Pediatric Radiology (2019) 49:297–300
https://doi.org/10.1007/s00247-018-4314-6

COMMENTARY

High-pitch CT, decreasing need for sedation and its potential side effects: some practical considerations and future directions

Sjirk J. Westra [1]

Received: 6 November 2018 / Accepted: 26 November 2018 / Published online: 10 December 2018

In this issue of *Pediatric Radiology*, Kino et al. [1] present their experience with fast pediatric chest CT. The authors compared image quality, motion artifact and presence of atelectasis in a group of children undergoing high-pitch spiral chest CT under general anesthesia (GA) with suspended respiration, compared to another group scanned with no sedation or anesthesia and during free breathing. The authors found that image quality and motion were slightly worse in the free-breathing group compared with the GA group, but that atelectasis did not differ between the groups. The authors reported poor results from atelectasis in a subgroup of GA patients scanned during free breathing, such that they had to abandon this approach. They concluded that the free-breathing technique was sufficient for most purposes because image interpretation is most hampered by atelectasis, and that GA should only be used for cases where image quality must be further optimized.

The paper of Kino et al. [1] offers a practical and clinically meaningful approach to the exploration of image quality as a determinant of diagnostic accuracy. One can question the validity of their scoring systems for image quality: what really is the clinical relevance of the difference among image-quality scores of "good" (3), "very good" (4) and "excellent" (5), when all that is required to make a confident diagnosis is "satisfactory" (2)? Also, one must consider the diagnostic task at hand: an image might be satisfactory to diagnose a large abscess but not to detect a 2-mm lung nodule, subtle bronchiectasis or tree-in-bud opacities. Apart from these controversies, any publication that would speak against the over-use of anesthesia for diagnostic procedures in children is welcome. Abandoning general anesthesia in pediatric chest CT would result in great benefits for children and could save substantial costs and potential morbidity [2, 3].

In the late 1990s, Drs. Pinar Garcia-Peña and Javier Lucaya from Barcelona pioneered the use of high-resolution low-dose CT in the diagnosis of chest diseases in children [4–6]. The advantage of the cross-sectional display of the pathology afforded by CT over the familiar projectional display from radiographs is obvious. Because of the high intrinsic contrast within aerated lung parenchyma, chest CT applications can successfully be performed at a low radiation dose. Aided by the technological advancement of high acquisition speeds enabled by dual-source wide-detector spiral CT, aggressive efforts to reduce radiation doses have brought these down to that of just a few chest radiographs [7–11]. The most limiting factor for image quality is internal physiological (cardiac and respiratory) and whole-patient (translatory) motion, and this can be largely "frozen" by the fast acquisitions that are now possible on these scanners, in combination with meticulous strategies for short periods of patient immobilization and distraction during the few seconds required for image acquisition. As a result of this evolution, the distinction between high-resolution CT (traditionally acquired sequentially with thin slices at 1-cm intervals) and conventional CT (contiguous thicker slices) has blurred: from a single three-dimensional dataset obtained with modern scanners one can reconstruct both sets of images without "missing" any portions of the lung parenchyma.

As CT has been made available for an increasing number of indications [12], so has the perceived need to perform sedation and anesthesia to facilitate these procedures in rambunctious toddlers. Dr. Frederic Long published impressive results using suspended respiration techniques to ensure motion-free images at full inspiration [13–19], without artifact from anesthesia-related atelectasis [20, 21]. This iatrogenic condition interferes more with diagnostic accuracy than motion and other interrelated parameters that determine image quality, such as reconstructed slice thickness, kernel and image noise (dose). In addition, artifacts emanate from the

✉ Sjirk J. Westra
swestra@partners.org

[1] Division of Pediatric Radiology, Massachusetts General Hospital, 34 Fruit St., White 246A, Boston, MA 02114, USA

endotracheal tube when it is employed, which interfere with the evaluation of the tracheobronchial tree.

In an analogy, we might compare the risk from anesthesia for diagnostic procedures such as CT and MRI with the radiation risk from CT. Regarding the latter, I believe it is no longer a point of discussion whether one CT scan causes damage to the deoxyribonucleic acid (DNA). This has been demonstrated with sufficiently sensitive techniques in every patient immediately after leaving the scanner [22, 23]. The crucial issue then becomes whether the DNA repair mechanisms are sufficiently capable to repair this damage, so that any latent damage caused by the scan [24] does not express later in life as cancer following a second hit [25]. The immediate risks of anesthesia are better known and, while generally considered low [2, 3], when multiplied by the increasing numbers of sedated diagnostic procedures now being performed on children, have had measurable unintended consequences [3], such as intensive care unit (ICU) admissions and even deaths. A similar public health argument could be made with respect to the delayed consequences of radiation carcinogenesis. A recent epidemiological study that followed up children exposed to CT radiation [26] has added substance to the claim made by prior studies [27–29] that a single CT scan is capable of causing cancer. Conversely, there is no formal proof that the postulated neurotoxic effects of one anesthesia administered to a child younger than 3 years can cause mental retardation [30–32]. This uncertainty has caused our subspecialty to vacillate between favoring CT and MR as the optimal cross-sectional modality (other than ultrasound) to image young children, with the pendulum lately swinging in favor of fast CT [33], especially in the chest.

With CT, we have become the obliging accomplices of our own success. This trend has been abetted by the combination of defensive medicine and the health care economics resulting from our current fee-for-service reimbursement paradigm [12, 34–37]. The following remarkable quote from an interventional radiologist caught my attention: "Me and my partner, we eat what we kill — in the radiology group itself, every rat eats what he kills" [38]. Indeed, I believe many radiology professionals including myself feel under pressure to apply this "business model" to earn our keep. I have referred to this issue as "the hidden financial conflict of interest of our profession" [39, 40]. In his recent opinion article on CT risk communication, Dr. Mervyn Cohen [41] expressed his belief that the radiation risk from CT "if any, is minute" and cannot be discussed in a meaningful way with parents. He went on to state that "It is like requiring a car salesman to explain the risks of dying in a car accident every time he sells a car." With this unfortunate choice of words, he compared pediatric radiologists with car salesmen, and he implied that we don't want to be seen as killing the golden goose of CT by having to bother (and confuse) parents with risks that cannot be quantified.

Before becoming aware of my "conflict of interest," I too tried to be a diligent salesman for my department by offering CT to referring physicians caring for patients with chronic pulmonary conditions such as cystic fibrosis, with rather disappointing results. I have learned from them that they have enough clinical tools to guide their treatment decisions, and that the detail provided by CT does not provide much clinical relevance (perhaps with the exception of localized bronchiectasis amenable to resection). I received a similar response after demonstrating diffuse or local air-trapping in the lung parenchyma in people with asthma and cystic fibrosis. Aided by sedation or anesthesia, we are now able to routinely acquire motionless images of the tracheobronchial tree at full inspiration and end-expiration [42] in a cross-sectional format [17–19, 43]; however these acquisitions do not truly investigate the dynamic nature of tracheo-bronchomalacia. To address this, others have developed free-breathing cine chest CT [44, 45] and "four-dimensional" CT on a scanner with enough detectors to cover the relevant anatomy without need for table motion [9, 46–49]. Yet, I have found that my results with these techniques usually did not affect the clinical management of dynamic airway collapse because most children eventually outgrow this condition and bronchoscopy has remained the diagnostic gold standard for this condition at my hospital [50]. My initial enthusiasm to use CT in the diagnosis of infantile interstitial lung diseases [51] has been tempered by the fact that CT findings are rarely specific enough to obviate the need for a lung biopsy. Even in cases of suspected neuroendocrine hyperplasia of infancy (NEHI), I have learned that my findings rarely followed the published typical criteria [52].

Of course, CT has proved its value in penetrating chest trauma, and in blunt trauma when there is continued blood or air drainage from chest tubes, raising the need for mechanical ventilation not explained by radiographs and a clinical or radiographic presentation of suspected traumatic aortic aneurysm [53]. CT is indispensable for the evaluation of congenital malformation of the lungs and the cardiovascular structures, and for oncological follow-up. For the initial evaluation of pleural complications of pulmonary infections in immunocompetent children, ultrasound has proven diagnostic superiority and greater cost-effectiveness than CT [54]. CT really should not be performed any more to obtain an abnormal Haller index as a prerequisite to gain insurance coverage of the corrective cosmetic surgery for pectus excavatum — it can be replaced by analogous measurements on plain radiographs [55] or MRI [56]. The issue here is not so much the avoidance of unnecessary radiation, the dose of which is very low with modern techniques [11], but rather the avoidance of inadvertent detection of incidentalomas (tiny inconsequential lung "ditzels" mislabeled as nodules) that require expensive and futile workup [57–59].

In conclusion, the study by Kino et al. [1] conveys the important message that image quality does not always have to be perfect for pediatric radiologists to make confident diagnoses, which is a refreshing perspective. Because we are not merely image readers, but primarily physicians, we have been trained in our fellowship and through experience to incorporate the limited information derived from our noisy low-dose images degraded by some motion into the larger medical picture. I first learned this from Dr. Webster Riggs, who stated this in a brilliant essay "Why radiologists tend to overcall pediatric chest radiographs" [60]:

> "[W]hen we approach a chest film, all our previous understanding of normal goes out the window. In our minds, we have a picture of an absolutely pristine chest film. If the film in question deviates one iota from this image of perfection, we call it abnormal. It does not have to be perfect to be normal. Technical imperfections, anatomic variations, and subtle combinations of these should be recognized."

Mutatis mutandis, this wisdom also applies to the interpretation of chest CT scans. Areas of "patchy ground-glass opacity in the posterior lung bases" and "tree-in-bud nodules" frequently disappear miraculously upon repeat scanning at suspended full inspiration or obtained in a different position (prone or decubitus [61]), quite analogously to what experienced old-school pediatric radiologists found when interpreting chest radiographs. The good news is that CT doses have plummeted in recent years to sub-milliSievert levels [10, 11] and I now don't regard such radiation as an obstacle to repeat an acquisition in the same session, if this can fundamentally change the interpretation of the exam. Such an approach requires pediatric radiologists to actively monitor exams while the child is still in the scanner, in a problem-oriented approach that distinguishes our subspecialty from the rule-out mindset adopted by our adult-focused colleagues. It can enable our desire to practice in a personalized, patient-centered manner, rooted in principles of cost-effectiveness, beneficence and evidence-based medicine, while adding value to the health care system [62]. In this process, we hope to rise above the rat race and continue to make a decent living for ourselves in an ethical manner.

Compliance with ethical standards

Conflicts of interest None

References

1. Kino A, Zucker EJ, Honkanen A et al (2018) Ultrasfast pediatric chest CT: comparison of free breathing vs. breath-hold imaging with and without anesthesia in young chidren. Pediatr Radiol. https://doi.org/10.1007/s00247-018-4295-5
2. De Francisci G, Papasidero AE, Spinazzola G et al (2013) Update on complications in pediatric anesthesia. Pediatr Rep 5:e2
3. Sanborn PA, Michna E, Zurakowski D et al (2005) Adverse cardiovascular and respiratory events during sedation of pediatric patients for imaging examinations. Radiology 237:288–294
4. Garcia-Pena P, Lucaya J (2004) HRCT in children: technique and indications. Eur Radiol 14:L13–L30
5. Lucaya J, Garcia-Pena P, Herrera L et al (2000) Expiratory chest CT in children. AJR Am J Roentgenol 174:235–241
6. Lucaya J, Piqueras J, Garcia-Pena P et al (2000) Low-dose high-resolution CT of the chest in children and young adults: dose, cooperation, artifact incidence, and image quality. AJR Am J Roentgenol 175:985–992
7. Shi JW, Xu DF, Dai HZ et al (2016) Evaluation of chest CT scan in low-weight children with ultralow tube voltage (70 kVp) combined with flash scan technique. Br J Radiol 89:20150184
8. Young C, Xie C, Owens CM (2012) Paediatric multi-detector row chest CT: what you really need to know. Insights Imaging 3:229–246
9. Zhu Y, Li Z, Ma J et al (2018) Imaging the infant chest without sedation: feasibility of using single axial rotation with 16-cm wide-detector CT. Radiology 286:279–285
10. Kim HJ, Yoo SY, Jeon TY, Kim JH (2016) Model-based iterative reconstruction in ultra-low-dose pediatric chest CT: comparison with adaptive statistical iterative reconstruction. Clin Imaging 40:1018–1022
11. Villanueva-Meyer JE, Naeger DM, Courtier JL et al (2017) Pediatric chest CT at chest radiograph doses: when is the ultralow-dose chest CT clinically appropriate? Emerg Radiol 24:369–376
12. Broder J, Fordham LA, Warshauer DM (2007) Increasing utilization of computed tomography in the pediatric emergency department, 2000-2006. Emerg Radiol 14:227–232
13. Long FR (2001) High-resolution CT of the lungs in infants and young children. J Thorac Imaging 16:251–258
14. Long FR (2007) High-resolution computed tomography of the lung in children with cystic fibrosis: technical factors. Proc Am Thorac Soc 4:306–309
15. Long FR, Castile RG (2001) Technique and clinical applications of full-inflation and end-exhalation controlled-ventilation chest CT in infants and young children. Pediatr Radiol 31:413–422
16. Mueller KS, Long FR, Flucke RL, Castile RG (2010) Volume-monitored chest CT: a simplified method for obtaining motion-free images near full inspiratory and end expiratory lung volumes. Pediatr Radiol 40:1663–1669
17. Long FR (2005) Imaging evolution of airway disorders in children. Radiol Clin N Am 43:371–389
18. Long FR, Williams RS, Adler BH, Castile RG (2005) Comparison of quiet breathing and controlled ventilation in the high-resolution CT assessment of airway disease in infants with cystic fibrosis. Pediatr Radiol 35:1075–1080
19. Long FR, Williams RS, Castile RG (2005) Inspiratory and expiratory CT lung density in infants and young children. Pediatr Radiol 35:677–683
20. Newman B, Krane EJ, Gawande R et al (2014) Chest CT in children: anesthesia and atelectasis. Pediatr Radiol 44:164–172
21. Sargent MA, McEachern AM, Jamieson DH, Kahwaji R (1999) Atelectasis on pediatric chest CT: comparison of sedation techniques. Pediatr Radiol 29:509–513
22. Nguyen PK, Lee WH, Li YF et al (2015) Assessment of the radiation effects of cardiac CT angiography using protein and genetic biomarkers. JACC Cardiovasc Imaging 8:873–884
23. Piechowiak EI, Peter JF, Kleb B et al (2015) Intravenous iodinated contrast agents amplify DNA radiation damage at CT. Radiology 275:692–697

24. Rothkamm K, Lobrich M (2003) Evidence for a lack of DNA double-strand break repair in human cells exposed to very low x-ray doses. Proc Natl Acad Sci U S A 100:5057–5062
25. Shuryak I, Sachs RK, Brenner DJ (2010) Cancer risks after radiation exposure in middle age. J Natl Cancer Inst 102:1628–1636
26. Meulepas JM, Ronckers CM, Smets A et al (2018) Radiation exposure from pediatric CT scans and subsequent cancer risk in the Netherlands. J Natl Cancer Inst. https://doi.org/10.1093/jnci/djy104
27. Huang WY, Muo CH, Lin CY et al (2014) Paediatric head CT scan and subsequent risk of malignancy and benign brain tumour: a nation-wide population-based cohort study. Br J Cancer 110: 2354–2360
28. 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
29. 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
30. Sun LS, Li G, Miller TL et al (2016) Association between a single general anesthesia exposure before age 36 months and neurocognitive outcomes in later childhood. JAMA 315: 2312–2320
31. Vutskits L, Davidson A (2017) Update on developmental anesthesia neurotoxicity. Curr Opin Anaesthesiol 30:337–342
32. Warner DO, Zaccariello MJ, Katusic SK et al (2018) Neuropsychological and behavioral outcomes after exposure of young children to procedures requiring general anesthesia: the Mayo Anesthesia Safety in Kids (MASK) study. Anesthesiology 129:89–105
33. Greenberg SB (2011) Rebalancing the risks of computed tomography and magnetic resonance imaging. Pediatr Radiol 41:951–952
34. Berdahl CT, Vermeulen MJ, Larson DB, Schull MJ (2013) Emergency department computed tomography utilization in the United States and Canada. Ann Emerg Med 62:486–494
35. Brenner DJ (2012) Minimising medically unwarranted computed tomography scans. Ann ICRP 41:161–169
36. Hendee WR, Becker GJ, Borgstede JP et al (2010) Addressing overutilization in medical imaging. Radiology 257:240–245
37. Gulla RP (2008) Massachusetts Medical Society first-of-its-kind survey of physicians shows extent and cost of the practice of defensive medicine and its multiple effects of health care on the state. http://www.macrmi.info/files/4913/5543/4626/PR_Medical_Society_Study_on_Defensive_Medicine_final_11-17.pdf. Accessed 13 Nov 2018
38. MedPage Today (2018) 'We eat what we kill': what we heard this week. https://www.medpagetoday.com/radiology/diagnosticradiology/71977. Accessed 6 Nov 2018
39. Kasraie N, Jordan D, Keup C, Westra S (2018) Optimizing communication with parents on benefits and radiation risks in pediatric imaging. J Am Coll Radiol 15:809–817
40. Westra SJ (2014) The communication of the radiation risk from CT in relation to its clinical benefit in the era of personalized medicine. Part 2: benefits versus risk of CT. Pediatr Radiol 44:525–533
41. Cohen MD (2015) ALARA, image gently and CT-induced cancer. Pediatr Radiol 45:465–470
42. Lee EY, Tracy DA, Bastos M et al (2010) Expiratory volumetric MDCT evaluation of air trapping in pediatric patients with and without tracheomalacia. AJR Am J Roentgenol 194:1210–1215
43. Lee EY, Boiselle PM (2009) Tracheobronchomalacia in infants and children: multidetector CT evaluation. Radiology 252:7–22
44. Goo HW (2013) Free-breathing cine CT for the diagnosis of tracheomalacia in young children. Pediatr Radiol 43:922–928
45. Goo HW, Kim HJ (2006) Detection of air trapping on inspiratory and expiratory phase images obtained by 0.3-second cine CT in the lungs of free-breathing young children. AJR Am J Roentgenol 187: 1019–1023
46. Ullmann N, Secinaro A, Menchini L et al (2018) Dynamic expiratory CT: an effective non-invasive diagnostic exam for fragile children with suspected tracheo-bronchomalacia. Pediatr Pulmonol 53: 73–80
47. Greenberg SB (2012) Dynamic pulmonary CT of children. AJR Am J Roentgenol 199:435–440
48. Wagnetz U, Roberts HC, Chung T et al (2010) Dynamic airway evaluation with volume CT: initial experience. Can Assoc Radiol J 61:90–97
49. Greenberg SB, Dyamenahalli U (2014) Dynamic pulmonary computed tomography angiography: a new standard for evaluation of combined airway and vascular abnormalities in infants. Int J Card Imaging 30:407–414
50. Carden KA, Boiselle PM, Waltz DA, Ernst A (2005) Tracheomalacia and tracheobronchomalacia in children and adults: an in-depth review. Chest 127:984–1005
51. Guillerman RP (2010) Imaging of childhood interstitial lung disease. Pediatr Allergy Immunol Pulmonol 23:43–68
52. Brody AS, Guillerman RP, Hay TC et al (2010) Neuroendocrine cell hyperplasia of infancy: diagnosis with high-resolution CT. AJR Am J Roentgenol 194:238–244
53. Moore MA, Wallace EC, Westra SJ (2011) Chest trauma in children: current imaging guidelines and techniques. Radiol Clin N Am 49:949–968
54. Kurian J, Levin TL, Han BK et al (2009) Comparison of ultrasound and CT in the evaluation of pneumonia complicated by parapneumonic effusion in children. AJR Am J Roentgenol 193: 1648–1654
55. Khanna G, Jaju A, Don S et al (2010) Comparison of Haller index values calculated with chest radiographs versus CT for pectus excavatum evaluation. Pediatr Radiol 40:1763–1767
56. Marcovici PA, LoSasso BE, Kruk P, Dwek JR (2011) MRI for the evaluation of pectus excavatum. Pediatr Radiol 41:757–758
57. Schroeder AR, Redberg RF (2013) The harm in looking. JAMA Pediatr 167:693–695
58. Swensen SJ, Duncan JR, Gibson R et al (2014) An appeal for safe and appropriate imaging of children. J Patient Saf 10:121–124
59. Westra SJ, Thacker PG, Podberesky DJ et al (2015) The incidental pulmonary nodule in a child. Part 2: commentary and suggestions for clinical management, risk communication and prevention. Pediatr Radiol 45:634–639
60. Riggs W (1996) Why radiologists tend to overcall pediatric chest radiographs. Appl Radiol 1996:38–39
61. Choi SJ, Choi BK, Kim HJ et al (2002) Lateral decubitus HRCT: a simple technique to replace expiratory CT in children with air trapping. Pediatr Radiol 32:179–182
62. European Society of Radiology (2017) ESR concept paper on value-based radiology. Insights Imaging 8:447–454