DIGITAL RADIOGRAPHY, A PARADIGM SHIFT

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With every passing day radiology departments are getting an increase in patient inflow. Fortunately the changing and evolving digital imaging devices are allowing better images to be obtained facilitating patient care. Radiologists need to remain aware of these advancements. During past two decades, screen-film radiography has been supplanted by digital radiography in many radiology departments. A variety of digital imaging solutions based on various detector and readout technologies have been provided by the manufacturers.

The transmission of x rays through an object and recording of the information is termed as radiography. The transmitted x rays carrying all the information can be recorded by various means which was conventionally done with the help of film screens thus termed film screen radiography (FSR). More recently digital detectors are being employed for this purpose and so the term digital radiography (DR) was coined.

In the case of FSR the X rays after being transmitted through the body get converted into light photons by means of intensifying screens. The film which is in contact with these screens records the latent image which then further requires chemical processing to get a meaningful image. The technology has reached its limits in terms of usability with the systems reaching their theoretical limits in terms of resolution, ease and speed of use.

Although FSR holds advantages like consistency of image appearance, high spatial resolution fairly good uniformity over a large area and added feature of high comfort level due to familiarity and long experience of radiologists in this regard, however quite a few limitations also accompany it, which is why sooner or later a shift from analogue screen-film to digital imaging is underway.[1]

The advent of digital radiography has substantially reduced the limitations associated with FSR techniques. There are several fundamental differences between film screen systems and digital systems. There are two further large classes of digital system namely Computed Radiography (CR) and Digital Radiography (DR).

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DIGITAL IMAGING MILESTONES

It is worth reviewing the historical milestones in the development of digital systems before embarking on the details of various detector types a historical overview of the evolution of digital radiography would allow understanding in context.

In 1977 Kruger et al did the first experimental digital subtraction angiography. It was then later in 1980 that the use of digital methods started in general radiography with cassette-based storage-phosphor image plates.[7] CCD slot-scan system was the first DR system, which appeared in 1990. In 1994, Neitzel et al first published investigations of the selenium drum DR system.[8] An year later the first flat-panel detector DR systems based on amorphous silicon and amorphous selenium were introduced.[9,10]

The introduction of Gadolinium-oxide sulfide scintillators in 1997 proved a great help in portable flat-panel.[11] Dynamic flat-panel detectors used for digital fluoroscopy and angiography are one of the latest development in digital radiography.[12,13]

Detector Systems

A. FILM SCREEN SYSTEMS:

In SF radiography, the X-rays after passing through the body are absorbed in the screen and give away their energy. This deposited energy results in production of multiple photons of visible light that travel through the screen and, in turn, deposit energy in the emulsion layers of the film. The grains in emulsion store the image information. Greater the number of exposed grains more is the optical density which corresponds to more X-ray absorption in the screen. However relationship between the optical density and the X rays absorbed is not necessarily linear.

In case of FSR, optical density ranges are limited by factors like luminance of view box and varied responses due differences in visual acuity. Thus the only realistic option left for maximizing image contrast is changing the exposure dynamic range termed as exposure latitude. One of the main advantages of digital radiography over SFR is its higher exposure latitude. Other than the short exposure latitude SFR has a few other limitations which need to be considered e.g. the requirement of chemical processing, inefficient mechanical handling, incompatibility with electronic transmission and image enhancement, and higher costs for film materials and labour intensity.[2]

B. COMPUTED RADIOGRAPHY:

CR utilizes the principle of photostimulable phosphor luminescence. Image plate made of a suitable phosphor material are exposed to X-rays in the same way as a conventional screen-film combination, however unlike a normal radiographic screen, which releases light spontaneously upon exposure to X-rays, the CR image plate retains most of the absorbed X-ray energy, in highly localized energy traps or metastable areas called f centers, which serve as energy dens. In this way, x-ray energy can be stored for several hours, depending on the specific physical properties of the phosphor crystals used.

With the passage of time following exposure the amount of stored energy decreases over time and therefore the readout process should start immediately. A scanning laser is then used to release the stored energy producing luminescence causing the energy to set free as emitted light with a wave length different from that of the laser beam. This light is collected by photodiodes and converted digitally into an image indigo light photons. Either a line or point scan approach is used. The point-scan approach however increases readout speed to some extent.[3]

The emitted light, is detected by a photomultiplier tube (PMT) for point-scan readers or a linear solid state photodiode array for line-scan readers. The acquired data is then converted to a digital image. The size of the image matrix depends on the dimensions of imaging plate used. The various sizes used are 18 24 cm, 24 30 cm, 35 35 cm, 35 43 cm, and custom sizes.[4]

Since CR systems are cassette based, they can easily be integrated into existing radiographic devices. Additionally on account of their mobile capacity, these systems are easy to use for bedside examinations and immobile patients, making them flexible in portable as well as routine setups.[5]

C. DIGITAL RADIOGRAPHY:

In screen-film radiography, film serves as both detector and storage medium. In contrast digital radiography employs digital detectors which generate the digital image, that is later on stored on a digital medium. Digital imaging systems produce a dynamic image that permits immediate display, image enhancement, storage, retrieval, and transmission.[6]

With the ongoing advancements in radiology equipments a number of technologies are now available in digital systems. Direct radiography basically involves the use of various types of photoconductors the most commonly used element amongst which is selenium. Selenium-based DR systems use either a selenium drum or a flat-panel detector.

Various published reports confirms that selenium drum detectors provide better image quality than CR systems. However, their basic pitfall is the mechanical design which reduces mobility, making them dedicated thorax stand systems.

The new generation selenium-based flat-panel detectors have an advantage since these detectors can be mounted on thorax stands and bucky tables.[14,15]

C.1 Indirect Conversion with a CCD

In CCD-based indirect conversion DR systems the incident x-ray energy is converted into light by a scintillator e.g Tl doped cesium iodide.

Two types of CCD system are used.
1) Lens-coupled CCD system and
2) Slot-scan CCD system

The lens used in first type of system reduces the area of the projected light to fit the CCD array. The problem with lens system is a reduction in the number of photons reaching the CCD, which results in a lower signal-to-noise ratio and relatively low quantum efficiency. In contrast the other type, i.e. Slot-scan uses a special type of X ray tube containing tungsten anode. The performance of lens-coupled CCD systems is somewhat inferior than slot-scan systems due their inherent technical principles substantially lower quantum efficiency and lower signal-to-noise ratio.[15,16]

C.2 Indirect Conversion with a Flat-Panel Detector

These systems consist of a scintillator layer, an amorphous silicon photodiode circuitry layer, and a TFT array.
The basic matrix of TFT array consist of detector elements called dels. Each of these dels contains a transistor which acts as openings for the flow of electrical charge. It is this electrical charge which when built up in the dels makes up the image during X-ray exposure. The amount of charge in each del is proportional to the number of X-rays absorbed in that region of detector (a linear relationship).
Visible light proportional to the incident energy is thus emitted and recorded by an array of photodiodes and then converted to electrical charges. The conversion of X-ray energy to stored electrical charge can either be indirect (involves conversion of X-ray energy to visible photons) or direct type.[17]
The scintillators commonly used are Caesium Iodide (CsI) or Gadolinium-Oxide Sulfide (GOS) crystals. The advantage of CsI-based scintillators is that it can be shaped into a structure array of scintillator needles which decreases the diffusion of light leading to higher strength of the emitted light and thus providing better optical properties and higher quantum efficiency.[18]
The small size of flat panel detectors is another advantage which makes it possible to incorporate them into the existing bucky and stands however CsI based detectors cannot bear mechanical load due to the fine structural framework they possess. This feature also reduces mobility of these detectors. Both of the latter drawbacks have largely been addressed in the most iteration of these detector systems with the modern detectors being both robust and portable.
The use of GOS based scintillators however increases the resistance to mechanical stress to some extent.[11]
The time interval between x ray exposure and image generation takes time as short as 10 seconds with flat-panel detectors. This increases the productivity to a large extent as more patients can be examined in the same amount of time than with other radiographic devices.
Studies by Kotter E, Strotzer M, Chotas HG and Geijer H, show indirect conversion flat-panel detectors to provide very good image quality and being superior to conventional screen-film combinations.[17,19,20,21,22,23]
With improvement in detector technology, digital radiography continues to evolve rapidly as well. Large area direct-readout flat-panel X-ray detectors promise rapid access to the digital image for diagnosis. The flat-panel characteristic allows multipurpose use with bucky tables and rotating units. These systems achieve a detective quantum efficiency, which exceeds the performance of storage phosphor plates and conventional screen-film systems and is comparable with the performance of the selenium-drum detector.[17,23.]
Once the data is acquired it is then further processed to be displayed on the computer. It is this key step in digital radiography, which greatly influences the way an image appears to the radiologist. Prokop and Schaefer-Prokop in their study have looked at the technical aspects and possibilities of digital image processing in more detail.[24]

FACTORS AFFECTING DIGITAL IMAGE QUALITY:

There are many factors affecting the image quality, some of which are discussed.

A. SPATIAL RESOLUTION:

The spatial resolution depends on pixel size. Smaller the pixel size (or the larger the matrix), higher is spatial resolution. For most DR examinations a limiting system spatial resolution of at least 2.5 mm-1 is essential and higher resolution is desirable for specialized applications (e.g., 5.0 mm-1).

The scattering of the laser light beam during readout of image plates is the primary source of spatial resolution loss in CR.[25]

In DR systems spatial resolution depends on two factors.

1) Spread of light photons in the X-ray to light conversion process for indirect systems. This results in blurring similar to screen of an SF system. To minimize this visible photon spread, structured converters are used so that the X-ray photons are incident along the long dimension of the columns. This is however not a problem with direct conversion DR systems because of minimal spread of the electrons occurs within the photoconductor material.

2) Size of the detector causing partial volume effect is the other limiting factor.

B. NOISE:

In radiography, noise can be defined as any fluctuations in the image that do not correspond to variations in the X-ray attenuation of the object being imaged. Noise can be of many types. e.g Random noise and fixed-pattern noise. Examples of random noise include film granularity noise in SF and electronic noise in CR and DR. Internal noise that has a fixed correlation to locations on the receptor is called fixed-pattern noise. Advantage of digital imaging is that fixed-pattern noise can be largely eliminated through digital post-processing.

Another type of noise called quantization noise occurs due to digitization of the analogue detector output voltage to form discrete pixel values.

In case of digital detectors quantization noise can be kept small by using 10 bits to 14 bits (1,024 to 16,384 unique ADUs) in the output image.[26]

Furthermore image can be degraded by scatter radiation. Scanned slot DR detectors possess inherent scatter rejection capability and do not require the use of a grid.

C. DYNAMIC RANGE:

Dynamic range is a measure of the signal response of a detector that is exposed to x-rays .

Digital detectors by having the advantage of a wider and linear dynamic range virtually eliminate the risk of a failed exposure.[27]

D. DETECTIVE QUANTUM EFFICIENCY

Detective quantum efficiency (DQE) refers to the efficiency of a detector in converting incident x-ray energy into signal for forming image.[27]

In practice, the DQE of digital detectors is limited to about 0.45 at 0.5 cycles/mm.

Screen-film systems have a DQE comparable to that of detector CR.

Radiation Dose

Another important issue in radiography is the radiation exposure. Exposure can be obviously be minimized by reducing the number of failed exposures. This reduction is made possible by the wider dynamic range of digital detectors compared with conventional screen-film combinations. Unlike storage-phosphor systems, in which the possibility of exposure reduction is limited, DR systems offer a significantly higher potential for general exposure reduction because of their far superior quantum efficiency.[28,29,30]

Flat-panel detectors achieved the best results in low-exposure imaging, followed by other DR systems such as selenium drum and CCD-based systems.[15,16]

Current State of ART

The current state of art is a novel flat-panel detector with CsI:TI scintillator.32 The detector consists of a single piece 43cm x 43cm amorphous silicon thin-film transistor (TFT) array with MIS (metal-insulator-semiconductor) photoelectric converter having a pixel pitch of 160 m coated with a needle-like crystal CsI:TI scintillator. This has a revised signal chain utilizing an innovative sensor technology. Comparative test have shown that this arrangement has a significant improvement in detector performance in the radiographic exposure range. This is accompanied by almost a 50% reduction in patient dose.

Conclusion

Although DR has a few pitfalls like higher initial cost (especially for DR), lack of familiarity on the part of both radiologists and technologists with electronic image display and with on-line softcopy reading (versus alternator-based batch mode reading), and the lack of consistent feedback to the technologist concerning the use of optimal acquisition techniques the advantages still overweigh the pitfalls.

DR provides us separation of acquisition, display, and archiving, which allows tremendous flexibility using image processing functions such as those that adjust the level (analogous to the brightness) and window width (analogous to the contrast) of the image grayscale presentation. Other advantages include, anatomy-specific presentation and disease-specific algorithms; in most but not all cases better X-ray detection efficiency and higher detective quantum efficiency (DQE) permitting lower dose to the patient; the ability to use a second computer reader to assist the radiologist; reduction in the number of image retakes due to under or overexposure, and elimination of labor-intensive handling and distribution of images during the acquisition process.

One of the major advantages of the digital system is the wide dynamic range of the detector and the histogram equalization. These characteristics explain the improved contrast throughout the image and allow better visualization of low-contrast regions, such as the mediastinum.[31]

The digital storage, availability of images at any required time and implementation of fully digital picture archiving and communication system is the most advantageous factor associated with this system. The feature of automated functionality has led to improved efficiency and throughput while making it easier to use by technologists.

Keeping an eye on healthcare and its dependency on imaging it seems that one day, out of financial necessity, radiology departments might begin to move patients through like a cattle drive. In such situations DR, given its faster cycle time and higher patient throughput will make inroads in medical imaging.

The remarkable advances in technology in DR systems today enable them to answer myriad needs of busy imaging departments. As healthcare facilities upgrade from analogue or CR to DR systems, an increased efficiency is anticipated that will ultimately result in positive cost-benefit ratios in this era of containment of healthcare costs.

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