Pediatric CT and radiation: our responsibility

Donald P. Frush
Division of Pediatric Radiology
1905 McGovern-Davison Children's Health
Box 3808 Department of Radiology
Duke University Medical Center
Durham, North Carolina 27710
Phone: 919-684-7293
Fax: 919-684-7151
E-mail: frush943@mc.duke.edu

1. INTRODUCTION

Computed tomography (CT) is an essential imaging modality. CT is fast, has relatively consistent image quality, is widely available, and can optimize the use of increasingly scarce medical resources. In short, the use of CT can improve diagnosis and diagnostic confidence. In support of this is the increasing prevalence of CT scanners in the Emergency Department. CT has gone from a virtually nonexistent role in many common clinical settings. For example, chest pain rule out pulmonary embolism, aortic dissection, or myocardial infarction was previously evaluated via catheter angiography; possible kidney stones previously underwent intravenous pyelography (IVP); rule out appendicitis was routinely assessed by sonography, and bowel obstruction via fluoroscopy. CT now occupies a primary, often exclusive, role in such situations, and in less than a decade. While the presentation and type of disorders in children may differ, the same advances and trends in use apply to this population. However, CT also requires radiation exposure. Radiation exposure in children also has different considerations from adults. Therefore, the two fundamental issues with pediatric CT are that the modality is an extremely valuable diagnostic option…but with requisite radiation, and potential biologic effects. The difficulty is that both of these considerations must be reconciled.

The following material focuses on the issue of CT radiation exposure and risk in children. This is partly because the benefit-side of the equation is more familiar to physicians, especially radiologists, and other allied health professionals. Therefore, the following discussion will be structured to address the fundamental questions: Why are we here? What has been done to date? And where do we need to go? Taken together, the answers to these questions will provide a landscape that will allow the reader to have sufficient familiarity with the topic for informed discussion with scientific and administrative colleagues, industry, regulatory agencies, and the public, including patients and their families.

2. WHY ARE WE HERE?

Radiation is the legacy of the radiology professional. Within a few years of the initial discovery, the bio-effects of x-rays were reported[1]. It is also worth noting that, with the introduction of CT in the 1970s, the need to investigate image quality and radiation dose, especially in children, was recognized[2]; therefore, the potential risk of cancer from CT radiation is not an issue only in the past decade of rapid technologic advancements. However, there has been a reawakening that has resulted in a much more intense and global effort and optimization of dose delivery in image quality. What conspired to cause this reawakening?

One explanation was a front page article in USAToday in January of 2001 [3] that summarized three scientific publications in the American Journal of Roentgenology. One of these three articles dealt with the potential risks of CT radiation [4], another with the fact that doses in children can be quite high and techniques are not adjusted based on size [5], and a third offered some strategies for making pediatric CT dose more appropriate for children [6]. According to Steinberg in USAToday "… about 1,500 of those [children who had 1 CT] will die later in life of radiation induced cancer according to research out today" [3]. This quotation in the opening remarks was among a number of inaccuracies that betrayed

Medical Imaging 2009: Physics of Medical Imaging, edited by Ehsan Samei, Jiang Hsieh,
Proc. of SPIE Vol. 7258, 725802 · © 2009 SPIE
CCC code: 1605-7422/09/$18 · doi: 10.1117/12.816518

available refereed scientific material cited in the USAToday article which actually used terminology such as “potential”, and “estimated”. The article generated an immediate and intense public reaction [7] and many practices reporting parents refusing to have CT examinations for their children. This obviously had potential adverse effects of not performing an indicated examination. A positive outcome from this article, however, was the recognition by many groups, including radiologists, technologists, physicists, engineers, and other health professionals, regulatory bodies, national medical organizations, and industry, as well as the public, that the issue of CT radiation exposure in children (as well as adults) must be addressed. Since that time, several facts have become clearer: (1) CT use was increasing, (2) CT examinations resulted in a large individual, as well as collective dose, (3) CT settings were often higher than they need to be especially for children (i.e. there is no image quality penalty for a high radiation dose CT examinations), and (4) guidelines for pediatric CT were scarce.

CT use has been increasing dramatically; currently (at least as of the first part of this decade) there are approximately 65 million CT examinations performed per year in the United States[8]. With a US population estimate of just over 300 hundred million, this equates to one CT examination for approximately *one in five people per year* with a rate of increase estimated to be about 10% per year. Up to 11% of all CT scans are done in the pediatric population [9]. The dose from CT is the largest contributor to diagnostic medical radiation, estimated to be up to 67% [9,10]. Technologic advances have probably contributed to the increase dose as well. In the late 1980s, CT scanning was incremental where images were obtained every two seconds. With the availability of helical technology, now with multiple detector rows (multidetector CT-MDCT), scans can be done in seconds, especially in the pediatric population. This technology has, at times, appeared to outpace our ability to use it appropriately. Much more effort has been directed at improvements in image quality than at radiation dose issues. For example, CT evaluation of coronary arteries has had widespread promotion over the past 5-7 yeas especially, but only recently has public attention been directed at the high doses including the potentially high breast dose, with a cancer risk quoted low as 1 in 114 [11]. While these estimates are debated[12], this contention does not always reach the public sector. For pediatric body CT, with increased complexities in scanning including tube current modulation technology, gated cardiac scanning, and even perfusion scanning, understanding *how* to obtain diagnostic information is conceivably at the expense of minimizing optimizing radiation dose. In an extreme example of this, the deterministic effect of epilation was reported following neuroimaging CT[13]. Digital image formation, including CT, does not provide any penalty for excessive radiation exposures. Dose beyond that sufficient for diagnostic quality (“over exposure”) does not degrade image information as with screen film technology. Without this visual reminder, CT settings and resultant doses can be higher than necessary. Moreover, doses, the dose to children from CT has been high due to use of adult settings[5]. This may be because the decisions about imaging evaluation in children are more difficult. There may be less familiarity with pediatric disease processes, imaging techniques to evaluate these processes, and imaging manifestations of disease processes versus the adult population. Most of pediatric imaging is actually performed by those without pediatric sub-specialization. There is also an increased level of anxiety when dealing with healthcare in children. For these reasons, it is reasonable to assume that the tendency would be to obtain high diagnostic quality, and subsequently high dose examinations. Finally, the wide availability of pediatric scanning guidelines, to help minimize higher-than-needed CT radiation doses in children, has been only recently promoted.

While it is a widely recognized that *dosing* issues must be different in children in medical sub-specialties in clinical practice, such as with antibiotics, analgesics, or chemotherapy, this has not necessarily conveyed to pediatric CT scanning with radiation *dose*. Manufacturers, while quick to market the image quality aspect of their technical advances, have been less forthcoming once the equipment is installed. Often times, in the past decade or two, the comment was “just talk to so and so at the Children’s Hospital to see what they do”. With MDCT, as x-ray tubes became more powerful, the opportunity for faster and longer duration scanning afforded new imaging options. For example, angiographic evaluation of essentially the entire body (e.g. angiographic evaluation of the neck, chest, abdomen, and pelvis including the lower extremities in an adult) can now be performed. This was impossible with older single slice helical CT technology. In some ways, the earlier scanners limited the opportunity for this “panscanning” evaluation. While the above considerations are not exhaustive, these are some of the principle issues which have been increasingly recognized as attention has been more directed at radiation dose delivered by CT scanning to the population in general, and children in particular.

What drives the increased use of CT? There are many factors, including recognized medical benefit, use by non radiologist, impact of industry and regulatory agencies, and media and the public perceptions. The scientific community can provide data that support the medical benefit of CT examinations. However, use is not always derived from direct medical benefit. A current issue both in the medical circles, as well as government, is the cause and impact of self referral. Discussion of this is beyond the intent of this manuscript however it is worth noting that one recent report demonstrated an asymmetrically increase in CT use is seen with professions outside of radiology[14]. Vendors will market the benefits for their equipment and, until the past few years, have minimized the radiation issues. Diagnostic quality was the thrust of prior marketing rather than image quality *and* dose savings, a more balanced approach; only recently has this balance been promoted.

Increasing use would not be as much of an issue if CT radiation doses were nominal. CT provides a large individual dose (per examination) as well as a large collective dose, as noted above. The effective dose of CT, one way to estimate CT doses, will vary depending on the method of estimation (use of anthropormorphic phantoms, CT dose index – CTDI— and dose length product – DLP – estimations, Monte Carlo modeling) and technical factors for the examination. The range per exam can be less than 1.0 mSv to 25-50 mSv [10]. Previously, medical imaging was reported to account for about 15% of all population exposure. Recently, Mettler and colleagues reported that CT (together with cardiac radionuclide imaging) now accounts for approximately 50% of the radiation exposure to the U.S. population[15]. Overall, CT is the highest contributor to dose and this will likely, given previously noted trends, exceed background exposure within one generation.

Diagnostic imaging, including CT, is essentially low level radiation exposure (< 100 mSv). Therefore, the risks are stochastic and when discussing CT radiation, primarily deal with the development of cancer. There is discussion of and debate over potential bioeffects and bioeffect severity with low level radiation exposure. The National Council on Radiation Protection and Measurements (NRCP) Annual Meeting in April of 2008 dealt exclusively with this issue. One point often debated is whether there is a linear no threshold (LNT) relationship of radiation and the development of cancer. This is generally accepted by major organizations including the International Commission on Radiological Protection (ICRP), the NCRP, the National Cancer Institute, and the Food and Drug Administration (FDA). Most medical organizations also accept the LNT model and most in the radiology community ascribe to the principle that exposure to radiation should be minimized whenever possible in both the patient and in the workers. However, the attention to these details in CT scanning has been less acknowledged, perhaps because of the separation (unlike with fluoroscopy) between the patient and the actual individual (usually the radiologist) determining protocols.

The risk of developing fatal cancer from a single CT examination is not based on a population exposed to CT; rather this is often based on atomic bomb data. Data from recent reports support the notion that exposures down as low as about 50 mSv may have significant increase risks of cancer [16]. There are potential differences between acute and protracted exposure and the type of radiation between CT examinations and atomic bomb data. Nevertheless, it is the responsibility of the radiology community to see that there is no unnecessary radiation when performing medical imaging procedures.

The determination of fatal cancer risk for a single CT examination will depend on many factors, including risk model used, age of patient, and technical factors employed. In general, the fatal cancer risk from a single CT ranges from about 1 in 500 to 1 in more than 10,000, with most estimates in pediatric population being 1 in 1,000 – 2,000. However, use of these numbers in isolation without the context of the benefit of CT from medical standpoint is discouraged. In general, if the potential benefit of the CT examination outweighs the risk then the examination should be performed. This does not mean that a CT must identify a problem to be indicated. The benefit of a normal CT in terms of reducing anxiety or providing guidance and further evaluation is also important. This is not always recognized by those even within the medical community.

3. WHAT HAS BEEN DONE TO DATE?

Efforts at dose management include guidelines for the appropriate use of CT and technical advancements that optimize CT dose during the examination. These can generally be divided into regulatory considerations (appropriateness, guidelines, standards), individual protocols, and technical advancements.

While not exhaustive, guidelines provided by medical organizations, such as the American College of Radiology (ACR) (acr.org) provide opportunities to improve the use of CT in both adults and children. These include CT accreditation, Appropriateness Criteria™, and guidelines and technical standards. Another organization that has directed its initial efforts at CT use in children is the Alliance for Radiation Safety in Pediatric Imaging. The Alliance, representing more than 500,000 imaging experts, currently consists of approximately 35 national and international medical organizations, including the founding organizations of the American Association of Physicists in Medicine (AAPM), American College of Radiology (ACR), American Society of Radiologic Technologists (ASRT), and the Society for Pediatric Radiology (SPR) (Table). The first campaign of this Alliance, Image Gently™ [17], targeted community radiologists, technologists, and physicists, providing information on CT, radiation, and risk in children to increase awareness, as well as offering guidelines for performance of brain and body CT in this population.

In addition to these organizational efforts, individual publications and institutional information on pediatric CT techniques and protocols has increased over the past decade. One such technique a unique color-coded system for pediatric body CT protocols, resulted in less errors, potentially resulting in unnecessary radiation exposure, in the pediatric population [18].

Major technical changes have resulted in decreased radiation dose in the past decade or so. These include automatic tube current modulation [19,20] with resultant reductions in dose to children ranging up to 43% [21]. Penumbra collimation technology (which reduces the unused portion of the tail of the beam outside of the scan range), more efficient detectors, and new scan data processing such as iterative reconstruction (IR) can shift the balance towards image quality and away from radiation dose and potential bioeffects. Another technical advancement is in-plane surface shielding, generally of the breast, thyroid, and eyes. While there is some debate over the benefit of this technology versus simply reducing tube current[2]2, most current pediatric data support the use of this technology in reducing surface dose without substantially impacting image quality [23,24]. For example, in one recent publication, there was a 52% reduction in breast dose in a 5 year-old anthropomorphic phantom using a combination of bismuth shielding and tube current modulation (24).

As always, further education for both radiologists as well as with non-imaging healthcare providers will potentially impact on appropriate CT use in children and adults. While the factors responsible for any change in practice may be difficult to identify, the fact that change has occurred is encouraging. For example, in a recent presentation at the 2008 Radiological Society of North America (RSNA) Annual Meeting, investigators from Children's Hospital Medical Center in Cincinnati, and Children's Hospital of Philadelphia (CHOP) reported total imaging volumes for the years 2003-2007. In these years, the total volume analyzed growth rate was 9.9% for MR imaging, 9.2% for sonography, and 1.7% for CT. In the years 2006-7, there was, in fact, a decline of 3.5% in CT use [25]. In addition, a recent report concludes that there has been a significant decline in tube current for both chest and abdomen scanning, as well as kVp for chest and abdomen scanning by members of the SPR between periods of 2001 and 2006 in children up to 16 years of age [26] (Figure).

4. WHERE DO WE NEED TO GO?

The first commitment that needs to be made is recognizing that the issues related to CT, radiation, and children are a collective responsibility. This responsibility must be shared between radiologists, other healthcare providers, technologists, physicists, engineers, epidemiologists, radiation biologists, the manufacturing sector, regulatory groups, administration, and the media and public. Unless all individuals assume a role, efforts will not move forward at a sufficient pace, or at all. There are several current needs. Appropriate dose estimations for pediatric CT scanning are lacking. Better dose indices such as CTDI and DLP for children would be of value. This was a topic of a recent vendor summit in Cincinnati, organized by the Alliance for Radiation Safety in Pediatric Imaging [27]. While there was consensus at this conference that better dose indices for pediatric CT were important, it was also recognized that changes will need the support of various regulatory agencies (i.e. International Electrotechnical Commission –IEC—and the FDA), underscoring the need for the type of cooperation highlighted above. In addition, there needs to be consistent displays of dose indices on scanners between vendors so that users can more easily estimate doses resulting from their protocols. More refinements in estimations of actual risks from radiation should be pursued. Current weighting factors used for various organs and tissues by the ICRP do not adjust for pediatric sensitivities. Advances should be made at more clinical useful dose estimations for CT examinations [28], including organ specific dose estimations [29] which afford improved risk assessment than with effective dose alone. Manufactures should also consider providing scanner-based dose warnings when settings may exceed standards of care. Efforts should continue at archiving doses for individual patients. This not only include PACS systems but conceivably an electronic medical record for individuals. Some efforts at least at an initial dose record for pediatric individuals are ongoing through the Alliance for Radiation Safety in Pediatric Imaging with the recent promotion of a pediatric CT examination record [30]. Along these lines, once dose records have been established, strategies to review and address individual patient dose records should ensue [31]. Further technical advancements must be encouraged through manufactures such as recent development of reduction of tube current when the tube is directly over sensitive areas [32]. Finally, and as or more important than the prior, resources should be directed at evidence-based use of CT to help determine when CT is appropriate.

5. CONCLUSIONS

CT radiation exposure of both children and adults is one of the most pressing issues in medical imaging. This is due to increasing CT use, the individual and collective radiation doses that can result from CT, and the potential radiation risks. Currently, there have been measures taken to optimize radiation exposure and image quality, but there are remaining needs for appropriate CT indication and performance, as well as dose assessment. Addressing these needs is a collective mandate which will serve to protect the welfare of our children while continuing to provide valuable imaging information.

6. REFERENCES

[1] Injury and Protection. In: Radiology: An illustrated history. Ed. RL Eisenberg, Mosby, St. Louis, MO, 156-182 (1992).
[2] Brasch RC, Boyd DP, Gooding CA. "Computed tomographic scanning in children: comparison of radiation dose and resolving power of commercial CT scanners". AJR 131, 95-101 (1978).
[3] Sternberg S. CT scans in children linked to cancer later. USA Today. January 22, 2001:1
[4] Brenner DJ, Elliston CD, Hall EJ, et al. "Estimated risks of radiation-induced fatal cancer from pediatric CT". AJR 176, 289-296 (2001).
[5] Paterson A, Frush DP, Donnelly LF. "Are settings adjusted for pediatric patients"? Am. J. Roentgenol. 176, 297-301 (2001).
[6] Donnelly LF, Emery KH, Brody AS, et al. "Minimizing radiation dose for pediatric body applications of single-detector helical CT: Strategies at a large children's hospital". Am J Roentgenol 176(2):303-306, (2001).
[7] Donnelly LF, Frush DP. "Fallout from recent articles on radiation dose and pediatric CT". Pediatr Radiol 31, 388 (2001).
[8] Linton OW, Mettler FA. "National conference on dose reduction in computed tomography, emphasis on pediatrics". AJR 181, 321-329 (2003).
[9] Mettler FA, Wiest PW, Locken JA et al. "CT scanning: patterns of use and dose". J Radiol Prot. 20, 353-359 (2000).
[10] UNSCEAR 2000 Medical radiation exposures, annex D. United Nations Scientific Committee on the Effects of Atomic Radiation Report to the General Assembly; New York.
[11] Einstein AJ, Henzlova MJ, Rajagopalan S. JAMA 2007; 298, 317-323
[12] Milka M. "Cardiac CT Cancer Risks Less Than Feared"? JAMA 301, 367 (2009).
[13] Imanishi Y, Kukul A, Niimi H etal. "Radiation induced temporary hair loss as a radiation damage occurring in patients who had the combination of MDCT and DSA". Eur Radiol 15, 41-46 (2005).
[14] Levin DC, Rao VM, Parker L, Frangos AJ, Sunshine JH. "Ownership or leasing of CT scanners by nonradiologist physicians: a rapidly growing trend that raises concern about self-referral". JACR 5, 1206-1209 (2008).
[15] Mettler FA Jr, Thomadsen BR, Bhargavan M, et al. "Medical radiation exposure in the U.S. in 2006: preliminary results". Health Physics 95, 502-507 (2008).
[16] Brenner DJ, Doll R, Goodhead DT, et al. "Cancer risks attributable to low doses of ionizing radiation: assessing what we really know". Proc Natl Acad Sci USA. 100, 13761-13766 (2003).
[17] Goske MJ, Applegate KE, Frush DP, et al. "The image gently campaign: working together to change practice". Am J Roentgenol 190, 273-4 (2008).
[18] Frush DP, Soden B, Frush KS, Lowry C. "Improved pediatric multidetector body CT using a size-based, color-coded format". AJR 178, 721-726 (2002)

[19] Kalra MK, Maher MM, Toth TL, et al. “Techniques and applications of automatic tube current modulation for CT”. Radiology 233, 649-657 (2004).
[20] McCollough CH, Bruesewitz MR, Kofler JM. “CT dose reduction and dose management tools: overview of available options”. RadioGraphics 26, 503-512 (2006).
[21] Greess H, Lutze J, Nomayr A, et al. “Dose reduction in subsecond multislice spiral CT examination of children by online tube current modulation”. Eur Radiol 14, 995-999 (2004).
[22] Geleijns J, Salvadó Artells M, Veldkamp WJ et al. “Quantitative assessment of selective in-plane shielding of tissues in computed tomography through evaluation of absorbed dose and image quality”. Eur Radio 16, 2334-40 (2006).
[23] Fricke BL, Donnelly LF, Frush DP, et al. “In-Plane bismuth breast shields for pediatric CT: effects on dose and imaging quality using experimental and clinical data”. AJR 180, 407-411 (2003).
[24] Coursey C, Frush D, Yoshizumi T, Toncheva G, Nguyen G, Greenberg S. “Pediatric chest MDCT and tube current modulation: effect on radiation dose with breast shielding”. Am J Roentgenol 190, 54-61 (2008).
[25] http://www.auntminnie.com/index.asp?Sec=sup&Sub=ped&Pag=dis&ItemId=83917&wf=1 Last accessed 2-11-09
[26] Arch ME, Frush DP. “Pediatric body MDCT: A five-year follow-up survey of scanning parameters used by pediatric radiologists”. AJR 191(2), 611-7 (2008).
[27] Strauss K, Morrison G, Frush D, et al. “Image gently vendor summit: working together for better estimates of pediatric radiation dose from CT scans”. (In press – AJR 2009).
[28] Huda W, Ogden KM. “Computing effective doses to pediatric patients undergoing body CT examinations. Pediatr Radiol”. 38: 415-23 (2008).
[29] Li X, Samei E, Segars WP,et al. “Patient-specific dose estimation for pediatric CT”. SPIE. Orlando FL February 9,2009
[30] Imagegently.org Last accessed 2-11-09
[31] Birnbaum S. “Radiation safety in the era of helical CT: a patient-based protection program currently in place in two community hospitals in new Hampshire”. J Am Coll Radiol 5:714-718 (2008).
[32] http://www.medicalnewstoday.com/articles/130930.php Last accessed 2-11-09

7. TABLE

Alliance for Radiation Safety in Pediatric Imaging

Founding Organizations:

The Society for Pediatric Radiology
American Association of Physicists in Medicine
American College of Radiology
American Society of Radiologic Technologists

Alliance Organizations:

Academy of Radiology Research
American Academy of Pediatrics
American Institute of Ultrasound in Medicine
American Osteopathic College of Radiology
American Registry of Radiologic Technologists
American Roentgen Ray Society
American Society of Emergency Radiology
American Society of Head and Neck Radiology
American Society of Pediatric Neuroradiology
Asian-Oceanic Society for Paediatric Radiology
Association of University Radiologists
Canadian Association of Radiologists
Canadian Interventional Radiology Association
Coalition for Imaging and Bioengineering Research
College of Radiology, Academy of Medicine of Malaysia
Conference of Radiation Control Program Directors
European Society of Paediatric Radiology
National Council on Radiation Protection and Measurements
North American Society for Cardiovascular Imaging
Radiological Society of North America.
The Royal Australian and New Zealand College of Radiologists
Society of Interventional Radiology
Sociedad Latino Americana de Radiología Pediátrica
Society for Pediatric Interventional Radiology
Society of Computed Body Tomography and Magnetic Resonance
Society of Gastrointestinal Radiologists
The Society of Nuclear Medicine
The Society of Nuclear Medicine - Technologist Section
Society of Radiologists in Ultrasound
Society of Uroradiology

8. FIGURE

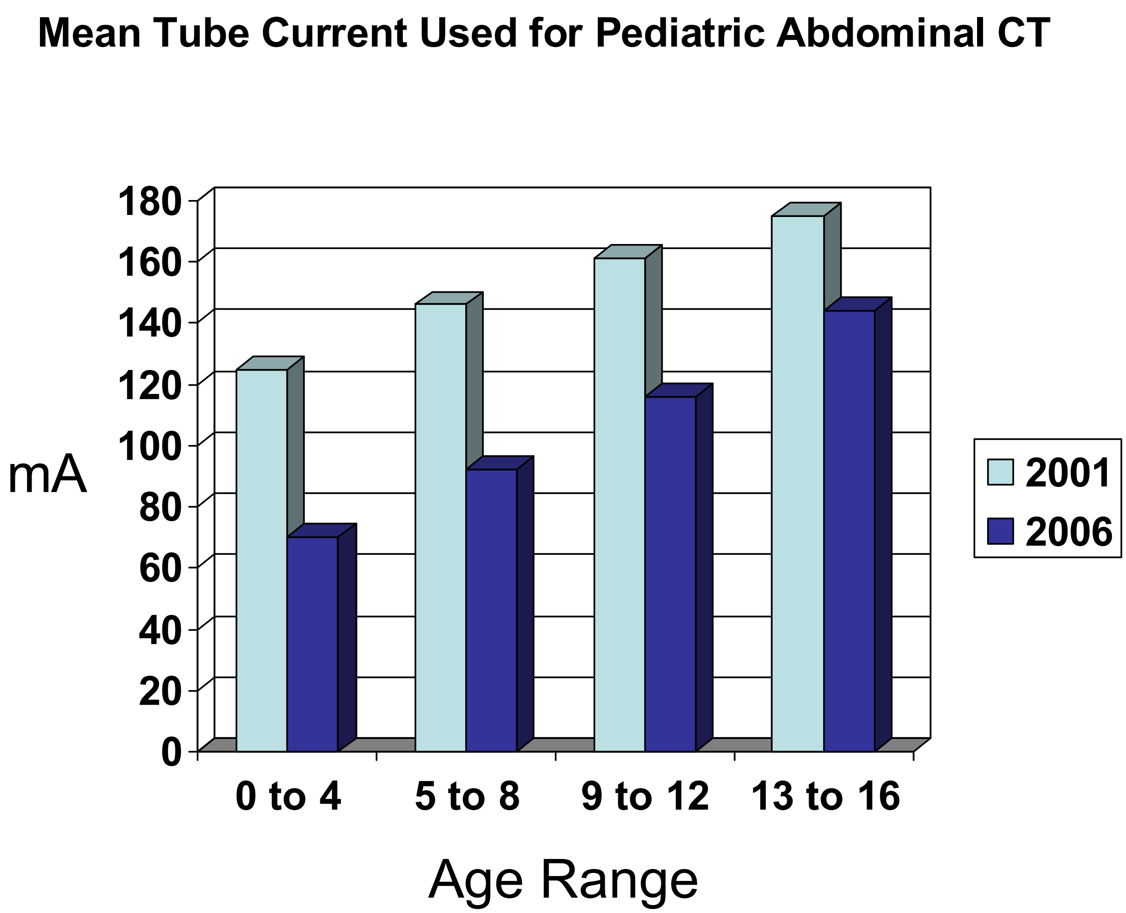

Figure 2: Mean tube current used by Society for Pediatric Radiology members for abdominal MDCT compared to 2001. Results were statistically significant ($p \leq .001$) for all age ranges. Borrowed with permission (26) American Roentgen Ray Society.