European Journal of Radiology 72 (2009) 266–273

Contents lists available at ScienceDirect

European Journal of Radiology

journal homepage: www.elsevier.com/locate/ejrad

Optimizing digital radiography of children

Charles E. Willis *

University of Texas M. D. Anderson Cancer Center, Department of Imaging Physics, 1515 Holcombe Boulevard, Unit 1352, Houston, TX 77030-4009, United States

ARTICLE INFO

Article history:
Received 25 February 2009
Accepted 4 March 2009

Keywords:
Pediatric radiography
Computed radiography
Digital radiography
Dose optimization

ABSTRACT

Pediatric projection imaging differs from imaging of the adult patient. Children are smaller, more radiosensitive, and less compliant than their adult counterparts. Their characteristics affect the way projection imaging is practiced and how dose is optimized.

Computed radiography (CR) and digital radiography (DR) have been embraced by pediatric practitioners in order to reduce dose and improve image quality. Unfortunately, dose optimization with CR and DR has been hampered by a lack of definition of appropriate exposure levels, a lack of standardization in exposure factor feedback, and a lack of understanding of the fundamentals of CR and DR technology. The potential for over-exposure exists with both CR and DR. Both the Society for Pediatric Radiology and the American Association of Physicists in Medicine recognize the promise and shortcomings of CR and DR technology and have taken steps to join with manufacturers in improving the practice of CR and DR imaging. Although the risks inherent in pediatric projection imaging with CR and DR are low, efforts to reduce dose are worthwhile, so long as diagnostic quality is maintained. Long-standing recommendations for limiting radiation dose in pediatric projection imaging are still applicable to CR and DR.

1. Introduction

"Optimization" is frequently used in diagnostic radiologic imaging to describe the process of obtaining the highest quality diagnostic images at the lowest practical ionizing radiation dose to the patient. An acronym that embodies this philosophy is "ALARA", i.e. "As Low As Reasonable Achievable". Optimization is a balancing act between the benefit of the diagnostic imaging examination to the patient and the associated risk of the ionizing radiation exposure. Optimization, therefore, cannot consider modifications of image quality without also weighing concomitant effects on patient radiation exposure and *vice versa*.

Dose optimization has been a longstanding concern in pediatric projection imaging because of the increased sensitivity of children to the stochastic effects of ionizing radiation. According to the National Academy of Sciences Biological Effects of Ionizing Radiations Committee (BIER VII), the risk of cancer mortality attributable to a single, acute radiation exposure for patients under 15 years of age is more than twice the average risk for patients in other age cohorts [1]. The age-time pattern of excess cancer deaths is strongly dependent on the age of exposure. From an actuarial perspective, even if the sensitivity was equivalent, younger patients have more years remaining to manifest deleterious effects of ionizing radiation. In terms of risk, projection radiography receives less attention than computed tomography (CT) and fluoroscopy, because patient dose per projection examination is typically one or two orders of magnitude lower than those other imaging modalities. However, many more projection examinations are performed than CT or fluoroscopic examinations.

Pediatric patients present imaging challenges that differ from typical adult patients. A substantial fraction of pediatric patients are uncooperative and many cannot stand unassisted. Small patient dimensions and patient motion make registering the appropriate anatomy with ion chambers for automatic exposure control (AEC) difficult, so that for pediatric examinations manual technique selection is the norm. The sizes of pediatric patients range from neonatal to adult. Adult technique guides based on the assumption that a single set of exposure factors can be appropriate for more than 80% of the patient population are clearly inappropriate for the wide range of dimensions presented by pediatric patients. The small dimensions of clinical features in pediatric patients are so demanding on imaging systems that some pediatric radiologists have deliberately chosen medium speed conventional screen-film systems over fast systems in order to get better sharpness, even after considering the penalty in terms of patient dose. A number of special projection examinations are performed more frequently for pediatric patients than adults including evaluation of skeletal development and asymmetry, such as the full-leg examination and scoliosis exams, as well as skeletal surveys for the purpose of excluding non-accidental trauma.

Recognizing the special needs of the pediatric population, the Society for Pediatric Radiology (SPR), the American Association of Physicists in Medicine (AAPM), the American College of Radiology, and the American Society of Radiologic Technologists have formed

* Tel.: +1 713 563 2721; fax: +1 713 563 8842.
E-mail address: chwillis@mdanderson.org.

0720-048X/$ – see front matter © 2009 Elsevier Ireland Ltd. All rights reserved.
doi:10.1016/j.ejrad.2009.03.003

"The Alliance for Radiation Safety in Pediatric Imaging", also known as "Image Gently^{SM}" with thirty other professional organizations. The purpose of the Alliance is to "raise awareness in the imaging community of the need to adjust radiation dose when imaging children." "The ultimate goal of the Alliance is to change practice."

2. History of image quality and dose optimization

Efforts to optimize image quality and dose in pediatric computed radiography (CR) and digital radiography (DR) began with the earliest introduction of the technologies into clinical practice and continue today. Early investigators reported dose reductions from reduced radiographic technique, lower incidence of repeated images, and post-acquisition digital image processing. Recently, a conference organized by SPR discussed the ALARA Concept in pediatric CR and DR [2]. The conference included papers from academia and industry and the proceedings were published in a special issue of *Pediatric Radiology*. Among the findings were that over-exposure in CR and DR is common, that standardization in the manner and nomenclature of dose feedback and image processing was lacking, and that a team approach including active participation of a radiologist, medical physicist, and manufacturer is needed for dose management. Training of radiologists, medical physicists, and especially radiographers in CR and DR was identified as a deficiency.

2.1. How much radiation is necessary?

When describing CR and DR examinations as "low-dose" it is important to establish an objective basis for comparison. Many pediatric radiographic examinations performed today still use conventional screen-film systems. The majority of dose estimates that exist in the literature are also based on screen-film radiography. Since the earliest introduction of CR and DR, screen-film technology has experienced advancements, resulting in widespread adoption of 250, 400, and 600 speed class systems for pediatric use. Therefore, screen-film as a gold standard has been a moving target. Recent surveys of the dose associated with conventional pediatric examinations are available in the literature [3,4]. Concurrently, CR has undergone continuous development with respect to detector technology. Generalizations about CR may be inappropriate since commercial CR systems vary widely with respect to dose efficiency and spatial resolution.

By means of a user preference study, Huda et al. demonstrated that the mottle on CR pediatric ICU chest images imposes a limitation on dose reduction [5]. They reported that CR required approximately three times the radiation needed for a 600 speed screen-film system, which correlates well with imaging physics characterizations. However, they noted that lower level of radiation might be appropriate for clinical evaluations where perceived mottle does not impede diagnosis.

The fundamental question in dose reduction is whether or not concomitant decreases in image quality affect the physician's ability to perform a diagnostic task. Roehrig et al. conducted a Receiver Operator Characteristic (ROC) Study using a stack of multiple image receptors to acquire clinical images of neonates with Hyaline Membrane Disease (HMD) simultaneously at four receptor dose levels [6]. They found that although the image quality rating at 50% reduction was significantly lower, observer performance was not statistically different at up to 75% dose reduction. There are some limitations to conclusions that can be drawn from this study. The mean exposure level of the group of images obtained with the highest dose level was already underexposed by a factor of 2.5. A contrast detail study was performed in order to demonstrate that objects in the size range of the disease pattern in HMD were detectible at the lowest exposure level. Unfortunately, the uncertainty in threshold contrast was approximately 100% of detail size, compromising conclusions that can be made regarding the effect of reduced exposure on observer performance.

Don et al. addressed the same question using a rabbit model to simulate neonatal pulmonary infiltrates and found that a 20% reduction in exposure was possible using CR compared to an optimized screen-film system [7]. The speed class of the screen-film system used as reference, however, remains undefined as in many other publications.

Hufton et al. compared pediatric images of a 600 speed class screen-film system to pediatric CR images according to Council of European Communities (CEC) criteria for visibility of clinical features [8]. Even though CR doses were about 40% lower except for chest images that were about the same, no significant difference was found in image quality scores for the different receptors. The authors suggest that CR could be used as approximately 1000 speed class for abdomen, pelvis, and skull and 600 speed class for chest exams. It is important to note that only an average of approximately 80% of the CR and screen-film images were deemed acceptable according to all CEC criteria.

Huda points out that the conventional concept of speed is inappropriate in describing digital imaging systems, because, unlike with conventional screen-film systems, there is no direct relationship between speed and limiting spatial resolution [9]. Furthermore, the noise characteristics of high speed screen-film systems are maintained by capturing more photons with thicker screens, whereas changing the exposure level where a digital imaging system operates directly changes the noise characteristics. Even though it is an incorrect surrogate for describing the operating exposure level of a digital imaging system, much of the existing literature uses speed to compare screen-film and CR/DR.

If the diagnostic task involves detection of high contrast clinical features, such as evaluation of curvature of the spine in scoliosis exams, it might be reasonable to use low dose where quantum mottle is not a limitation so long as contrast can be developed. Except for the initial evaluation of scoliosis where exclusion of bony or soft tissue abnormalities is necessary, follow-up examinations would not require the same degree of image quality, so dose could be reduced [10]. A similar rationale is used for tailoring ICU exams intended to verify feeding tube and central line placement. Reduced dose/quality imaging might not be indicated for tube placements when the clinical consequence of incorrect placement, such as pneumothorax, might not be detectable in a low quality image.

2.2. How much radiation was used?

The disconnection of display from acquisition which gives CR and DR the ability to produce consistent images irrespective of variations in exposure factor also introduces the potential for systematic over-exposure [11,12]. Over-exposed CR and DR images have a crisp, noise-less appearance that is preferred by radiologists. Oversight of the "exposure indicator", a derived quantity automatically calculated by the CR system that suggests the quantity of exposure to the image receptor is the key to controlling exposure levels in CR and DR radiography [13].

The ability for CR and DR to compensate for over-exposure and under-exposure means that the operator cannot simply rely on a superficial evaluation of image density to indicate proper exposure technique. Many CR and DR systems provide feedback in the form of a derived numerical indicator of exposure. At the present time, there is no standardization of the mathematical form, calibration conditions, or units of exposure indicators among manufacturers. As illustrated in Table 1, this variety leads to confusion among practitioners as to the meaning of the values reported by the systems. AAPM Task Group #116 is working with manufacturers to establish these standards. Simultaneously, the International Electrotechnical