mSv) approximately doubled (1.2–2.5 % for high exposures and 0.6–1.4 % for very high exposures, respectively). This trend was also observed when looking at the North Carolina Medicaid population (NCMP); the percentage of high-exposure patients (10 or more CTs per year) increased from 1.5 to 2.7 % between 2007 and 2012 [14]. Both studies showed a leveling off of CT use in 2010, which coincided with the heightened awareness of radiation risk from increasing media coverage and corresponded with national trends [12, 15, 16]. A similar trend was identified within children; Migloretti et al. reported a doubling of CT utilization for children younger than 5 years of age and tripling for children between 5 and 14 years of age between 1996 and 2005 [17].

Populations who are likely to receive repeat imaging and medical radiation exposure—and are therefore at risk of receiving very high doses—are patients with chronic and recurrent illnesses. Such populations include patients with hydrocephalus, cardiac disease, pulmonary thromboembolic disease, renal colic, end-stage renal disease, inflammatory bowel disease, and patients undergoing endovascular aortic repair [9, 18, 19]. Many patients had total effective doses over 50 mSv over a three-year period [18]. The patients who were at greatest risk of having repeated exposures were those with pulmonary thromboembolic disease [18].

Patients with chronic and recurrent illnesses frequent emergency departments (EDs) where CT utilization has increased in parallel with outpatient CT utilization [12, 14–16, 20–22]. Korley et al. found that use of CT or MRI increased from 6 to 15 % from 1998 to 2007 in the ED. Interestingly, there was no associated change in patient disposition and only a small increase in the prevalence of life-threatening conditions among those tested, suggesting the additional examinations did not result in significant change in patient care. The increased imaging did, however, increase the patients' length of stay; the average time patients were seen in the ED increased an average of 2 h for patients undergoing CT or MRI [23]. Similarly Pines found that CT for abdominal pain increased from 10.1 % in 2001 to 22.5 % in 2005 but the detection rates for appendicitis, diverticulitis, and gallbladder pathology did not increase, nor did the admission rate decrease [24]. CT utilization rates vary by hospital characteristics (lower in smaller EDs) and physician characteristics (lower for non-emergency medicine boarded physicians) [25].

While there has been an overall increase in the number of CT scans performed through the ED, there is a differential increase among type of the scans performed. Imaging rates have risen dramatically related to trauma [25]. In the pediatric population, cervical spine and chest CTs demonstrated the most pronounced increase (around 300–400 % between 2000 and 2006) [26], a trend also seen in adults [27]. It is not clear the impact of the greater imaging on outcomes. Inaba et al. report increased use of CT among trauma patients between 2002 and 2005 (2.1 vs. 3.2 mean CTs per patient) with an increase in estimated radiation dose (11.5 vs. 20.7 mSv). Despite this increase in CT use and radiation exposure, there was no significant improvement in the diagnosis of missed injuries, mortality, or hospital length of stay [28].

Repeat imaging is also a contributor to use of CT. Many trauma patients are initially scanned at a small hospital and subsequently transferred to a regional Level 1 trauma center where radiologic studies are repeated, secondary to lack of studies being transferred with the patient, or because the studies are deemed of poor quality. Jones et al. reported that 82 of 211 trauma patients underwent at least one repeat CT scan which averaged an additional $1,762 in hospital charges and an estimate effective dose radiation of 21.5 mSv [29]. In a separate study of 100 trauma patients who were transferred to a level 1 trauma center with repeat imaging, only 7 % had new findings as a result of the repeat imaging, none of which were significant enough to alter treatment [30].

Consequences of Increasing CT Utilization and Radiation

Although risk estimates are imprecise, several authors have estimated cancer risk from CT radiation exposure. Berrington et al. estimate approximately 29,000 future cancers from CT scans performed in the United States in 2007, largely from CT examinations of the head, chest, abdomen, and pelvis [31]. The majority of these cancers are suspected to occur in females who are 35–54 years of age at the time of the imaging. An estimate of the number of patients undergoing CT that would lead to the development of 1 radiation-induced cancer by age at exposure and sex was also recently published in the Archives of Internal Medicine [32•]. As expected, there is an increased risk of radiation-induced cancer among females and younger age cohorts [8, 32•].

Similar work in the pediatric field emphasizes this increased risk of radiation-induced malignancy. Depending on age and gender, Migloretti projects that a radiation-induced solid cancer may occur in every 300–390 abdominal scans, 330–480 chest CTs, and 270–800 spine CTs in the pediatric population, equaling approximately 4870 new cancers per year secondary to the 4 million annual pediatric CT examinations [17]. Unfortunately, the majority of pediatric scans occur at non-pediatric facilities, where radiation reduction techniques may not be employed [33]. The results of a pivotal study out of Australia in 2013 demonstrate an increased incidence rate ratio for all solid and lymphoid and hematopoietic cancers with a 24 % increase in cancer incidence compared to nonexposed patients. This equated to an estimated absolute excess cancer incidence rate of 9.38 per 100,000 person years at risk [10].

The only study to directly assess the risk of CT scan exposure in children relied on individually collected clinical data and assessed the risk of leukemia or brain cancer for children exposed to as few as one CT scan. The results demonstrate a significant correlation between the estimated radiation dose from CT to red marrow and brain tissue, and thus an increased incidence of leukemia and/or brain cancer, even after one CT examination. The study concludes that cumulative doses of 50 mGy (5–10 head CTs) to the bone marrow in children may triple the risk of leukemia and doses of 60 mGy (2–3 head CTs) to the brain may triple the risk of brain cancer [34•].

While risk estimates exist in the literature, there is a lack of sufficient knowledge on radiation risk on the part of referring physicians and radiologists, and a lack of transference of knowledge to patients, which is likely widespread. A study in 2004 evaluating patient education regarding radiation dose and risks associated with particular imaging studies found that only 7 % of adult emergency room patients were informed of the risks, benefits, and average radiation dose of their CT scan. The authors report that the majority of radiologists and emergency department physicians in their study were unable to accurately estimate dose associated with individual CT examinations, regardless of their experience level [35]. It is also noted that there is considerable variability in CT dose between institutions, and the actual dose can be significantly higher than generally quoted in the literature, which further complicates individualized patient education [32•].

The increased risk of radiation-induced malignancy, particularly among young adults and pediatric patients, is compelling from a quality and safety perspective; however, there are several additional consequences related to the increased utilization of imaging. One consequence is healthcare cost, which has more than doubled in some populations over the last decade [13]. This increased cost has caused many divergent organizations to join forces to decrease the use of inappropriate imaging including insurance companies and physician lead safety groups such as Image Wisely.

It is important to note that even with the increased cost of increased imaging, many physicians would justify the use of advanced imaging if the imaging were always obtained appropriately. Unfortunately, the appropriateness of imaging use is a difficult metric to study, and it is estimated that 26–44 % of CT scans are ordered inappropriately [32•, 36–38].

What Should We Do

The ACR has recently outlined 37 recommendations focused on reducing unnecessary imaging and radiation exposure [39•]. The ACR has assigned appropriateness criteria to all imaging studies and incorporated these criteria in decision support software. Unfortunately, computerized decision support software has not been widely implemented, in part reflecting that these systems are often expensive, time consuming, and there is hesitancy among physicians to be directed by automated systems with regard to the best management of their patients when many of the recommendations are not evidence based [40, 41].

Another frequently employed method is direct patient education. The ACR discusses improving work with patient advocacy organizations to improve communication with patients regarding the risks and benefits of imaging procedures [39•]. Image Gently and Image Wisely have been specifically formed to raise awareness in the imaging community and help reduce radiation dose [42, 43]. Direct patient education is not always successful; individualized patient education to the NCMP regarding the risks of excessive radiation exposure resulted in no temporal association with decreased CT exposure [44]. Although the population was limited, the results may suggest that changing behavior requires more than simply patient education, but education of all the involved parties (patient, primary physician, radiologist). On the other hand, it may be that this short-term high use of imaging was appropriate, occurring in the setting of trauma or serious medical illness.

In the pediatric field, researchers studied the effects of parenteral knowledge of radiation risks from CT with differing results. Boutis et al. found that while almost half of parents were aware that ionizing radiation may potentially increase the child's lifetime risk of malignancy, higher than previously reported [35, 45], parental willingness to proceed with a physician recommended head CT decreased by 20 % after learning of the current risk estimates [46]. This differed from prior pediatric research, where there was no change in willingness to undergo CT examination [45].

Other strategies for minimizing inappropriate exposure to imaging and radiation include keeping an active record of an individual's cumulative radiation exposure. California recently adopted a bill, which mandates individual patient's radiation exposure to be recorded, with the desire to identify patients with high radiation exposure and potentially avoid further radiation [39•, 47]. These data, now already assembled by institutions, can be followed and added over time. To implement this most successfully, efforts for a centralized registry would need to be created, as many radiology studies are performed at non-affiliated individually owned imaging centers.

As discussed earlier, there remains substantial variation in radiation doses with CT. By standardizing CT dose and modifying existing protocols to reduce field of view and multi-pass scanning, radiation doses can be decreased and more appropriate individualized patient counseling on radiation risks can occur [48]. The ACR will soon require protocol review for CT accreditation to help ensure radiation dose is as low as reasonably achievable, an effort that should assist in standardizing CT dose.

Other efforts include technical developments such as automated tube current modulation, iterative reconstruction, and adaptive collimation [37, 49, 50]. Automated tube current modulation alone can reduce dose by 20–50 % [37]. Using iterative reconstruction and kVp and mAs modulation in pediatric abdominal, CT may reduce dose by as much as 64 % while maintaining image quality [51]. Many physicists and radiologists are continuing to study these techniques to optimize dose reduction while maintaining image quality. As more research is performed, it will be important for equipment manufacturers to incorporate these techniques in future CT scanners in a simple, straightforward manner.

While there are strategies to lower doses for individual patients, in order to truly ensure doses come down, it is important for institutions to assess the doses they use in consecutive patients and compare these with other institutions. One of the authors has an ongoing research project focused on assembling and standardizing doses for CT across institutions and any organizations that might be interested in participating should contact Smith-Bindman directly.

Conclusion

It is no mystery as to why CT volume and thus medical radiation exposure has increased over the last decade in the United States. Recognizing which patients are at highest risk for significant radiation exposure is the first step in identifying which patient cohorts require more judicial use of CT. Nationwide efforts to improve the appropriateness of imaging, reduce radiation exposure, and raise awareness have already been successful to a degree, but require buy-in from all stake-holders across the nation.

Compliance with Ethics Guidelines

Conflict of Interest Dr. Lauren M. B. Burke and Dr. Rebecca Smith-Bindman each declare no potential conflicts of interest. Dr. Richard C. Semelka reports research support from Siemens and is a section editor for Current Radiology Reports.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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