

## **Improvements in Diagnostic Techniques in Medicine with Lower Exposure of the Patient and Staff**

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### **ABSTRACT**

It is a well known fact that radiation doses from the use of ionizing radiations and radionuclides in medical diagnosis and treatment are the largest contribution to the collective dose from all man-made sources of radiation, occupying about 15% of the total collective dose, and rapidly increase over the world, due to their relatively high frequency. From this, it is obvious that medical use of ionizing radiation should be of major concern for radiation protection.

There has been significant development of imaging technology for diagnostic radiology and other medical imaging technology over the past 100 years, and the doses of radiation to the patient and staff in medical uses have steadily decreased. Despite of developments in diagnostic techniques, the problem of trading off image quality against health risk due to radiation exposure still persists.

This paper will briefly summarize the historical overview of developments of techniques and equipments in diagnostic radiology, and introduce the goal of a radiation safety philosophy and ALARA in diagnostic radiology.

### **INTRODUCTION**

Imaging technology for medical diagnostic purposes has its beginning with the discovery of x-rays in 1895. Over the past 100 years, there has been a significant advances in the fields of diagnostic radiology and other medical imaging technologies including nuclear medicine, ultrasound and magnetic resonance imaging.

Presently the use of x-rays and radiopharmaceuticals for medical diagnostic examinations and therapeutic treatments is quite common over the world. Most of the equipments and the procedures performed are installed in industrialized countries, in which 25% of the world's population is located. The largest portion of the total dose from medical radiation sources arises from diagnostic radiology due to their relatively high frequency. The personal annual effective dose averaged over the population from all diagnostic examinations is 1.1 mSv. The population weighted world average is 0.3 mSv(1,5).

Yet the problem of an imaging procedure is to find the balance between the reduction of dose to the patient and staff, and the loss of diagnostic information. Reducing the dose to the patient may reduce the quality of information provided by the image and may be counter-productive. Much of the effective doses from medical uses of radiation is offset by direct benefits to the examined patients.

Even though these procedures are assumed to produce a net benefit, the potential for radiation induced injuries to patients exists. Understanding the typical doses and the factors that affect them therefore becomes very important. The goals of radiation safety is to provide regulatory oversight, education, and radiation safety program, that serve to minimize exposure to radiation while promoting the safe and effective use of radiation sources in diagnosis, therapy, and research based on the concept of "as low as reasonably achievable (ALARA)."

### **DEVELOPMENTS OF DIAGNOSTIC IMAGING TECHNOLOGY**

Since the discovery of x-rays in 1895 by Wilhelm C. Roentgen, imaging technology for medical diagnostic purpose including nuclear medicine has been a dramatic advances over 100 years. The major developments presented include the introduction of x-ray tubes, generators, the Potter-Bucky grid, the image intensifier, and the CT scanner. The chronological list of technology in the diagnostic application of x-rays excluding non x-ray diagnostic modalities are listed as follows(2,7).

#### **GIANT STEPS IN DIAGNOSTIC X-RAY TECHNOLOGY**

- 1895: Roentgen discovered x-rays
- Edison: Intensifying screen (Calcium tungstate phosphor)
- 1913: Coolidge tube was introduced
- 1917: Potter: The Potter-Bucky grid
- 1920s: Three phase generator first available
- 1948: Coltman: The x-ray image intensifier
- 1970s: Rare earth screen phosphors introduced

- 1971: Hounsfield: First CT scanner
- 1977: Several groups: Digital subtraction angiography
- 1990s: Slip ring helical CT volume imaging

## X-RAY TUBES

The x-ray tube serves the function of creating x-ray photons from electron energy supplied by the x-ray generator. The process of creating the x-ray beam is very inefficient, with only 1% of the electric energy converted to x-ray photons and remaining 99% of converted to heat in the x-ray tube assembly. Thus, to produce sufficient x-ray output for diagnostic imaging, the x-ray tube must withstand and dissipate a substantial heat load, a requirement that affects the design and composition of the x-ray tube.

A basic understanding of the x-ray tube is important because x-ray beam characteristics substantially affect spatial resolution, image contrast, and patient dose. The x-ray tube components are the cathode, anode assemblies, and the tube housing.

The earliest x-ray tube used by Roengen and others were based upon a design implemented by Crookes gas tube. But the gas tube performance was unreliable with regard to standardizing the operating tube voltage and current for specific examination and indirect x-rays were generated at the tube wall, which affected the resolution of x-ray image. A significant breakthrough occurred with the development of hot cathode electron source by Coolidge in 1913, which improved reproducibility of exposure output, and high heat load characteristics of the tungsten. But higher instantaneous x-ray output capabilities coupled with the insufficiency of x-ray production at low energies and consequent heating of anode soon became a problem for longevity of the anode target. The implementation of rotating anode x-ray tube in 1929 by Bouwers was the first significant technological advance of Coolidge tube which increased the heat loading limits of stationary anode design.

Thereafter, the design of x-ray tubes has been developed to the modern types(3).

## X-RAY GENERATORS

The x-ray generator provides the power necessary to produce x-rays within the x-ray tube, and permits the selection of x-ray energy, x-ray quantity, and exposure time. The circuit consists of a high-voltage transformer, rectifiers to change the AC current to DC, and a filament, which produces the current in the x-ray tube. Three-phase generator was introduced in 1928 by Siemens. Three-phase circuits (6 pulse) have higher voltage and higher average current values than single-phase (2 pulse) circuits. X-ray production is more efficient at higher voltages. The higher average voltage of three-phase circuit produce more x-rays per milliamperere that can be obtained with a single-phase circuit with the same average current. Thereafter, the design of x-ray generator has developed by several investigators such as constant potential generators (1960's) and high-frequency generators (1980's). High-frequency inverter generator which has been available for the past 10-15 years, are becoming the universal choice for diagnostic radiographic systems, which improve the accuracy of diagnostic examinations, and protect the x-ray tube and patient(4).

## IMAGE QUALITY IMPROVEMENT BY REDUCTION OF SCATTERED X- RAY

### 1) INTENSIFYING SCREENS.

Intensifying screens convert the invisible energy of a x-ray beam into visible light energy. About 99% of the latent image on x-ray film is formed because of this visible light created by intensifying screen. The process of using intensifying screens with film is especially important in diagnostic radiology, where imaging detail and limiting the dose to the patient is more critical. The phosphor layer is the key to the conversion power of the intensifying screen. Calcium tungstate phosphor screen was first introduced by Edison in 1886 and over the years, several materials have been used as phosphors. Some of the older materials such as barium platinocyanide, zinc sulfide, barium lead sulfate, and calcium tungstate have a lower conversion factor. The newer one, rare earth screen such as gadolinium, lanthanum, and yttrium have a more efficient x-ray-light conversion factor. The conversion factor for rare earth screens average about 15-20% compared with 5% for calcium tungstate screen. Rare-earth screen achieves a 50% more reduction in radiation exposure without a clinically important decrease in image quality. Rare-earth screen, most containing a gadolonium oxysulfide compound, are in wide use today.

### 2). GRIDS.

During an exposure, reducing scatter or secondary radiation is essential to improving image quality. Less scatter radiation is produced by restricting the beam through collimation of x-ray shutter blades.

Collimating the primary x-ray beam is the first line of defence in controlling unwanted secondary radiation. A grid absorbs scatter photons as a second line of defence. A grid is a device placed between the patient and image receptor to absorb scatter radiation. The primary purpose of grid is to reduce scatter radiation and improve contrast.

From the earliest radiographs, a significant degradation that reduced the contrast and quality of the image was caused by scattered radiation.

In the period of 1913 to 1921, the development of Potter-Bucky moving grid overcame the image obscuring effects of scattered x-rays, which is still used universally. Focused grid was introduced in 1923. Common designs for grid include linear parallel grids, linear focused grids, and crossed grids. The antiscatter grid of today have been essentially unchanged for several decades(7).

## COMPUTED TOMOGRAPHY

The advent of CT in the mid 1970's revolutionized the practice of diagnostic imaging with ability to accurately depict the x-rays attenuation of three dimensional objects in computer reconstructed tomographic slices without superimposing other anatomy. This, combined with ability to differentiate tissue contrast differences not possible with conventional radiography has made CT technology the most significant contribution to diagnostic medicine since the discovery of x-rays(2).

### MAJOR ADVANCE IN COMPUTED TOMOGRAPHY

- 1917: Radon: Inversion formula for reconstruction from line intergrals
- 1956: Bracewell: Reconstruction in solar astronomy radiation imaging
- 1961: Olderdorf: Reconstruction from transmission data.
- 1963: Cormack: Demonstration of reconstruction from line intergrals using narrow beams.
- 1971: Hounsfield: First commercial CT scanner
- 1973: Introduction of fan beam geometry (second generation)
- 1975: First scanner with tube and detector rotation (third generation)
- 1976: First scanner with tube rotation only (fourth generation)
- 1985: Peschmann et al: High speed CT for angiocardiology
- 1989: Kalender et al: Spiral CT

## RADIATION SAFETY PHILOSOPHY AND ALARA IN DIAGNOSTIC RADIOLOGY

Radiation safety is important in diagnostic radiology, not only because of regulatory requirements but also because of staffs and patients considered. The pervading philosophy is that of "as low as reasonably achievable". ALARA also include the concept of including economic and social considerations. In most environments, radiation safety means minimizing all radiation exposure to all individuals; however medical care presents a unique situation in which patients are intentionally irradiated. Protection philosophy requires consideration of the benefits of the radiation to which a person is exposed. The goal is to perform diagnostic procedures that optimize both radiation exposure and diagnostic information.

Patients and staffs must be considered separately: regulatory dose limits for radiation workers do not apply to medical irradiation received by patients. Therefore, when a radiation worker becomes a patient, only patient considerations are applicable.

### 1). CURRENT TRENDS IN OCCUPATIONAL EXPOSURE OF RADIOLOGIC STAFF.

In diagnostic radiology, the main source of occupational dose is scattered radiation from the patient. For all procedures, judicious applications of time, distance, and shielding can be reduced exposure dose during all procedures. Appropriate use of includes collimating properly, optimizing beam-on time, minimizing distances between image intensifier and patient, ensuring sufficient distance between patients and x-ray tube, and optimizing exposure rates for imaging quality and dose.

### 2). PATIENT DOSES IN DIAGNOSTIC RADIOLOGY.

Because most procedures causing medical radiation exposures are clearly justified and because the procedures are usually for the direct benefits of exposed individuals, less attention has been given to the optimization of protection in medical exposures than in most other applications of radiation sources. Therefore, factors affecting patients dose in all x-ray imaging modalities include beam energy, filtration, collimation, patient size and imaging process. Although there are no dose limits for patients, medical procedures that use of radiation must meet the basic principles of protection, that, is, provide a positive net benefit and use an optimal level of radiation. For example, maintaining the highest peak kilovoltage that provide acceptable image contrast leads to lower patients dose(8).

Optimization in diagnostic radiology involves two aspects: the first is to establish quality assurance and quality control programs to ensure a proper performance of the x-ray equipment: the second is the necessity to find a reasonable compromise between high image quality and low patient dose.

Factors affecting patients dose are

- 1). basic x-ray/image system parameters (nominal focal spot value, filtration, anti-scatter grid, screen-film systems, etc)
- 2). radiographic techniques (KV, exposure time, focus film distance)
- 3). reference dose values
- 4). diagnostic requirements (image criteria and important image details)

#### Reference or guidance levels for ESDs

Radiograph		Reference entrance surface dose (mGy)
Lumbar spine	AP	10
	Lat	30
	LSJ	40
Abdomen	AP	10
Pelvis	AP	10
Chest	AP	0.3
	Lat	1.5
Skull	AP	5
	PA	5
	Lat	3

\*data from the current UK national reference dose(6).

## CONCLUSIONS

When used under properly controlled conditions, radiation is a safe and indispensable tool for medical diagnoses. Proper radiation safety management should ensure that staffs are knowledgeable about typical patient doses that are imparted in each type of radiologic procedures and about the factors that affect these doses. Typically, reducing patient dose also reduces dose to staffs. Therefore, performing optimized procedures is important aspect of radiation protection in diagnostic radiology. By understanding the factors that affect patient doses, radiological staff can concentrate on reducing patients and staff doses as low as possible while creating diagnostic quality images.

As technology develops, regulations change with time. Continuing education in radiation protection is an important aspect of maintaining personal ALARA policies.

## REFERENCES

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SIDM catalyzes and leads change to improve diagnosis and eliminate harm from diagnostic error, in partnership with patients, their families, and the healthcare community.Â \*Research published in Diagnosis. Diagnostic errors affect an estimated 12 million Americans each year, and likely cause more harm to patients than all other medical errors combined. \*Research published in BMJ Quality & Safety. Roughly 40,000â€80,000 deaths in U.S. hospitals each year can be attributed to diagnostic error. National Academies of Sciences, Engineering, and Medicine. 2015. Improving Diagnosis in Health Care. Washington, DC: The National Academies Press. doi: 10.17226/21794.Â Health IT plays key roles in various aspects of the diagnostic process: capturing information about a patient that informs the diagnostic process, including the clinical history and interview, physical exam, and diagnostic testing results; shaping a clinicianâ€™s workflow and decision making in the diagnostic process; and facilitating information exchange. The committee concluded that health IT has the potential to impact the diagnostic process in both positive and negative ways. In patients with critical limb ischaemia (CLI) an accurate diagnosis can be established with modern non-invasive vascular diagnostic techniques to provide adequate information for creation of a therapeutic plan. When required, non-invasive physiological and anatomical data will be supplemented by the use of more accurate imaging techniques, such as computed tomography angiography (CTA) or magnetic resonance angiography (MRA), and selective use of lower extremity angiographic techniques.Â establish or disprove the CLI diagnosis in patients with lower limb rest pain or non-healing ulcers. â€ Toe-brachial measurements are particularly useful in individuals with incompressible crural and pedal arteries. â€ Together, patient and provider can determine an appropriate course of actionâ€or no course of action if thatâ€™s on the joint decision. The benefit of this approach is that providers listen to patient concerns and take them into consideration to determine the appropriate treatment plan. The Five Ways Evidence-Based Medicine Adds Value to Health Systems.Â This is an exciting time to be in healthcare because of the opportunities for improvement evidence-based medicine provides. Patients will feel confident they are getting the best care possible because treatments are based on the most current medical knowledge. Costs will also decrease when care improves. patients against exposure to ionising radiation. IAEA. Diagnostic Radiology Physics: A Handbook for Teachers and Students â€“ 19.4.2 Slide 68 (51/118).Â Facility should not allow equipment to be used for medical exposures unless the results of the critical examination are satisfactory so. â€ medical physicist present should ideally represent the radiology. facility.