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Directed Reading

The New Exposure Indicator for Digital Radiography

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ABSTRACT

This article describes the essential elements of the new standardized exposure indicator (EI) established by the International Electrotechnical Commission for digital radiography systems. First, a review of the limitations of the narrow exposure latitude of film screen radiography is presented followed by the brief description of two digital radiography systems, a computed radiography system and a flat-panel digital radiography system. These systems feature wide exposure latitude, variable speed class, and image processing to produce images that appear with the same density regardless of the exposure used and a characteristic EI displayed on images to provide the technologist with some indication of the exposure level to the digital detector. The third point described focussed on the major elements of the standardized EI of the IEC and described them with respect to standardization efforts, deviation index, and the target EI (EI_T), responsibilities of both the manufacturers and users. This new standardized EI is now proportional to the detector exposure and requires the user to establish EI_T values for all examinations in order to ensure optimization of the dose to the patient without compromising the image quality. The values (EI and EI_T) can now be used to calculate the DI, which provides immediate feedback to the technologist as to whether the correct exposure was used for the examination. Finally, an insight into optimization research will be presented as a means of illustration of a dose-image quality optimization strategy that can be used to determine EI_T values objectively.

Keywords: new exposure indicator (EI); digital radiography; international standardized EI; target EI; deviation index (DI)

Learning Objectives

At the completion of the article, the reader should be able to

1. Define the term "digital radiography"
2. Describe the problems of the narrow exposure latitude of film screen (FS) radiography
3. Describe how the wide exposure latitude of DR systems to overcome the limitations of FS narrow exposure latitude
4. State the meaning of the term "exposure creep"
5. Identify the major system components of CR and FPDR and how each system works
6. Explain the difference between indirect and direct FPDR systems
7. Describe the main features of the exposure indicator (EI) for DR systems
8. Explain the nature of the EI for the Fuji, Agfa, and Carestream (formerly Kodak) DR systems. Specifically state the relationship between the EI and the detector exposure for each of the three systems
9. State three uses of the EI in routine clinical practice
10. Describe the basic steps to determine the EI
11. List typical ranges of EI values for several DR systems recommended by their respective manufacturers
12. State two reasons why it is not possible to compare directly the EIs between different digital radiography systems
13. Describe briefly the background work in an effort to standardize the EI
14. Outline the conditions that must be considered in order to establish a standardized EI proposed by the IEC
15. Provide the IEC definition of each of the following:
    - EI
    - Target exposure indicator (EI_T)

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- Deviation index (DI)
- Volume of Interest (VOI)

16. Outline the details in the determination of an international standardized EI
17. Explain the interpretation of the following DI values:
    - DI = 0
    - DI = +1
    - DI = −1
    - DI > +1 and < −1
18. Discuss the role of the manufacturer and the user in the implementation of the new international standardized EI
19. Describe one possible scenario for establishing objectively optimized EI_T values

Introduction

Digital radiography (DR) is defined by the American Association of Physicists in Medicine (AAPM) [1] as "radiographic imaging technology producing digital projection images such as those using photostimulable storage phosphor (computed radiography or CR), amorphous selenium, amorphous silicon, charge-couple device (CCD), and metal oxide semiconductor-field effect transistor (MOSFET) technology."

The term *digital radiography* as used in this article refers to projection radiography whereby a digital computer is used to process attenuation data collected from patients using special photostimulable phosphor and electronic detectors that have replaced the x-ray film cassette. The detectors capture and convert x-ray attenuation data from the patient into electronic signals (analog signals) that are subsequently converted into digital data for processing by a digital computer [2]. The result of processing is a digital image that must be converted into one that can be displayed on a computer monitor for viewing by an observer. The displayed image can be manipulated using a variety of digital image processing techniques to enhance the interpretation of diagnostic radiology images [3]. Furthermore, DR includes image and information management systems, image storage, and image and data communications.

One of the significant benefits of DR systems is to solve the problem of the narrow exposure latitude of film screen (FS) radiography. Such exposure latitude can be described by the well-known film characteristic curve or the Hurter-Driffield curve, which provides information on the film response to exposure [2]. The curve is a plot of the optical density to the log of the relative exposure used for the examination as shown in Figure 1. The acceptable image contrast is obtained with an exposure that falls within the slope of the curve. This slope defines the exposure latitude as well as the film contrast characteristics (the steeper the gradient the higher the contrast) [2]. Exposures that fall in the toe and shoulder region of the curve will result in images that are light (underexposed) and images that are dark (overexposed), respectively. As such, the image density is used as an exposure indicator that provides immediate feedback to the technologist that the correct exposure technique factors (kV and mA) have been used for the examination. This curve also shows that FS imaging systems have fixed film speeds (sensitivity) and a fixed-dose requirement.

DR systems "have wide exposure latitude, a variable speed class of operation, and image post processing capabilities that provide consistent image appearance even with underexposed or overexposed radiographs" [4]. The wide exposure latitude of DR systems that have a linear response to exposure is about 100 times that of FS imaging systems [5]. Furthermore, DR image processing ensures that the image densities created with low exposures (more noise) and high exposures (less noise) appear visually similar (Figure 2), meaning this is now a challenging and difficult task for the observer to recognize underexposure and overexposure on digital images.

The inability of the technologist to detect overexposure will lead to an unnecessary extra radiation dose to the patient. Overexposures 5 to 10 times a normal exposure will appear acceptable to the technologist. Subsequently, this will lead to what has been popularly referred to as exposure creep or dose creep [4].

To address these problems, DR manufacturers provide an exposure indicator (EI) (also referred to as an exposure index) to give the technologist some indication of the exposure level to the digital detector. Furthermore, there is a wide variety of EIs for the different DR systems available from different DR manufacturers (eg, Fuji, Carestream, Agfa, Konica, Siemens, Philips, and so on). This means that there are several proprietary methods to calculate the EI, which has therefore led to different EI names. For example, although Fuji refers to its indicator as a "sensitivity" (S) number, Carestream uses the term "exposure index," and Agfa uses the term "log of the median of the histogram (lgM)." Manufacturers also provide EI ranges for technologists to use when imaging patients. These differences have created "widespread confusion and frustration" for all those using DR systems [4], and this has provided the motivation for the development of a standardized EI, championed by most notably the International Electrotechnical Commission (IEC) [6] and the AAPM [1].

The purpose of the directed reading article is to describe the nature and characteristics of the new international standardized EI for digital radiography. First, basic principles of DR systems, notably CR and flat-panel digital radiography (FPDR), will be reviewed briefly followed by an outline of the major features of the "old" EI. Furthermore, the standardized EI will be described with respect to standardization efforts, deviation index (DI), and the target EI (EI_T), responsibilities of both the manufacturers and users. Finally, an insight into optimization research will be presented as a means of illustration of a dose-image quality optimization strategy to objectively determine EI_T values.

DR: A Review of Basics

This section provides a generalized review of CR and FPDR systems. The basic components unique to each system