The Effect of Computers in Imaging
And Radiation Safety

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Objectives: Upon the completion of this CME article, the reader will be able to:

1. Define the difference between analog and digital imaging.
2. Describe radiation safety standards and discuss how radiation exposure is measured and its effects.
3. Define basic computer terminology and describe digital transformation.
4. Explain how image quality is improved through computer technology and by laser imaging and how this can affect radiation exposure.

Integrating Computers in Imaging

The computer age is amongst us. Since the 1970s, computers have changed from research tools into a standard of practice in nearly all modalities of imaging. Today's radiologic imaging department is unique among medical disciplines in its dependence upon computer applications. In most other areas of the health care delivery system, computers are an adjunct to the direct care of patients. However, in radiology where ionizing radiation was once the sole producer of images, computers are now at the heart of imaging techniques.

The current generations of imaging creators (the brains of production) are manufactured with microprocessor controls. Computerized Radiography (CR), Nuclear Medicine (NM), Ultrasound (US), Computerized Tomography (CT) and Magnetic Resonance Imaging (MRI) procedures cannot be performed without the aid of computers. More importantly, advances in imaging procedures are often based on new hardware (the machine) or computer software (the programs).

Conventional production of latent images with the use of ionizing radiation is defined as "analog images." When images are produced by computer representations of anatomical information, they are called "digital images." This form of imaging relies on a computer to integrate and manipulate the collected data.

Biomedical Ethics

Imaging with ionizing producing equipment has a direct impact on biomedical ethics. Ethics is defined as rules of conduct recognized in respect to a particular class of human actions. The imaging profession has international standards regarding radiation safety. Licensed imaging professionals must maintain these standards. This represents the core of the imaging standards of ethics. The recommended standards and regulations for radiation safety of the general public and occupational exposure is established by the International Commission on Radiological Protection (ICRP) and the National Council on Radiation Protection and Measurements (NCRP). The principal recommendations about radiation safety standards are based on the current scientific consensus from these governing bodies, which includes the following:

- Justifiable sources of radiation exposures are those that result in an overall net benefit to society.
- Radiation exposures to the public from controllable sources should be maintained "as low as reasonably achievable" (ALARA); with economic and social factors being taken into account.
- Public radiation-safety standards should be based on specified values of dose rather than hypothetical estimates of risk. These standards should be expressed as an "effective dose" measured in sieverts or rem.
- Standards should be established to control the receipt, possession, use, transfer, and disposal of radioactive materials by licensees.

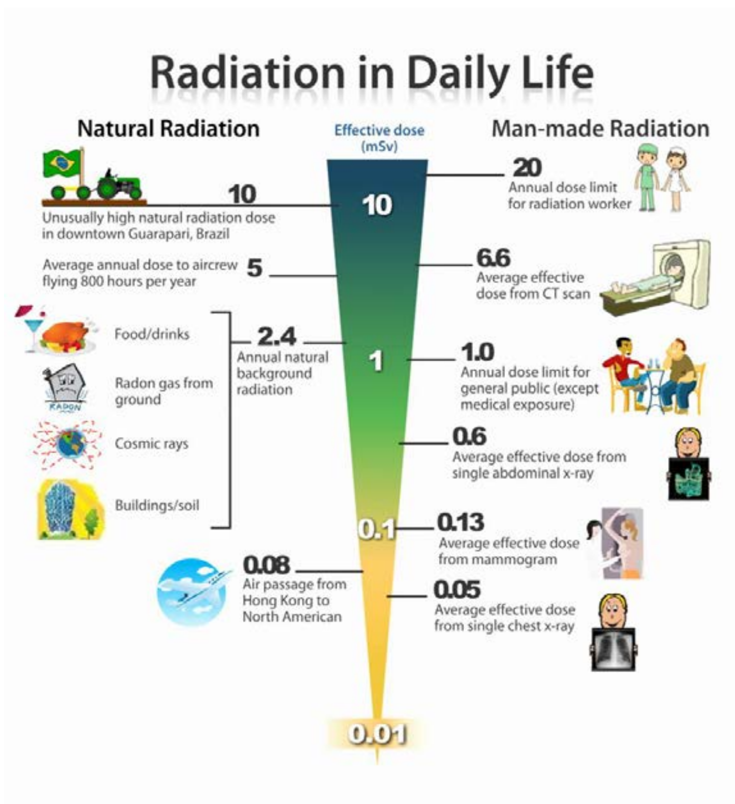
The following is for definition purposes:

1. Sievert (Sv) – is the international unit of effective radiation dose (1 Sv = 100 rem)
2. Rem (Roentgen Equivalent Man) – is the traditional unit of dose equivalent that applies to the absorbed dose in rads multiplied by the quality factor, distribution factor, and any other necessary modifying factors (in essence, it is normalized for biological effectiveness) (1 rem = .01 Sv)

Occasionally a patient will ask if the amount of radiation they are receiving from a procedure is harmful. Many patients ask: "Are x-rays safe?". The imaging professional has an ethical duty to be informative and to provide a reasonable honest and understandable answer. It is important to ensure the public that diagnostic x-rays are safe. There is no scientific data to suggest otherwise.

Answering the question about the amount of radiation is difficult but definable. The "effective dose" is the technical answer. However, it is unlikely that the average person would be informed by this value. The best professional explanation would be to convert the effective dose of radiation into the amount of time in days, weeks, months, or years that it would take to accumulate the same exposure from background radiation. Most people are unaware that they are exposed to small amounts of radiation on a day-to-day basis.

"Background Equivalent Radiation Time" (BERT) utilizes this background rate in the United States, which is approximately 3mSv per year (or 300 mrem/year). It is natural for patients to confuse medical x-ray production with radioactivity. They might think that man-made ionizing radiation is more dangerous than natural background radiation. Most people are unaware the majority of background radiation is produced within our own bodies.



Health care workers, specifically nurses, in areas where portable x-ray exams are performed are generally more concerned with the dangers of ionizing radiation. In these areas, it is not uncommon to have radiation measuring devices assigned that are called dosimeters. Dosimeters are used for quantitative radiation measurements such as the dose rate and are the standard device used in radiation protection programs (RPP) in imaging departments. Under the recommended standards and regulations for radiation safety, a properly developed and implemented RPP can assist in documenting exposure rates, areas that are affected, and personnel involved.

Occupational dose limits have been established by these standards as well. The occupational exposure of general employees resulting from ionizing radiation producing equipment is regulated so annual limits are not exceeded. The following list defines some of these annual limits:

- A total effective dose equivalent of 5 rems (or 0.05 Sv)
- The sum of the deep-dose equivalent and the committed-dose equivalent to any individual organ or tissue of 50 rems (or 0.5 Sv)
- The lens of the eye dose equivalent of 15 rems (or 0.15 Sv)
- A shallow dose equivalent of 50 rems (or 0.5 Sv) to the skin or to any extremity
- Doses received in excess of the annual limits, including doses received during accidents, emergencies, and planned exposures shall be subtracted from the limits for planned special exposures

Another integral part of an RPP is quality assurance programs such as the Repeat-Reject Analysis. Repeat-Reject Analysis programs that monitor image quality has recorded a decreased number of films rejected due to under or over exposure as imaging moved into the computer era. Digital computers are represented in all imaging equipment manufactured today. Conventional x-ray is no exception. Photo-timing chambers use microprocessors to measure the energy absorbed. Computerized Radiography is a filmless system that absorbs the energy in the cassette screen. The absorption rate is analyzed and scanned in a computer processor and printed out using a laser processor. From a single exposure, image quality can be manipulated on computer-generated images. With the introduction of computers in imaging, the capture, recognition, storage, retrieval, and immediate communication of data has a direct effect in reducing radiation exposure to both the public and occupational worker. The repeats-rejected rate was around 5% in the U.S. before digital guidelines and have been reduced to approximately 3.97% after guidelines.

The Architecture of the Computer

Some fundamental concepts and associated terminology of computer technology are imperative for those who work in the imaging field as we integrate energy production and computer reformation.

A computer is a machine that processes discrete batches of information in a predetermined (programmed) manner. Its main purpose is to solve mathematical problems. The use of the computer can provide rapid calculations of the radiation dose that is distributed. Basically, it takes information in (input), uses a management device to process the information (program), and displays the results in a manner dictated by the management device (output).

The actual electronic and mechanical equipment reading in the data, doing the computing, and outputting the data is referred to as the "hardware." The managing device or program that supplies the instructions for controlling the operation of the equipment is called "software."

The input may be in one of two forms, which are analog or digital. The computer can obtain measurements of energy that are passing through an object, are absorbed by an object, or may involve energy interaction. The energy data that is collected is then transformed into a complex mathematical equation.

A digital computer solves problems by counting. It operates on digital (numerical) data through arithmetic or logical operations. Data can be represented as a binary digital pulse waveform propagating along a transmission line. This transformation is configured or reconstructed into an image of an object. Digital Image processing (or conversion) scans the image into small areas referred to as "picture element," or "pixel." Thus, the image array is defined rows and columns of pixels varying in energy (or quantization).

Digital transmission offers data processing options that are not available with analog processing. It has more flexibility and is less subject to interference of the signal and to distortion of the gathered data. Manufacturing of digital circuits is more reliable and costs less than analog circuits to be produced.

The Image

The invisible image (often called the latent image) obtained from ionizing radiation on a radiographic film or transformed on a cathode ray tube (CRT) is converted into a visible image, also called a manifest image. The purpose of medical imaging is to provide information and documentation of the anatomical and possibly the physiological condition. The objective is to produce as much physical information as needed to make a diagnosis. High-quality recording of the manifested image is the most important factor.

The ability to differentiate between adjacent structures is the basic principle of image quality. This process begins when x-ray energy passing through the patient (technical exposure) is absorbed at different amounts based on the anatomical composition of the tissue exposed (i.e., physical density, thickness, etc.). The energy that exits from the patient varies in intensity (or attenuation) and is recorded by a receptor (the film, imaging plate, digital camera, and/or CRT). The difference of attenuation is referred to as subject contrast. With conventional image recording media, attenuation is converted into optical density differences or transmitted light intensity. These differences in light intensity are referred to as image contrast.

Radiographs (x-ray images on film) is experiencing the same fate as record players, LPs, cassette recorders and cassette tapes. Under the Consolidated Appropriations Act (CAA) of 2016, imaging facilities will see a 20 percent reduction in Medicare reimbursement if they continue the use of x-ray film (analog images). On film, the image is represented by a pattern of optical densities. Image quality can be reduced on conventional medical film by improper film storage, handling, and/or chemical processing. Poor image quality leads to an increase in radiation exposure due to a need for repeat images. Factors that influence conventional radiographic quality include the following:

- Patient Factors – anatomy / physiology / pathology
- Chemical Processing – time / temperature / chemistry / mechanical conditions
- Image Receptors – film / illumination screens / film-screen combination
- Technical Exposure – kVp / mA / time / focal spot / geometric (SID, SOD, OID)

The medical professional, who processes images, should understand the functions of the automatic processing system in order to identify problems that can affect image quality. The interaction of x-rays with conventional medical film and the development of the latent image are accomplished by chemical processing. In Repeat-Reject Analysis, film processing represents a high percentage of the cause of repeat exposure to ionizing radiation. This is primarily due to the factors associated with automatic processing, a procedure that involves four basic steps inside a mechanical unit.

Automatic processing chemicals have very distinct functions in the development, integrity, and quality of the manifested image. Developing is the first step. The primary chemical agents used in this portion of image processing are reducing agents along with an activator, restrainer, preservative, hardener, and water (which acts as a solvent). The role of the reducing agents is to convert the latent image into visible shades of gray. This reduction process produces the film with varying degrees of blackness based on the activity of the chemical's interaction with the silver ions that are attached to the silver halide crystals. If the reducing agents are overly active because of a high temperature of the solution, or if the chemical solution is overly concentrated with reducing agents, or if the interaction time with the film is prolonged, the entire film can be overexposed (will be black).

The second most important step involves fixation of the image. Undeveloped silver crystals must be removed from the film. If they are not removed, the silver ions attached to the silver halide crystals will continue to develop leading to a slow blackening of the film. In order to "fix" the developed image onto the film, a clearing agent that bonds and removes unexposed silver halide crystals are utilized (the fixer agent). The fixer solution in an automatic processor also includes an activator, preservative, hardener, and water.

To protect medical films from fading and long-term degradation, a wash and drying cycle is added to the process. The purpose of the wash cycle is to remove the developer and fixer solution from the film. The drying of the film is achieved by using air temperatures ranging from 120^0 to 150^0 F, which sets a final hardening to the film emulsion and seals the super-coat that is manufactured on the film.

In contrast, the subject figure in computerized systems is converted into electrical signals that are reconstructed as visible images. The computer image is called a matrix, which is an array of pixels arranged in two dimensions (or picture elements of the image displayed in rows and columns). Each pixel represents a voxel of electronically transformed subject contrast depth, width, and length. As the number of pixels increases, the larger the matrix becomes, which improves the quality of the image. A computer matrix is displayed on a TV monitor (CRT) and can be printed or recorded onto film.

With the application of computers in medical imaging, the storage, retrieval, and printing of images have drastically reduced the need for repeat exposures. The integration of laser images has further advanced the reduction of exposure. Laser technology uses photographic techniques to transfer an image from a CRT to a single emulsion film that is sensitive to laser light. The recorded data is written directly on the dedicated film by a laser beam.

Another application of laser imaging involves dry processing. DryView laser imagers are continuous tone laser imagers with an integrated photothermographic film developer. The processing of images occurs each time the laser printer unit receives a print command from an interfaced computer module software program called a DICOM PACS Link. DICOM (or Digital Imaging and Communications in Medicine) images are routed to specified DICOM devices such as PACS (or Picture Archiving and Communications Systems) for immediate processing of commands. The following dry-laser imaging sequence occurs after a print command is received:

- A suction cup device in the non-exposed film cartridge area lifts a single sheet of film out of the supply cartridge and feeds it into the film transport roller system.
- The film transport drives the film down into the exposed module area.
- The film is exposed by a laser beam and then fed back into the film transport system.
- The film transport drives the film up into the film developer area.
- As the film passes over the film developer drum, heat generated by the drum develops the film.
- The film is then driven out of the film developer, though a densitometer area (density measuring device), and out to the receiver tray.

The densitometer is a key element in dry-laser processing. It assists in image quality control that allows the imager to automatically adjust image processing parameters to ensure optimum image quality, thus reducing the need for repeat ionizing exposure for better image contrast.

The degree at which subject contrast is recorded determines the ability to interpret an image. Thorough knowledge of factors influencing image quality is an important aspect for reducing the amount of ionizing radiation directed to the patient and occupational worker due to over or under exposure, the need for repeat imaging, poor film processing, and film integrity. However, radiation safety measurements have been enhanced through the use of computers in the processing of images in the field of radiology.

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Dr. Theresa Roberts-Hollaway, RT(R)(MR), graduated from California Southern University – Psychology Doctorate Program, Quinnipiac College in Hamden, Connecticut with a Master - Health Sciences, Bachelor of Sciences - Southern New Hampshire University and A.S. Radiologic Technology Program Gateway College/Yale-New Haven Hospital. She is the proprietor of X-Ray Imaging Today Website which provides continued online education in the imaging sciences.

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