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Computed and Digital Radiography

Stacy Randel, MSRS, RT (R)(M), RDMS(BR)
Director/Associate Professor
Radiologic Sciences
South Plains College
Levelland, Texas
Digital Imaging

- Digital imaging: any image acquisition process that produces an electronic image that can be viewed and manipulated using a computer
- Currently, there are two major types of digital imaging detectors available
  - computed radiography (CR)
  - digital radiography (DR)

CR Imaging Plate

- The CR imaging system includes:
  - the cassette, which looks very much like a conventional cassette
    - the cassette front is constructed of a radiolucent plastic
    - the back is a radiopaque material, like aluminum
  - Inside the cassette, the film/screen combination is replaced by a photostimulable phosphor plate (PSP)
  - The PSP plate is made up of layers similar to an intensifying screen
    - a protective layer of very thin, tough, clear plastic
    - prevents damage due to handling and processing
- The phosphor layer is the active layer of the plate
- The CR phosphor layer contains europium-activated barium fluorohalide as the photostimulable phosphor
- The phosphor may be either a turbid or structured phosphor layer

CR Imaging Plate

- Turbid phosphor layers have a random distribution of phosphor crystals within a resin material
  - there is no structured pattern
  - results in excessive scattered light
- A structured phosphor layer is one with columnar phosphor crystals within the resin layer
  - the crystals resemble needles standing on end and packed tightly together
- The needle-like crystal formation
  - enhances x-ray absorption
  - limits the spread of stimulated light production
  - increases image sharpness
- A conductive layer grounds the plate to reduce static electricity problems
  - also absorbs excess light to increase sharpness in the phosphor layer
- A support layer provides a rigid structure to the imaging plate
- A light shield layer reduces light backscatter
- A backing layer protects the back of the plate
CR Image Formation

• Three phases to CR image formation
  – exposure
  – light stimulation
  – image plate (IP) erasing

• Exposure
  – incident remnant radiation interacts with the photostimulable phosphors
  – the europium of the phosphor layer and the incident x-ray photon undergo a photoelectric interaction
  – the phosphor crystal activator, europium, is responsible for the storage property of the PSL
  – the stimulated electrons are elevated to the conductive layer
    • just above the electron’s ground energy state (level)
• The ionized and excited photoelectrons are free to migrate within the crystal
  – these migrating photoelectrons ionize other electrons leaving holes or wells in the europium
• Approximately 50% of the ionized electrons and holes immediately recombine
  – emitting an initial light intensity which is NOT involved in the CR image formation
• The remaining 50% of the ionized electrons become trapped in an ionized state
• The areas of trapped electrons and their corresponding electron “holes” are called color centers or F-centers
  – form the CR latent image
• The quantity and distribution are proportional to the exposure

CR Image Formation

• Over time, the trapped electrons will return to their ground state
  – if the imaging plate is not processed within a reasonable time the latent image will fade
• Approximately 25% of the stored electrons will return to ground state in 8 hours
• However, the return to that normal ground energy state can be accelerated or initiated by exposing the phosphor crystals to intense infrared light from a laser
• Light stimulation
  – processing the PSP latent image requires the use of a CR reader
  – the energy of the trapped electrons is released by exposure to an infrared laser beam
    • this is called photostimulable luminescence
• Either a helium-neon laser or solid state laser device is used in a CR reader
• Solid state lasers are replacing the helium-neon laser as the device of choice in CR readers
  – solid state lasers produce a very finely-focused beam with a diameter of 50-100 nanometers (nm) which is much smaller than the helium-neon laser beam
• In addition, the solid state laser beam is more monochromatic (made up of one color or shades of one color) which makes it easier to separate the polychromatic (multicolored) emissions from the stimulated PSPs
CR Image Formation

• The CR imaging plate cassette is handled similar to a daylight film processor
  — does not require a darkroom environment
• When the cassette is inserted into the reader, the plate is removed and fed into the scanning area
  — the laser beam is focused and moved across the imaging plate
• This light stimulation process is called image retrieval or the secondary excitation phase
  — image retrieval: when the imaging plate is exposed to remnant x-radiation
• The laser energy releases the trapped electrons from the conduction band
• The emitted light is directed to the photodetector by way of a fiber optic bundle or a solid, light-conducting material
• CR photodetectors are typically photodiodes
  — a solid state device that converts light into an electric current
• Before the emitted light can be fed to the photodiode, the blue to blue-violet photons have to be separated from the laser’s red photons
• This is done by placing a filter in front of the connecting device that connects the imaging plate to the photodiode
• The photodiode then transmits the electronic signal to the analog to digital converter (ADC)
• Analog refers to a device or system that represents an infinite range of continuously varying quantities
  — Such as 1, 1.1, 1.2, 1.3, 1.4, etc.
• From near zero continuously changing to a maximum value
• Digital computers used for medical imaging only handle data composed of finite quantities
  — on or off

CR Image Formation

• The signal undergoes three stages in the ADC:
  — scanning
  — quantization
  — coding
• Scanning
  — the incoming analog signal is scanned as a series of equally spaced horizontal lines
  — they are further divided into a number of equally spaced points
  — producing a series of small boxes
  — each box forms a single pixel
• Quantization
  — this process assigns a numerical value to each pixel relative to the value of the electric current
  — is relative to the level of photon exposure
• Coding
  — this final stage converts the numerical value produced by quantization into a binary number
    • 0 for off
    • 1 for on
• The more pixels there are, the greater the image resolution
• The image is digitized both by position (spatial location) and by intensity (brightness) of each pixel
• Each of the pixels contains bits of information
CR Image Formation

• The number of bits per pixel is known as bit depth
  — defines brightness level assigned to that pixel
  — determines contrast resolution

• Example:
  — a pixel has a bit depth of 8
  — the number of different brightness levels that pixel is capable of is $2^8$ (256 different levels of brightness)

• Some CR imaging systems have bit depths of 10 (1024 brightness levels) or 12 (4096 brightness levels)
  — a 12-bit CR system is capable of brightness levels ranging from 0 ($2^0$) to 4096 ($2^{12}$)
    • depending on the number of photons

• Once the digitized information is stored in the computer, it is available for manipulating, enhancing, and viewing

• IP erasing
  — photostimulable phosphors can be reused
  — they are estimated to have a life of 10,000 laser scans before they need to be replaced
  — not all of the trapped metastable electrons are stimulated to return to ground state during signal acquisition
  — those electrons that are not stimulated must be removed prior to reusing the IP
    • ghosting may appear otherwise
  — any residual latent image is removed by flooding the phosphor with very intense white light from specially-designed fluorescent lamps

The CR Reader

• The back and forth motion of the laser beam must be precisely controlled
  — erratic movement of the imaging plate causes fluctuations in the plate’s velocity, resulting in banding artifacts
    • gives the image edges a wavy appearance

Digital Radiography

• Digital radiography (DR) is a direct imaging system
  — cassetteless
  — no latent image to process
  — almost immediate digital image access

• In 1995, technological advances introduced the first flat-panel detector DR systems

• Based on amorphous silicon and amorphous selenium scintillation
  — both silicon and selenium are typically grown as crystals
  — the amorphous state is one of a liquid that can be painted onto a support surface

• In addition to cesium-iodide scintillators, gadolinium-oxide sulfide scintillators were introduced in 1997

• Many different DR detectors are now being marketed

• It would be a mistake to assume that all the various systems were equal and interchangeable

• There are currently three methods used in digital radiography to produce a projection radiograph:
  — two indirect methods
  — one direct method
Digital Radiography

• The two indirect methods require that the remnant x-ray energy must be converted to light before an electric signal can be generated
  – one method uses a charge-coupled device (CCD)
  – the other uses a flat-panel thin-film transistor (TFT) array
• The direct method converts the x-ray energy directly into an electric signal
  – does not need to first convert the x-ray energy into light
  – the direct method uses a flat-panel TFT array as well
• As in CR, the difference between DR and film/screen systems involves the image receptor
  – the detection, acquisition, and production of a radiographic image
• Ideal DR image receptor
  – high spatial resolution
  – high contrast resolution
  – high dose efficiency
  – similar to size and weight of a film/screen system
  – easy to use
  – light weight
  – sturdy
  – requires no cassette handling

Digital Radiography

• The capture element in DR acquires the subject contrast of the remnant x-ray beam photons
• The capture element can be
  – sodium iodide (NaI)
  – cesium iodide (CsI)
  – gadolinium oxysulfide (GdOS)
  – amorphous selenium (a-Se)
• The coupling element transfers the x-ray-generated signal to the collection element
• The coupling element can be in the form of a
  – lens system
  – fiber optic assembly
  – contact layer
  – a-Se (performs both functions of capture element and coupling element)
• The collection element gathers the electric signal and directs it forward for computer processing
• The collection element can be one of the following
  – photodiode
  – CCD
  – a TFT flat-panel array
• The photodiode and CCD are light-sensitive devices that collect light photons
• The TFT is a charge-sensitive device that collects electrons
Digital Radiography

- DR is more efficient in time, space, and personnel than film/screen imaging
- DR can provide image quality that exceeds both film-screen and CR
- The x-ray circuit, transformers, x-ray tube, etc. do not require replacement to convert to a DR system
- The Bucky is replaced by a detector array
  - table
  - wall stand
  - portable
- With digital radiography, the image-forming remnant radiation is captured by the detector array
  - it is then transferred immediately to a computer
- Image viewing is almost instantaneous
- The two categories of cassetteless systems are:
  - indirect capture
  - direct capture

Digital Radiography Systems

- CCD indirect digital radiography requires optical coupling and image demagnification
- CCDs are used to capture light from a scintillator
  - the CCD is a silicon-based semiconductor
  - a CCD measures approximately 1-2 cm
- The CCD is capable of responding to very low light intensities
  - has a wide dynamic range
- The CCD is connected to a scintillator (image) plate by either:
  - a fiber optic bundle
  - optical lens system
- There is a significant gap between the CCD and the scintillator
  - demagnification is required
- The size of a CCD chip is limited
  - many small CCDs are tiled together to form one large detector
  - the detector array matches the image’s matrix of pixels
- The seams between the smaller CCDs result in an unequal response
  - this problem is addressed by computer correction software that interpolates (averages) the pixel values along the seams
  - makes the seams disappear
- The scintillator light must be optically “bundled” to fit the size of the CCD chip
Computed and Digital Radiography

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