Pediatr Radiol
DOI 10.1007/s00247-014-3198-3

COMMENTARY

ALARA, Image Gently and CT-induced cancer

Mervyn D. Cohen

Received: 9 August 2014 / Accepted: 28 September 2014

Introduction

The term As Low As Reasonably Achievable (ALARA) goes back to articles in 1980, 1986 and 1999 [1–3]. In 2001, a group of inspired pediatric radiologists introduced the ALARA concept into routine clinical radiology practice [4–7]. The ALARA and the Image Gently campaigns have been very successful in achieving their goals of reducing unnecessary imaging and radiation exposure, inspiring the development of new technology, and expanding our understanding of measuring radiation dose in humans [6–15].

ALARA and Image Gently evolved from a belief that even if the true cancer risks of X-ray imaging were not known, a cautious approach of minimizing radiation was sensible. Although most radiologists believe the cancer risks from medical imaging are extremely small, if they exist at all, the media and some medical journals have so magnified and advertised this cancer risk that some patients and referring physicians may be avoiding medically indicated CT scans (Table 1).

The objectives of this article are to make radiologists aware of the extensive adverse publicity that CT has received in respected media (television and newspapers) and in publications from non-radiologists. My hope is that, with this knowledge, pediatric radiologists can improve the care of their patients by being prepared to address questions from parents and referring physicians with honest reassuring answers.

I will review and critique many of the misleading conclusions regarding cancer risk from CT that have appeared in the media and some journals. I will also review the historical background that led to a belief that data on the cancer incidence from the survivors of the atom bombs in Japan can be extrapolated back in a linear fashion to calculate the cancer risk from tiny radiation doses. This belief that no threshold exists for cancer risk from radiation is termed the linear no threshold theory. With new data from atom bomb survivors, this linear no threshold theory is being seriously challenged [16–20]. Finally, I will discuss recent epidemiological studies that have linked CT to cancer. These studies must be interpreted with great caution. I will provide the pediatric radiologist with information regarding real weaknesses in these studies that they can share with patients, parents and referring physicians.

Negative perceptions and exaggerations of risks of cancer from diagnostic X-ray imaging

This will be discussed from the perspectives of the media, the medical world, society and patients.

Media

Radiology may not always be perceived favorably by the media. Medical television series routinely portray radiology unfavorably, and the public's perception of radiologists is often unflattering [21, 22]. After the publication of Brenner's 2001 article [23] saying that "In the United States, at least 600,000 abdominal and head CT examinations per year are currently performed on children less than 15 years old and, of these individuals, a rough estimate is that approximately 500 will ultimately die from a cancer attributable to the radiation from the CT", the newspaper USA Today published an article entitled "CT scans in children linked to cancer" [24]. There is an abundance of public media output saying CT imaging *causes* cancer - without any comments that the risk is extremely small or even zero (Table 1). This is hardly surprising

M. D. Cohen (✉)
Department of Radiology,
Indiana University School of Medicine,
Riley Hospital for Children,
520 W. Cedar St, Zionsville, IN 46077, USA
e-mail: mecohen@iupui.edu

Published online: 14 February 2015

Table 1 Media comments on the 2012 Pearce Lancet article, "Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study" [32]

"CT scans in kids linked to leukemia, brain cancer risk"	ABC World News, June 6, 2012
"CT scans increase children's cancer risk, study finds"	New York Times, June 6, 2012
"CT scans boost cancer risks for kids"	National Public Radio (NPR), June 7, 2012
"CT scans warning after study claims too many could lead to brain cancer"	Guardian newspaper (UK), June 6, 2012
"CT scans can triple the risk of children getting leukemia"	The Times Newspaper (London), June 7, 2012
"CT scans could triple risk of a brain tumour in children"	The Telegraph Newspaper (London), June 7, 2012
"Multiple CT scans on children can increase risk of developing cancer"	BBC News, 7 June 7, 2012
"CT scans on children could triple brain cancer risk"'	BBC News, June 6, 2012
"CT scans in children raise risk of cancer"	American Cancer Society, June 7, 2012
"Multiple CT scans in kids triples cancer risk, but researchers caution overall risk low"	CBS News, June 7, 2012
"Child CT scans could raise cancer risk slightly"	USA Today, June 6, 2012
"Childhood CT scans may raise brain cancer, leukemia risks slightly"	Huffington Post, June 6, 2012
"NIH study finds childhood CT scans linked to leukemia and brain cancer later in life"	National Institute of Health NIH News, June 7, 2012
"Child CT scans may up risk of brain cancer, leukemia"	U.S. News and World Report, June 7, 2012
"Children's CT scans pose cancer risk"	Wall Street Journal, June 7, 2012
"CT scans in childhood can triple brain tumor, leukemia risk"	Los Angeles Times, June 6, 2012
"Childhood CT scans can triple risk of brain cancer"	Fox TV News, June 7, 2012
"CT scans 'can triple the risk of children getting leukaemia'"	Royal College of Pediatrics and Child Health, June 2012
"CT scans raise cancer isk for children"	Medical News Today, June 8, 2012
"CT scans tied to cancer in children"	WISH TV Indianapolis, June 7, 2012

when prestigious journals such as the New England Journal of Medicine publish articles titled "Elements of Danger – The case of medical imaging" saying a physician inflicted harm on a single patient because he exposed the patient to radiation by ordering a series of imaging tests including CT coronary angiogram and angiography [25]. The author goes on to say that "we must conclude that with a few exceptions—such as mammography—most radiologic imaging tests offer net negative results. There is little high-level evidence of benefit, whereas cumulative radiation exposure can produce real harm" [25]. The New York Times published an opinion editorial in 2014 entitled "We are giving ourselves cancer" [26]. The article states unequivocally that "we are silently irradiating ourselves to death" and "neither doctors nor patients want to return to the days before CT scans, but we need to find ways to use them without killing people in the process" [26]. The authors continue that "there is distressingly little evidence of better health outcomes associated with the current high rate of (CT) scans; there is, however, evidence of its harms" [26]. The authors also called for a decrease in the number of CT scans. In his response letter in the New York Times, the president of the American College of Radiology agreed with the need to decrease the number of CT scans [27]. He did not challenge the dogmatic statements that CT causes cancer and "we are silently irradiating ourselves to death." The media loves to exaggerate [25, 28–30]. It sensationalizes any article or comment that advocates the viewpoint that cancer can be caused by low-dose radiation from CT scans [31]. Table 1 summarizes media headlines, all reported within a 7-day period in 2012, following publication of the Pearce [32] epidemiological study in Lancet, claiming that as little as a single CT scan increases cancer risk in children.

Medical world

The idea that very low doses of radiation are harmful goes back to the Nobel Prize Herman Muller's acceptance speech in 1946 [28, 33]. Muller stated that there are no safe levels of radiation exposure, and no threshold below which radiation is not harmful. He had no foundation for this statement as he only studied the effects of very high radiation doses on fruit flies. Muller's statement was the start of the linear no threshold belief. Recent experiments have shown that Muller was wrong and that low doses of radiation have no harmful effects on fruit flies [34].

The current opinion among most radiologists is that low- dose radiation should be considered as a possible very small, if not definite, cause of cancer. Although many radiology publications indicate that cancer risks from CT scans are extremely small, this is unfortunately not always the case [4, 11, 23, 32, 35–42].

Many articles on the risks of CT scans causing cancer are now being published in prestigious non-radiology medical journals [25, 26, 43–47]. The fact that cancer risk from CT is less than the risk of an erroneous diagnosis from failure to do a CT scan is not always clearly stated. This may lead to the perception of a risk that is very much larger than it truly is. An editorial in JAMA this year states "it is well accepted that malignancy risks from CT radiation are real" [44]. An article in Pediatrics in 2003 states "It is apparent that without extrapolation or animal experimentation, low-dose radiation has a small but statistically significant individual risk of excessive cancer over a child's lifetime" [46]. Another article in Pediatrics states that CT can be dangerous with "a significant increased risk of fatal cancer from low dose radiation" and "there was the potential for inducing an increase in the number of cancer fatalities from a single CT" [47]. Recent articles in the New England Journal of Medicine claim "as many as 2% of cancers may be attributable to radiation exposure during CT scanning" [25]; an article entitled "Elements of danger – the case of medical imaging" states that "irradiation represents a direct danger imposed by a physician's decision to refer a patient for imaging" [26]; in 2007, Brenner [36] wrote "In summary there is direct evidence from epidemiologic studies that the organ doses corresponding to a common CT study (two or three scans, resulting in a dose in the range of 30 to 90 mSv) result in an increased risk of cancer. The evidence is reasonably convincing for adults and very convincing for children." An editorial article in the Archives of Internal Medicine claimed that 15,000 people will die from CT scans performed in the USA in 2007 and concludes that the "explosion of CT scans in the past decade has outpaced evidence of their benefit" [43].

Risk estimates from CT scans vary. Brenner [23], in one of the earliest articles, in 2001, estimated that a year-old child had a 1 in 500 chance of getting cancer from a single CT scan. "… radiation from CT studies currently being performed may ultimately account for 1.5% to 2% of all cancers in the future" [48]. "For girls, radiation-induced solid cancer is projected to result from every 300 to 390 abdomen/pelvis scans, 330 to 480 chest scans, and 270 to 800 spine scans, depending on age" [49] "Nationally, 4 million pediatric CT scans…performed each year are projected to cause 4870 future cancers" [49]. "…1 in every 270 forty-year-old women undergoing a CT coronary angiogram will develop cancer from the procedure" [43].

Society

All the publicity generated by publications linking diagnostic CT scan with cancer may result in legal action. There is already one reported case of a woman suing because an error resulted in her having a CT scan with a larger than necessary radiation dose [50]. It is entirely possible that we could see class-action lawsuits from parents of children with leukemia or other pediatric tumors, diagnosed a few years after CT scans performed for unrelated reasons.

There are calls for routinely informing patients of the risk of cancer when they undergo CT scan [47, 51]. The National Cancer Institute says, "People should discuss the risks and benefits of CT with their doctors" [52]. The value of this has been questioned [31, 53]. It is time-consuming and, thus, expensive. Explaining the theoretical CT risks are not only impossible to do, but also meaningless as the risk, if any, is minute. It is like requiring a car salesman to explain the risks of dying in a car accident every time he sells a car.

Patients

The current attention in journals and public media regarding CT scans and cancer may impact the quality of medical care provided. The risk of harm from all the negative publicity may now exceed any cancer risk from CT scans. Scientific studies to prove a negative impact on patient care by not doing a CT scan are difficult to perform. We can, however, speculate that our patients may be harmed in three different ways.

Patients may be denied valuable, needed CT scans [28]. Patients may try to avoid prescribed CT scans because they have been informed that scans increase their risk of cancer [13, 28, 31, 54]. Referring doctors may avoid ordering needed CT scans because of cancer fears. We truly risk doing far more harm to our patients by denying them clinically needed and potential therapy-changing CT scans. The risk of missing a diagnosis or complication today, by not doing a CT scan, is surely greater than the hypothetical risk of getting cancer from the CT scan many years in the future.

CT scans could be performed with non-diagnostic dose levels [53, 55–57]. Ultimately, the diagnostic quality of any CT study is a subjective individual radiologist's decision [58]. The problem is that we cannot know what we are missing on a very noisy image. We may believe that we miss nothing, but do we know this for certain? It has been stated that the purpose of the scan should be to get a highly diagnostic image, and whatever techniques needed to achieve this should be used [31].

Predictions that CT scans cause cancer create substantial anxiety. Statements that the dose from one CT scan is 60–100 times more than a chest X-ray dose may be true [31, 47], but as the number seems horrific, anxiety increases [54]. Parental anxiety is accentuated by comments that "organs and tissues in younger children are more susceptible to radiation-induced cancer" [47]. Sick patients now have additional unnecessary anxiety and worry about getting cancer from their CT scans [28]. This anxiety cannot be measured, but it is real and unnecessary. Anxiety is compounded by ill-advised recommendations to discuss the radiation risks of CT with parents and patients [47, 59]. It is inconceivable that a patient can understand this complex topic.

Is there proof that low-dose radiation, <100 msv, causes cancer?

One must acknowledge that there is debate about the presence or absence of a threshold and the effects of low-dose radiation causing cancer [47, 54, 58, 60–62]. There is, however, growing evidence that earlier assumptions that CT scanning causes cancer, lack final absolute proof [16–20, 63]. Almost all evidence is based on regression models from data from exposure to extremely high radiation dose from the Hiroshima atomic bomb [25, 32, 35, 38, 57]. These models assume and claim that there is no threshold for radiation toxicity and that even the tiniest radiation dose from a CT scan has some toxicity. This is the linear no threshold theory. This is now challenged [16–20, 28, 31, 57, 64]. However, once concepts have been accepted, they can be difficult to refute [65].

In a powerful policy statement in 2011, the prestigious American Association of Physicists in Medicine stated that the "Risks of medical imaging at effective doses below 50 mSv for single procedures or 100 mSv for multiple procedures over short time periods are too low to be detectable and may be nonexistent" [66]. Predictions of hypothetical cancer incidence and deaths in patient populations exposed to such low doses are highly speculative and should be discouraged [13, 14, 66, 67].

Epidemiological studies have been used in an attempt to prove cancer risk from CT. There are arguments that epidemiological studies cannot provide an answer to the relationship between low doses of radiation and cancer. Epidemiological studies all use effective dose. Several authorities, including the International Commission on Radiological Protection, have argued that this dose calculation is not valid in epidemiological studies to estimate the risk from radiation [28, 54]. It is only of value in estimating annual population radiation exposure [28, 54]. Because of the high natural incidence of cancer, it is virtually impossible to detect a few radiation-induced cancers from CT scans, even if they did exist [13, 28, 41, 43, 54]. In many of the epidemiological studies, exposure assessment relies on interviews or retrospective studies of medical records [68]. These are subject to recall bias and very inaccurate reporting [68]. The relationship between radiation and cancer can be masked by confounding factors, not part of the causal pathway [41, 68].

Over the years, there have been many small epidemiological studies reporting associations between low-dose radiation and cancer. They forget that statistical correlation does not prove cause and effect. Their findings are being disproved [57].

In the past 2 years, two extremely large epidemiological studies have been reported. These have attracted a considerable amount of media attention. The first study was published by Pearce [32] in Lancet in 2012. The second was published by Mathews [42] in BMJ in 2013. Both these studies have flaws [57]. Pearce studied 178,000 children in the United Kingdom. The article has major study design flaws and inaccuracy in reported information [69–73]. The first sentence in the patients and study design portion of Pearce's methods section states that they "obtained typical machine settings for CT in young people from U.K.-wide surveys undertaken in 1989 and 2003." These statements cannot be true [69, 74]. Review of these surveys reveals that they did not provide this data. The 1989 U.K. survey included no children, only adults. The 2003 survey included 1,892 adults and only 72 children, 16 undergoing chest CT for malignancies and 56 undergoing head CT for trauma. More than 50% of the patients who developed cancer had only one CT scan; it is difficult to believe that a single CT scan causes cancer.

Mathews [42] reported a study of 10.9 million children in Australia of whom 680,211 had a prior CT scan. His results are difficult to accept [75]. During 9 years, the incidence of cancer in those children with prior CT scans was 24% greater than in those children never having had a CT. Even more astounding is that the estimated radiation dose received in the CT group was 4.5 mSv per scan (equivalent to about 1 year's normal background radiation) and 82% of the children had only one CT scan [42]. The study methods have been criticized [75, 76]. About half of the study cohort had unknown CT status but were classified as unexposed [75, 76]. Mathews' study showed an increase in cancers after latent periods as low as 1 year after CT exposure; it showed increase in tumors such as melanoma and Hodgkin not known to be associated with even very high doses of radiation; it ignored that patients having CT scans may already have other factors increasing their cancer risk [41, 75, 76]. It is concerning that there are already more than 94 citations of the Mathews article and 416 citations of the Pearce article. Many of these citations use the articles to spread fear.

Conclusion

ALARA and Image Gently have been amazing success stories, and we need to continually monitor current practice to ensure that the gains are not lost. Of course, we need to continue to use CT wisely and only when clinically needed. However, this objective is not unique for CT, but it is true across the entire field of medicine for every medical patient contact. This should be done because it is good medical practice and because it helps minimize health care spending. It should not be done because of fear of cancer. One adverse result of the focus on reducing radiation is the exaggeration of potential cancer from CT scans in media and some non-radiologic medical environments. These claims are easily refuted and pediatric radiologists need to have the knowledge to address any concerns raised by their patients and their families and also by referring physicians. Pediatric radiologists should also possibly become more assertive in defending the value of CT when claims of excessive cancer risk are published in media or journals.

Conflicts of interest None

References

1. Winkler NT (1980) ALARA concept; now a requirement. Radiol Technol 51:525
2. Hendee WR, Edwards FM (1986) Alara and an integrated approach to radiology protection. Semin Nucl Med 16:142–150
3. Brateman L (1999) Radiation safety considerations for diagnostic radiology personnel. Radiographics 19:1037–1055
4. Slovis TL (2003) The ALARA concept in pediatric CT: myth or reality? Radiology 223:5–6
5. Slovis TL (2011) Where we were, what has changed, what needs doing: a decade of progress. Pediatr Radiol 41:S456–S460
6. Newman B, Callahan MJ (2011) ALARA (as low as reasonably achievable) CT – executive summary. Pediatr Radiol 41:S452–S455
7. Goske MJ, Applegate KE, Boylan J et al (2008) The image gently campaign: working together to change practice. AJR Am J Roentgenol 190:273–274
8. Voss SD, Reaman GH, Kaste S et al (2009) ALARA Concept Pediatr Oncol 39:1142–1146
9. Goske M (2013) Image gently: child-sizing radiation dose for children. JAMA Pediatr 167:1083
10. Goske MJ, Phillips RR, Mandel K et al (2010) Image gently: a Web-based practice quality improvement program in CT safety for children. AJR Am J Roentgenol 194:1177–1182
11. Willis CE, Slovis T (2004) The ALARA concept in pediatric CR and DR: dose reduction in pediatric radiographic exams – a white paper conference executive summary. Pediatr Radiol 34:S162–S164
12. Strauss KJ, Goske MJ, Kaste SC et al (2010) Image gently: Ten steps you can take to optimize image quality and lower CT dose for pediatric patients. AJR Am J Roentgenol 194:868–873
13. McCollough CH (2010) Medical radiation: An overview of the issues. Oral statement to House Energy and Commerce Committee, Subcommittee on Health. February 26, 2010. http://democrats.energycommerce.house.gov/Press_111/20100226/McCollough.Testimony.pdf. Accessed 10 June 2013
14. Schenkman L (2011) Second thoughts about CT imaging. Science 331:1002–1004
15. Sierzenski PR, Linton OW, Amis S et al (2014) Applications of justification and optimization in medical imaging: examples of clinical guidance for computed tomography use in emergency medicine. J Am Coll Radiol 11:36–44
16. Ozasa K, Shimizu Y, Suyama A et al (2012) Studies of the mortality of atomic bomb survivors, report 14, 1950–2003: an overview of cancer and noncancer diseases. Radiat Res 177:229–243
17. Cohen BL (2008) The linear no-threshold theory of radiation carcinogenesis should be rejected. J Am Phys Surg 13:70–76
18. Doss M (2014) Adoption of linear no-threshold model violated basic scientific principles and was harmful: Letter from Mohan Doss regarding Edward Calabrese's paper 'How the US National Academy of Sciences misled the world community on cancer risk assessment: new findings challenge historical foundations of the linear dose response.' (Arch Toxicol [2013] 87:2063–2081) and the letter from Ralph J. Cicerone (Arch Toxicol [2014] 88:171–172) Arch Toxicol 88:849–852
19. Cuttler JM (2010) Commentary on using LNT for radiation protection and risk assessment Dose Response 8:378–383
20. Siegel JA, Stabin MG (2012) Radar commentary: use of linear no-threshold hypothesis in radiation protection regulation in the United States. Health Phys 103:90–99
21. Gunderman RB, Mortell KE (2009) Radiologists on television. J Am Coll Radiol 6:144–146
22. Mamlouk MD (2014) Using the media to improve the public's perception of radiologists. J Am Coll Radiol 11:6
23. Brenner D, Elliston C, Hall E et al (2001) Estimated risks of radiation-induced fatal cancer from pediatric CT. AJR Am J Roentgenol 176:289–296
24. Sternberg S (2001) CT scans in children linked to cancer. USA TODAY. http://usatoday30.usatoday.com/news/nation/2001-01-22-scans.htm. Accessed 7 Jan 2012
25. Lauer MS (2009) Elements of danger — the case of medical imaging. N Engl J Med 361:841–843
26. Redberg RF, Smith-Bindman R (2014) We are giving ourselves cancer. New York Times. http://www.nytimes.com/2014/01/31/opinion/we-are-giving-ourselves-cancer.html. Accessed 14 Feb 2014
27. Ellenbogen PH (2014) The uses and abuses of CT scans. New York Times. http://www.nytimes.com/2014/02/07/opinion/the-uses-and-abuses-of-ct-scans.html?_r=0. Accessed 14 Feb 2014
28. Hendee WR, O'Connor MK (2012) Radiation risks of medical imaging: separating fact from fantasy. Radiology 264:312–321
29. Bogdanich W, Mcginty JC (2010) Radiation worries for children in dentists chairs. New York Times. http://www.nytimes.com/2010/11/23/us/23scan.html?pagewanted=all&_r=0. Accessed 5 Sep 2012
30. Prabhu SP (2004) Ionising radiation in infancy and adult cognitive function. BMJ 328:582
31. McCollough CH, Guimarães L, Fletcher JG (2009) In defense of body CT. AJR Am J Roentgenol 193:28–39
32. Pearce MS, Salotti JA, Little MP et al (2012) Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study. Lancet 380:499–505
33. Cherry S (2011) Radiation's big lie. IEEE spectrum. http://spectrum.ieee.org/podcast/at-work/education/radiations-big-lie. Accessed 12 Sep 2012
34. Antosh M, Fox D, Hasselbacher T et al (2014) Drosophila melanogaster show a threshold effect in response to radiation. Dose Response 1:1–30
35. Mahesh M (2013) Radiation. J Am Coll Radiol 10:557–558
36. Brenner DJ, Hall EJ (2007) Computed tomography — an increasing source of radiation exposure. N Engl J Med 357:2277–2284
37. Brenner DJ, Hricak H (2010) Radiation exposure from medical imaging: time to regulate? JAMA 304:208–209
38. Hall EJ (2008) Cancer risks from diagnostic radiology. Br J Radiol 81:362–378
39. Hall EJ (2012) Cancer risks from diagnostic radiology: the impact of new epidemiological data. AJR Am J Roentgenol 85:316–317
40. Hricak H, Brenner D, Adelstein SJ et al (2011) Managing radiation use in medical imaging: a multifaceted challenge. Radiology 258:889–905
41. Brenner DJ (2014) What we know and what we don't know about cancer risks associated with radiation doses from radiological imaging. Br J Radiol 87:20130629
42. Mathews JD, Forsythe AV, Brady Z et al (2013) Cancer risk in 680,000 people exposed to computed tomography scans in childhood or adolescence: data linkage study of 11 million Australians. BMJ 346:f2360
43. Redberg RF (2009) Cancer risks and radiation exposure from computed tomographic scans. How can we be sure that the benefits outweigh the risks? Arch Intern Med 169:2049–2050
44. Schroeder AR, Redberg RF (2013) The harm in looking. JAMA Pediatr 167:693–696

45. Brady Z, Cain TM, Johnston PN (2012) Justifying referrals for paediatric CT. Med J Aust 197:95–99
46. Slovis TL (2003) Children, computed tomography, radiation dose and the As Low As Reasonably Achievable (ALARA) concept. Pediatrics 112:971–972
47. Donnelly LF, Frush DP, Rosen N (2003) Computed tomography and radiation risk: what health care providers should know. Pediatrics 112:951–966
48. Raman SP, Mahesh M, Blasko RV et al (2013) CT scan parameters and radiation dose: practical advice for radiologists. J Am Coll Radiol 10:840–846
49. Miglioretti DL, Johnson E, Williams A et al (2013) The use of computed tomography in pediatrics and the associated radiation exposure and estimated cancer risk. JAMA Pediatr 167:700–707
50. Smith-Bindman R (2010) Is computed tomography safe? N Engl J Med 363:1–4
51. Massion C, Fugh-Berman A (2012) CT scan safety. The Women's Health Activist. http://nwhn.org/newsletter/node/147. Accessed 14 Feb 2013
52. National Cancer Institute Fact Sheet (2013) CT scans and cancer. http://www.cancer.gov/cancertopics/factsheet/detection/CT. Accessed 22 Nov 2013
53. Cohen MD (2009) More on the risks associated with radiation. J Am Coll Radiol 6:463
54. Boone JM, Hendee WR, McNitt-Gray MF, Seltzer SE (2012) Radiation exposure from CT scans: how to close our knowledge gaps, monitor and safeguard exposure–proceedings and recommendations of the radiation dose summit, sponsored by NIBIB, Feb. 24–25. Radiology 265:544–554
55. Cohen MD (2009) Pediatric CT radiation dose: how low can you go? AJR Am J Roentgenol 192:1292–1303
56. Cohen MD (2009) CT radiation dose reduction: can we do harm by doing good? Pediatr Radiol 42:397–398
57. Doss M (2014) Radiation doses from radiologic imaging do not increase cancer risk. Br J Radiol 87:20140085. doi:10.1259/bjr.20140085
58. Huda W (2009) What ER radiologists need to know about radiation risks. Emerg Radiol 16:335–341
59. Nelson C (2014) A radiation reality check. Wall Street Journal. http://on.wsj.com/1oVxkHo. Accessed 16 May 2014
60. Costello JE, Cecava ND, Tucker JE et al (2013) CT radiation dose: current controversies and dose reduction strategies. AJR Am J Roentgenol 201:1283–1290
61. Frush DP (2011) CT dose and risk estimates in children. Pediatr Radiol 41:S483–S487
62. Brenner DJ, Hall EJ (2012) Cancer risks from CT scans: now we have data, what next? Radiology 265:330–331
63. Zondervan RL, Hahn PF, Sadow CA et al (2013) Body CT scanning in young adults; examination indications, patient outcomes, and the risk of radiation induced cancer. Radiology 267:460–469
64. Cuttler JM (2013) Leukemia incidence of 96,000 Hiroshima atomic bomb survivors is compelling evidence that the LNT model is wrong. Arch Toxicol 87:2063–2081
65. Schuck C (2011) What can we do about junk science? Popular Mechanics. www.popularmechanics.com/science/health/what-can-we-do-about-junk-science-16674140. Accessed 13 Mar 2013
66. American Association of Physicists in Medicine. Policy statement on radiation risks from medical imaging. 13 Dec 2011. www.aapm.org/org/policies/details.asp?id=318&type=PP
67. Storrs C (2013) How much do CT scans increase the risk of cancer? Scientific American. http://www.scientificamerican.com/article/how-much-ct-scans-increase-risk-cancer/. Accessed 21 Nov 2013
68. Linet MS, Kim KP, Rajaraman P (2009) Children's exposure to diagnostic medical radiation and cancer risk: epidemiological and dosimetric considerations. Pediatr Radiol 39:S4–S26
69. Cohen MD (2013) Cancer risks from CT radiation: is there a dose threshold? J Am Coll Radiol 10:817–819
70. Deng J, Zhang Y, Nath R et al (2012) CT scans in childhood and risk of leukemia and brain tumors. Lancet 380:1735–1736
71. Gardavaud F, Luciani A, Rahmouni A (2012) CT scans in childhood and risk of leukaemia and brain tumours. Lancet 380:1735–1736
72. Hauptmann M, Meulepas J (2012) CT scans in childhood and risk of leukaemia and brain tumours. Lancet 380:1736
73. Zopf DA, Green GE (2012) CT scans in childhood and risk of leukaemia and brain tumours. Lancet 380:1735–1736
74. Cohen MD (2011) Searching for the holy grail: the pretense and fallacy of measuring CT radiation exposure in an individual patient. Radiology 260:306–307
75. Walsh L, Shore R, Auvinen AN et al (2013) Cancer risk in 680,000 people exposed to computed tomography scans in childhood or adolescence: data linkage study of 11 million Australians. BMJ 346:f3102
76. Walsh L, Shore R, Auvinen AN et al (2014) Risks from CT scans—what do recent studies tell us? J Radiol Prot 34:E1–E5