

Chapter One

Introduction

1.1. History of Medical Diagnosis and Diagnostic Imaging

Radiology is a medical sub-specialty; it has been begun at the first decade of the 1900's after the discovery of X-rays by Professor Wilhelm Roentgen. The development of radiology grew at a good pace until World War II. Extensive use of X-ray imaging during the second world war, and the advent of the digital computer and new imaging modalities like ultrasound and magnetic resonance imaging have combined to create an explosion of diagnostic imaging techniques in the past 25 years. [Gerhard 2006]

For the first fifty years of radiology, the primary examination involved creating an image by focusing x-rays through the body part of interest and directly onto a single piece of film inside a special cassette. In the earliest days, a head X-ray could require up to 11 minutes of exposure time. Now, modern x-rays images are made in milliseconds and the X-ray dose currently used is as little as 2% of what was used for that 11 minute head exam 100 years ago. Further, modern X-ray techniques (both analogue film screen systems and digital systems) have significantly more spatial resolution and contrast detail. This improved image quality allows the diagnosis of smaller pathology that could not be detected with older technology. [Bansal 2006] The next development involved the use fluorescent screens and special glasses so the physician could see X-ray images in real time. This caused the physician to stare directly into the X-ray beam, creating unwanted exposure to radiation. In 1946, George Sc Hoenander developed the film cassette changer which allowed a series of cassettes to be exposed at a movie frame rate of 1.5 cassettes per second. By 1953, this technique had been improved to allow frame rates up to 6 frames per second by using a special "cut film changer.

A major development along the way was the application of pharmaceutical contrast medium to help visualize organs and blood vessels with more clarity and image contrast. These contrast media agents were first administered orally or via vascular injection between 1906 and 1912 and allowed physician to see the blood vessels, digestive and gastro-intestinal systems, bile ducts and gall-bladder for the first time.

In 1955, the X-ray image intensifier (I.I) was developed and allowed the pickup and display of the X-ray movie using a TV (television) camera and monitor. By the 1960's, the fluorescent system was largely replaced by the image intensifier/TV combination. Together with the cut-film changer, the image Intensifier opened the way for a new radiologic sub-specialty known as angiography to blossom and allowed the routine imaging of blood vessels and the heart.

Digital imaging techniques were implemented in the 1970's with the first clinical use and acceptance of the Computed Tomography or CT scanner, invented by Godfrey Hounsfield. Analog to digital converters and computers were also adapted to conventional fluoroscopic image intensifier/TV systems in the 70's as well. Angiographic procedures for looking at the blood vessels in the brain, kidneys, arms and legs, and the blood vessels of the heart all have benefited extremely from the adaptation of digital technology.

Over the next ten to fifteen years a large majority of conventional X-ray systems will also be upgraded to all digital technology. Eventually, all of the film cassette/film screen systems will be replaced by digital X-ray detectors. This technology is currently works-in-progress and is only available at a handful of sites worldwide. An intermediate step called phosphor plate technology is currently available at hundreds of sites around the world. These plates trap the X-ray energy and require an intermediate processing step to release the stored information so it can be converted into a digital picture. [Navas 2008]

1.2 Interventional Radiology: Applications and advantages

Interventional radiology (IR) is a sub-specialty of radiology that has become increasingly important since the mid-1970s, it contributing to some of the most significant medical developments in recent years. Using imaging techniques such as X-ray, CT, MRI and ultrasound for guidance, patients can be diagnosed and treated using minimally invasive procedures. It is probably safe to say that the world of medicine changes more rapidly than most other disciplines. Perhaps more than other medical specialties, radiology has grown faster and become more complex. It enables us to see precisely inside the body and allow minimally invasive sampling and treatment of body structures and organ systems. It has to be noted that in almost every case,

IR procedures are justified from the point of view of radiation protection. [Miller et al 2010, Walker et al 2010, and Dauer et al 2012]

The 1st percutaneous transluminal angioplasty marked a new era in the treatment of peripheral atherosclerotic lesions. The early techniques used in peripheral percutaneous transluminal angioplasty form the basis for subsequent percutaneous intervention both in the peripheral and coronary arteries and are largely the contribution of Charles Dotter. Dotter was the 1st to describe flow-directed balloon catheterization, the double-lumen balloon catheter, the safety guide wire, percutaneous arterial stenting, and more. This practical genius dedicated his considerable energy to the belief that there is always a better way to treat disease. His personal contributions to clinical medicine, research, and teaching have saved millions of limbs and lives all over the world. [Payne 2001]; however it took quite a while for angiographers to change diagnostic thinking and to develop interventional technique and devices. In 1976, Grüntzig reported on percutaneous transluminal angioplasty (PTA) balloon catheters for iliac and peripheral arteries stenosis and in 1979 on coronary balloon catheters for coronary angioplasty Charles Theodore Dotter is generally credited with developing a new medical specialty, interventional radiology. His contributions to vascular and interventional radiology are fundamental and broad in scope. He was a leading force in Machlett's development of an X-ray tube capable of obtaining millisecond exposures. He was the 1st to describe flow-directed balloon catheterization, the double-lumen balloon catheter, the safety guide-wire, and the "J" tipped guide-wire. Percutaneous transluminal angioplasty was his landmark contribution. He also introduced the concepts of percutaneous arterial stenting and stent grafting by placing the 1st percutaneous "coil-spring graft" in the femoral artery of a dog. He pioneered the techniques of low-dose fibrinolysis with injection of streptokinase directly into an occluding thrombus. Dotter (along with Marcia K. Bilbao) invented the "loop-snare catheter" for retrieving intravascular foreign bodies. He developed tissue adhesives for vascular occlusion and organ ablation. [Payne 2001] Knowledge of radiation protection is not enough and further skills and competences are needed. Training in radiation protection should become an essential part of the IR training process. Clearly, the best IR performer will use less fluoroscopy. The dose management and radiation protection training should therefore be an integral, essential component of any training and not stand alone. [Stecker et al 2009]

Recently, medical simulators have been introduced in almost every field of modern medical practice, including fluoroscopy-guided procedures. The scenarios are almost identical to the real procedure, but have no limitations regarding the complications or use of ionizing radiation, which mean the skills required are also the same. Moreover, many new techniques used by any trained specialist can be, and are initially, rehearsed on the simulator. Simulators include procedure logs that allow individual recording and documentation of any learning (self-assessment) process, as well as a means to examine the trainee. [Gould et al 2006]

1.2.1 Applications of interventional radiology (IR):

One of applications of IR is a radiofrequency ablation (RFA) which aims to destroy small tumor deposits by applying thermal energy under image guidance. [Ahmed et al 2004] There is a difference in the origin of radiation exposure between patients and physicians. For patients, the primary beam is the source of radiation exposure. On the contrary, as the X-ray passes forward straight from the X-ray tube to the detector, the main source of physicians' exposure is the X-ray emitted from the patient via photoelectric effect and Compton scattering. The latter Compton scattering gives the largest radiation dose to the physician and is a phenomenon of X-rays interacting with atoms, thus scattering radiation in various angles. [Yamagata et al 2016]

The transjugular intrahepatic portosystemic shunt (TIPS) represents a major advance in the treatment of complications of portal hypertension. Technical improvements and increased experience over the past 24 years led to improved clinical results and a better definition of the indications for TIPS. Randomized clinical trials indicate that the TIPS procedure is not a first-line therapy for variceal bleeding, but can be used when medical treatment fails, both in the acute situation or to prevent variceal re-bleeding. The role of TIPS to treat refractory ascites is probably more justified to improve the quality of life rather than to improve survival, except for patients with preserved liver function. It can be helpful for hepatic hydrothorax and can reverse hepatorenal syndrome in selected cases. It is a good treatment for Budd Chiari syndrome uncontrollable by medical treatment. Careful selection of patients is mandatory before TIPS, and clinical follow-up is essential to detect and treat complications that may result from TIPS stenosis (which can be prevented by using covered stents) and chronic encephalopathy (which may in severe cases justify reduction or occlusion of the shunt). A multidisciplinary approach,

including the resources for liver transplantation, is always required to treat these patients. [Layrargues et al 2012] Percutaneous urinary interventions are a relief of acute urinary obstruction was the most common intervention performed by radiologist. Percutaneous access to the kidney has also been used to remove stones, or to place integrate ureteral stents when retrograde stenting by urologist failed. [Šurlan et al 1986]

1.2.2 Advantages of interventional radiology (IR):

While no treatment is risk free, the risks of interventional radiology procedures are far lower than the risks of open surgery, and are a major advance in medicine for patients. Advantages of interventional radiology are; most procedures can be performed on an outpatient basis or require only a short hospital stay, general anesthesia is usually not required, risk, pain and recovery time are often significantly reduced, and procedures can be less expensive than surgery or other alternatives. In several clinical situations, IR has proven to be a reasonable, safe, and cost-effective alternative to other therapeutic options such as open surgery. [Fioole B et al 2009, Stroszczynski et al 2008]

With a growing proportion of elderly patients with higher co-morbidity due to chronic diseases and, hence, fewer options for more invasive approaches, an increasing demand for IR experts and procedures is notable. [Lakhan et al 2009, Manchikanti Let al 2009, O'Brien J et al 2007, Manchikanti et al 2007, Kwan et al 2010, Ng KL et al 2010]

1.2.3 Disadvantages of interventional radiology (IR):

Also interventional radiology has advantages, too has disadvantages compromise technical expertise - demanding, equipment, high cost, adverse effects unique to each procedure, catheter insertion can lead to injury of the artery. Balloon can also cause blood clots or rupture the artery, blockages can recur, heavy bleeding requires special medication or even blood transfusion, risk of stroke when performed on carotid artery, and abrupt vessel closure - emergency bypass also maybe done. Unfortunately, long-term use of tunneled dialysis catheters (TDCs) often leads to infections, acute occlusions, Mechanical complications, and chronic venous stenosis, depletion of the patient's conventional access routes, and prevention of their recanalisation. [Keith Pereira et al 2015]

1.3 Patients exposure

1.3.1 Introduction and Overview

Diagnostic imaging has seen many developments as it has evolved over the years, and in the last 30-40 years the pace of innovation has increased, starting with the introduction of computed tomography in the early 1970s. During the last decade, the rate of change has accelerated even further. Most patient exposure now arises from practices that barely existed two decades ago. These developments are evident in technology such as multi-detector CT scanning. However, this advance is achieved at the cost of a radiation burden to the individual patient and to the community. Contrary to other exposures to ionizing radiation, which have remained constant or decreased over the past decades, medical exposures have increased at a remarkable rate.

Specific training is undertaken for radiologists, nuclear medicine doctors, radiotherapists, and other MDs using ionizing radiation (such as surgeons or cardiologists), as well as physicists and radiographers. For doctors, this training includes individual justification for patient exposures based on general justification using guidelines. Regular use of referral guidelines can also lead to a reduction in the number of request forms and ultimately to a reduction in patient exposure to ionizing radiation. [Nobuhiko 2009]

Radiation has been proven to have adverse biological effects on living organisms. These adverse effects vary according to dose and duration of exposure; [Brenner DJ et al 2003, Sont et al 2001] however, the threshold dose for causing cancer in humans is as yet unknown. Some experimental and epidemiological investigations have tried to determine this threshold (1). Radiation is used widely in the diagnosis and treatment of many diseases, but limited usage of radiation for medical purposes is important. Previous investigations proved that doctor knowledge of radiation safety is insufficient and hundreds of unnecessary examinations are performed every year. [Shiralkar et al 2003, Quinn et al 1997, Jacob et al 2004] The technique factors specific to X-ray technology and patient parameters mainly affect the patient doses and image quality. The patient dose resulting from an X-ray examination depends on a number of parameters such as energy of the X-ray beam, beam current, exposure duration, type of image recording system, technique of examination and the type of X-ray generator. [Sharma et al 2012]

Therefore, it is necessary to record these parameters while measuring the doses using indirect methodology. Several studies reported the wide variations in patient dose levels e.g. up to a factor of 100 for the same X-ray examination. [Shrimpton et al 1986, Faulkner et al 1998]

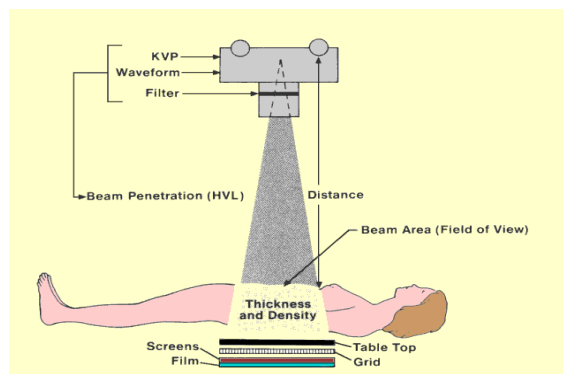


Figure 1.1 Factors That Affect Patient Exposure in a Radiographic Procedure [Sprawls 2005]

Angiography which uses X-ray to study the blood vessels, an angiogram uses a radiopaque substance, or dye, to make the blood vessels visible under X-ray. Arteriography is a type of angiography that involves the study of the arteries. It is an important technique in current clinical medicine, and a vital approach to characterizing the vessels. [Tian 2004]

1.6 Problem of the study:

UNSCEAR, ICRP and IAEA have devoted significant time over the last years to improve radiation safety in IR. In Sudan there are several combined factors: prolonged localized fluoroscopy, multiple radiographic exposures, and repeated procedures can cause acute radiation injury to the skin. Occupational radiation protection should not only include interventional radiologists, radiographers and nurses, who spend a substantial amount of time in a radiation environment, but also other professionals such as anaesthesiologists, who may work occasionally in such an environment. According to these reasons and others we are selected this topic to be our research. No data on eye-lens doses are collected and measurements are done, no typical patient dose levels in interventional radiology and cardiology installations for the patient dosimetry through the dose area product. Erythema dose, concerning deterministic risks to the eyes, patients suffer consequently radiation-induced skin injuries due to unnecessarily high radiation doses and younger patients face an increased risk of future cancer. Also no DRLs in Sudan and the data were collected are very few.

1.7 Objectives:

1.7.1 General Objectives:

This study evaluates the patient radiation doses to interventional cardiology procedures.

1.7.2 Specific Objectives:

To determine patient radiation doses for interventional cardiology procedures, to identify procedures associated with high irradiation doses, and to determine the effects of various parameters on patient doses.

To reduce the risk of stochastic effects to an acceptable level in interventional cardiology.

1.8 Thesis arrangement:

Chapter one represents introduction, chapter two deals with literature review and previous studies, chapter three illustrates methodology (materials and methods of the study), and chapter four represents results. Whereas chapter five deals with Discussions, conclusion and recommendations. Finally there is references and appendices.

1.9 Thesis outcome:

1.9.1 Publications:

1. Babikir E, Hasan HA, **Abdelrazig A**, Alkhorayef MA, Manssor E, Sulieman A. Radiation dose levels for conventional chest and abdominal X-ray procedures in elected hospitals in Sudan. Radiation Protection Dosimetry. 165(1-4):102-6(2015).
2. **Ali Abdelrazig Almhdi**, M. Abuzaid, A. Sulieman, E Babikir. Measurement of patients' radiation dose in computed tomography brain examinations. The Polish Journal of Radiology. Accepted for publication.
3. **Ali. Abdelrazig**, E. Babikir, M. Yousif, A. Sulieman. Evaluation of Patient Effective Doses and Imaging protocols in Cardiac catheterization Procedures. 2nd International Conference on Dosimetry and Applications, ICDA-2, University of Surrey. UK. 3rd -8th July, 2016.

4. **A. Abdelrazig**, A. Sulieman, M. Alkhorayef, E. Babikir, H. Al-Mohammed, D. Bradley. Patient Effective Doses and Radiation Risks in Cardiac catheterization Procedures. 10th International Topical Meeting on Industrial Radiation and Radioisotope Measurement Application: July 9-13, 2017. Chicago, USA
5. **Ali. Abdelrazig**, E. Babikir, A. Sulieman Evaluation of patient radiation dose during Percutaneous Coronary Intervention in Sudan. Submitted to International Conference on Radiation Protection in Medicine: Achieving Change in Practice. IAEA Headquarters, Vienna, Austria on 11–15 December 2017.
6. A.SULIEMAN, Y. HAMZA, **Ali. Abdelrazig**. Evaluation of Radiation exposure and risk in Paediatric Renal Scan procedures. International forum on advances in radiation physics 4-5 May 2017 – Buenos Aires – Argentina.

Chapter Two

Theoretical Background

2. Radiation classifications (ionizing radiation and sources)

2.1 Introduction to Radiation

Radiation is energy in the form of waves or streams of particles. There are many kinds of radiation all around us. When people hear the word radiation, they often think of atomic energy, nuclear power and radioactivity, but radiation has many other forms. Sound and visible light are familiar forms of radiation; other types include ultraviolet radiation (that produces a suntan), infrared radiation (a form of heat energy), and radio and television signals. Figure 1.2 presents an overview of the electromagnetic spectrum.

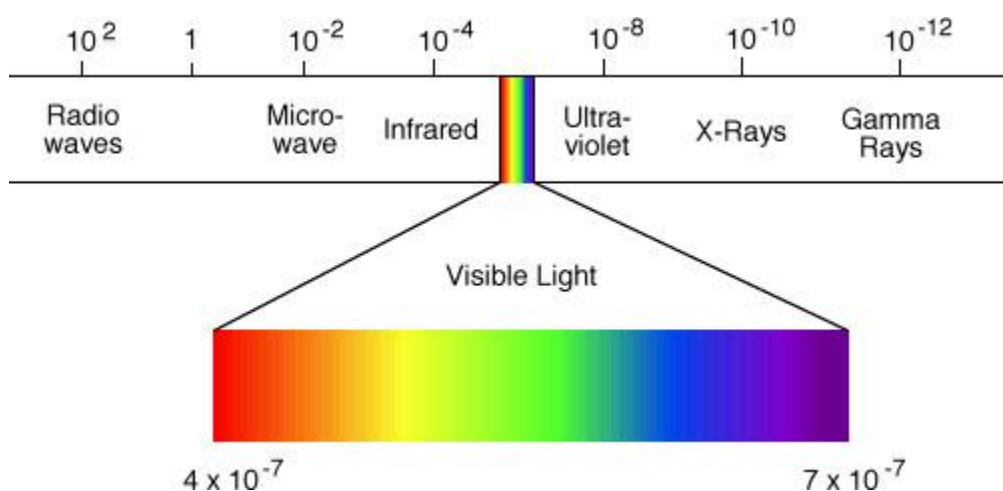


Figure 2.1: The electromagnetic spectrum

Electromagnetic spectrum. Available at:

http://www.redorbit.com/reference/electromagnetic_spectrum/ Accessed February 19, 2017.

Uncontrolled use of man-made radiation carries a potential risk to the health and safety of workers and the public. This is where the Canadian Nuclear Safety Commission (CNSC) comes in. The CNSC regulates the use of nuclear energy and materials to protect the health, safety and security of Canadians and the environment from the effects of radiation. All life has evolved in

an environment filled with radiation. The forces at work in radiation are revealed upon examining the structure of atoms.

2.3 X-ray Equipment (fluoroscopy)

Fluoroscopy is an imaging procedure that allows real-time X-ray viewing of the patient with high temporal resolution. Before the 1950s, fluoroscopy was performed in a darkened room with the radiologist viewing the faint scintillations from a thick fluorescent screen. Modern fluoroscopic systems use image intensifiers coupled to closed-circuit television systems. Image-intensified fluoroscopy has experienced much technologic advancement in recent years. The image intensifier (II) has increased in size from the early 15-cm (6-inch) diameter systems to 40-cm (16-inch) systems available today. Modern television (TV) cameras are superior in quality to, and higher in resolution than, earlier cameras, and digital image technology is intrinsic to most modern fluoroscopy systems. New features such as variable frame rate pulsed fluoroscopy provide improved x-ray dose efficiency with better image quality. And while II-based fluoroscopy has matured technologically, flat panel detectors based on thin film transistor (TFT) technology are just over the horizon, poised to compete with and eventually replace image intensifiers.

2.3.1 Functionality

"Real-time" imaging is usually considered to be 30 frames per second, which is the standard television frame rate in the United States. Most general-purpose fluoroscopy systems use television technology, which provides 30 frames per second imaging. Fluoroscopic image sequences are typically not recorded, but when recording fluoroscopy is necessary (e.g., barium swallow examinations), high-quality videotape recorders can be used for playback and interpretation. Newer fluoroscopy systems allow the acquisition of a real-time digital sequence of images (digital video), that can be played back as a movie loop. Unrecorded fluoroscopy sequences are used for advancing catheters during angiographic procedures (positioning), and once the catheter is in place, a sequence of images is recorded using high frame rate pulsed radiography as radiographic contrast media are injected in the vessels or body cavity of interest. In gastrointestinal fluoroscopy, much of the diagnosis is formulated using the unrecorded fluoroscopy sequence; however, radiographic images are acquired for documenting the study, and to show important diagnostic features. For recording images of the heart, cine cameras offer

up to 120-frame-persecond acquisition rates using 35-mm cine film. Digital cine is also available and gaining favor in the cardiology community. Additional imaging devices associated with the fluoroscopy imaging chain such as film photo-spot, digital photo-spot, or spot film devices provide the hard-copy acquisition capability for documenting the entire range of fluoroscopic procedures.

2.3.2 Fluoroscopic Imaging Chain Components

A standard fluoroscopic imaging chain is shown in Fig. 9-1. The X-ray tube, filters, and collimation are similar technologies to those used in radiography and are not discussed in detail here. The principal component of the imaging chain that distinguishes fluoroscopy from radiography is the image intensifier. The image output of a fluoroscopic imaging system is a projection radiographic image, but in a typical 10-minute fluoroscopic procedure a total of 18,000 individual images are produced. Due to the sheer number of images that must be produced to depict motion, for radiation dose reasons, fluoroscopic systems should produce a usable image with relatively few X-ray photons. Consequently, a very sensitive detector is needed. Image intensifiers are several thousand times more sensitive than a standard 400-speed screen-film cassette and in principle can produce images using several thousand times less radiation. In practice, standard fluoroscopy uses about 1 to 5 μR incident upon the image intensifier per image, whereas a 400-speed screen-film system requires an exposure of about 600 μR to achieve an optical density of 1.0.

2.3.2.1 The Image Intensifier

A diagram of a modern II is shown in Fig. 2.3.2. There are four principal components of an II: (a) a vacuum bottle to keep the air out, (b) an input layer that converts the X-ray signal to electrons, (c) electronic lenses that focus the electrons, and (d) an output phosphor that converts the accelerated electrons into visible light.

2.3.2.2 Input Screen

The input screen of the II consists of four different layers, as shown in Fig. 2.3.3. The first layer is the vacuum window, a thin (typically 1 mm) aluminum (Al) window that is part of the vacuum bottle. The vacuum window keeps the air out of the II, and its curvature is designed to withstand the force of the air pressing against it. The vacuum window of a large field-of-view (FOV) (35-cm) II supports over a ton of air pressure. A vacuum is necessary in all devices in which

electrons are accelerated across open space. The second layer is the support layer, which is strong enough to support the input phosphor and photocathode layers, but thin enough to allow most X-rays to pass through it. The support, commonly 0.5 mm of aluminum, is the first component in the electronic lens system, and its curvature is designed for accurate electronic focusing.

After passing through the Al input window and the Al substrate, X-rays strike the input phosphor, whose function is to absorb the X-rays and convert their energy into visible light. The input phosphor in an II serves a purpose similar to that of the intensifying screen in screen-film radiography, and is subject to the same compromise it must be thick enough to absorb the majority of the incident X-rays but thin enough not to degrade the spatial resolution of the image significantly. IIs offer a high vacuum environment that a screen-film cassette cannot, and therefore unique phosphor technology can be used. Virtually all modern IIs use cesium iodide (CsI) for the input phosphor. CsI is not commonly used in screen-film cassettes because it is hygroscopic and would degrade if exposed to air. CsI has the unique property of forming in long, needle-like crystals. The long, thin columns of CsI function as light pipes, channeling the visible light emitted within them toward the photocathode with minimal lateral spreading. As a result, the CsI input phosphor can be quite thick and still maintain high resolution. The CsI crystals are approximately 400 μm tall and 5 μm in diameter, and are formed by vacuum evaporation of CsI onto the substrate (Fig. 9-4). For a 60-keV X-ray photon absorbed in the phosphor, approximately

3,000 light photons (at about 420 nm wavelength) are emitted. The Kedges of cesium (36 keV) and iodine (33 keV) are well positioned with respect to the fluoroscopic X-ray spectrum, and this fact helps contribute to high X-ray absorption efficiency.

The photocathode is a thin layer of antimony and alkali metals (such as Sb_2S_3) that emits electrons when struck by visible light. With 10% to 20% conversion efficiency, approximately 400 electrons are released from the photocathode for each 60-keV X-ray photon absorbed in the phosphor.

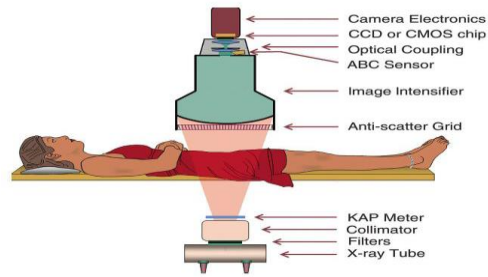


Figure 2.2 The fluoroscopic imaging chain with key components indicated.

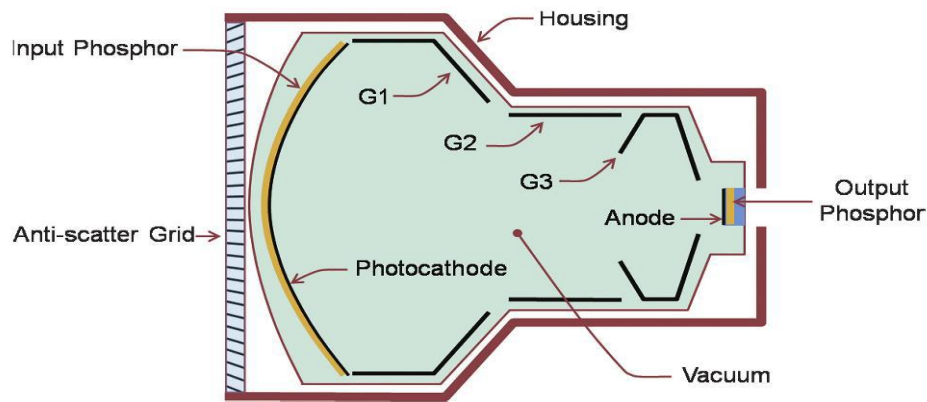


Figure 2.3 the internal structure of an image intensifier. The photocathode (in the input screen), the three focusing electrodes (G1, G2, and G3), and the anode (part of the output window) make up the five-element (pentode) electron optical system of the II.

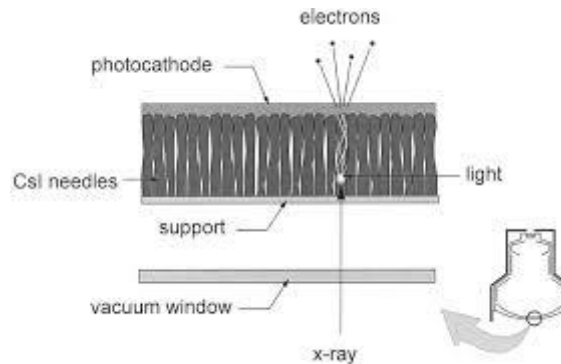


Figure 2.4 The input section of an image intensifier (II). X-rays must pass through the vacuum window and support, before striking the cesium iodide (CsI) input phosphor. CsI forms in long crystalline needles that act like light pipes, limiting the lateral spread of light and preserving spatial resolution. Light emitted in the cesium iodide strikes the photocathode, causing electrons to be liberated into the electronic lens system of the II.

2.3.2.3 Electron optics

Once X-rays are converted to light and then to electrons in the input screen, the electrons are accelerated by an electric field. The energy of each electron is substantially increased, and this gives rise to *electronic gain*. The spatial pattern of electrons released at the input screen must be maintained at the output phosphor (although minified), and therefore electron focusing is required. Focusing is achieved using an electronic lens, which requires the input screen to be a curved surface, and this results in unavoidable *pincushion distortion* of the image. The G1, G2, and G3 electrodes illustrated in Fig. 2.3.2, along with the input screen substrate (the cathode) and the anode near the output phosphor comprise the five-component ("pentode") electronic lens system of the II. The electrons are released from the photocathode with very little kinetic energy, but under the influence of the ~ 25000 to 35000 V electric field, they are accelerated and arrive at the anode with high velocity and considerable kinetic energy. The intermediate electrodes (G1, G2, and G3) shape the electric field, focusing the electrons properly onto the output layer. After penetrating the very thin anode, the energetic electrons strike the output phosphor and cause a burst of light to be emitted.

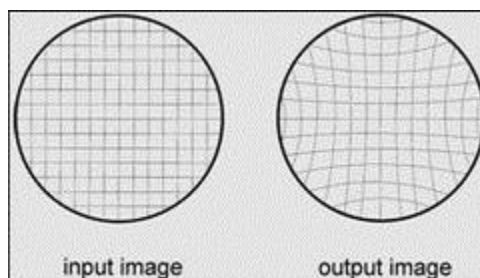


Figure 2.5 Because the input surface of the image intensifier is curved, and the output surface is flat, pincushion distortion results. For a true rectilinear grid input to the system (left), the output image will demonstrate spatial distortion (right).

2.3.2.4 The Output Phosphor

The output phosphor (Fig.2.3.5) is made of zinc cadmium sulfide doped with silver (ZnCdS:Ag), which has a green (~530 nm) emission spectrum. Green light is in the middle of the visible spectrum and is well matched to the spectral sensitivity of many video camera target materials. The ZnCdS phosphor particles are very small (1 to 2 ~m), and the output phosphor is quite thin (4 to 8 ~m), to preserve high spatial resolution. The anode is a very thin (0.2 ~m) coating of aluminum on the vacuum side of the output phosphor, which is electrically conductive to carry

away the electrons once they deposit their energy in the phosphor. Each electron causes the emission of approximately 1,000 light photons from the output phosphor.

The image is much smaller at the output phosphor than it is at the input phosphor, because the 23- to 35-cm diameter input image is focused onto a circle with a 2.5-cm diameter. To preserve a resolution of 5 line pairs/mm at the input plane, the output phosphor must deliver resolution in excess of 70 line pairs/mm. This is why a very fine grain phosphor is required at the output phosphor. The reduction in image diameter also leads to amplification, since the energy incident on the 415 cm^2 area of the 9-inch-diameter input phosphor is concentrated to the 5 cm^2 output phosphor. By analogy, a magnifying glass collects sunlight over its lens surface area and focuses it onto a small spot, and in the process the light intensity is amplified enough to start a fire. The so-called minification gain of an image intensifier is simply the ratio of the area of the input phosphor to that of the output phosphor. The ratio of areas is equal to the square of the diameter ratio, so a 9-inch II (with a 1-inch output phosphor) has a minification gain of 81, and in 7-inch mode it is 49.

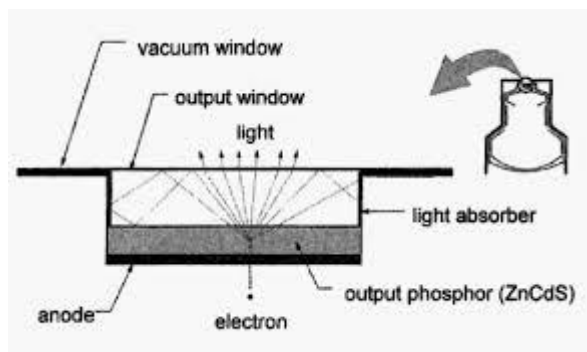


Figure 2.6 The output window of an image intensifier. The electrons strike the output phosphor, causing the emission of light. The thick glass output window is part of the vacuum housing and allows light to escape the top of the II. Light that is reflected in the output window is scavenged to reduce glare by the addition of a light absorber around the circumference of the output window.

The last stage in the II that the image signal passes through is the output window (Fig.2.6). The output window is part of the vacuum bottle, and must be transparent to the emission of light from the output phosphor. The output phosphor is coated right onto the output window. Some fraction of the light emitted by the output phosphor is reflected at the glass window. Light bouncing

around the output window is called veiling glare, and can reduce image contrast. This glare is reduced by using a thick (about 14 mm) lead glass window, in which internally reflected light eventually strikes the side of the window, which is coated black to absorb the scattered light.

2.3.3 Characteristics of Image Intensifier Performance

The function of the X-ray II is to convert an X-ray image into a minified light image. There are several characteristics that describe how well the II performs this function. These parameters are useful in specifying the capabilities of the II, and are also useful in troubleshooting IIs when they are not performing properly.

2.3.3.1 Conversion factor

The conversion factor is a measure of the gain of an II. The input to the II is an X-ray exposure rate, measured in mR/sec. The output of the II is luminance, measured in candela per meter squared. The conversion factor of an II is the ratio of the (output) luminance divided by the (input) exposure rate, resulting in the peculiar units of $\text{Cd sec m}^{-2} \text{mR}^{-1}$. The conversion factor of a new II ranges from 100 to 200 $\text{Cd sec m}^{-2} \text{mR}^{-1}$. The conversion factor degrades with time and this ultimately can lead to the need for II replacement.

2.3.3.2 Brightness Gain

The brightness gain is the product of the electronic and minification gains of the II. The electronic gain of an II is roughly about 50, and the minification gain changes depending on the size of the input phosphor and the magnification mode. For a 30-cm (12-inch) II, the minification gain is 144, but in 23-cm (9-inch) mode it is 81, and in 17-cm (7-inch) mode it is 49. The brightness gain therefore ranges from about 2,500 to 7,000. As the effective diameter of the input phosphor decreases (increasing magnification), the brightness gain decreases.

2.3.3.3 Field of View/Magnification Modes

Image intensifiers come in different sizes, commonly 23-, 30-, 35-, and 40-cm (9-, 12-, 14-, and 16-inch) fields of view (FOV). Large IIs are useful for gastrointestinal/genitourinary (GI/GU) work, where it is useful to cover the entire abdomen. For cardiac imaging, by comparison, the 23-cm (9-inch) image intensifier is adequate for imaging the heart, and its smaller size allows tighter positioning. In addition to the largest FOV; this is determined by the physical size of the II, most IIs have several magnification modes. Magnification is produced (Fig. 2.3.6) by pushing a button that changes the voltages applied to the electrodes in the II, and this results in different

electron focusing. As the magnification factor increases, a smaller area on the input of the II is visualized. When the magnification mode is engaged, the collimator also adjusts to narrow the x-ray beam to the smaller field of view.

As discussed above, the brightness gain of the image intensifier decreases as the magnification increases. The automatic brightness control circuitry (discussed later) compensates for the dimmer image by boosting the X-ray exposure rate. The increase in the exposure rate is equal to the ratio of FOV areas. Take for example a 30-cm (12-inch) II, which has 23-cm (9-inch) and 18-cm (7-inch) magnification modes. Switching from the 12-inch mode to the 9-inch mode will increase the X-ray exposure rate by a factor of $(12/9)^2 = 1.8$, and going from the 12-inch to the 7-inch mode will increase the exposure rate by a factor of $(12/7)^2 = 2.9$. Therefore, as a matter of radiation safety, the fluoroscopist should use the largest field of view (the least magnification) that will facilitate the task at hand.

2.3.3.4 The contrast ratio

The contrast ratio is an indirect measurement of the veiling glare of an image intensifier. With a constant input X-ray exposure rate to the II, the light intensity at the center of the output phosphor is measured using a light meter. A thick, 2.5 cm diameter lead disk is then placed in the center of the input phosphor, blocking the radiation to the input and theoretically cutting the light at the center of the output phosphor to zero. However, light produced in the periphery of the II will scatter, and consequently some light intensity will be measured at the center of the output phosphor. The contrast ratio is simply the ratio of light intensity, with and without the lead disk being present. Contrast ratios of 15 to 30 are commonly found.

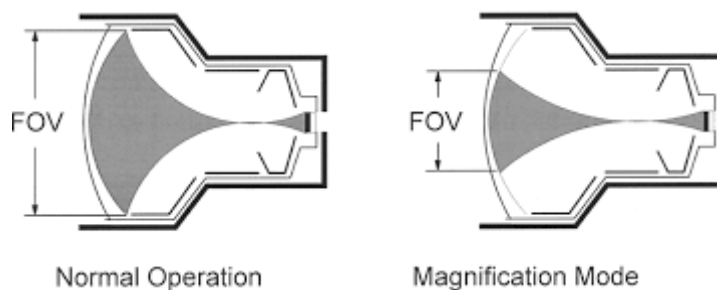


Figure 2.7 In normal operation of the image intensifier (above), electrons emitted by the photocathode over the entire surface of the input window are focused onto the output phosphor, resulting in the maximum field of view (FOV) of the II. Magnification mode (below) is achieved by pressing a button that modulates the voltages applied to the five electrodes, which in turn changes the electronic focusing such that only electrons released from the smaller diameter FOV are properly focused onto the output phosphor.

2.3.3.5 Quantum Detection Efficiency (QDE)

X-rays must pass through the vacuum window (~1.0 mm Al) and the input screen substrate (~0.5 mm Al) before reaching the CsI input phosphor (~180 mg/cm²). Figure 2.3.8 illustrates the kVp-dependent quantum detection efficiency (QDE) of an II. The quantum detection efficiency is maximal around 60 kVp; however, the dose to the patient will decrease at higher kVp, so the optimal kVp for a given examination will generally be higher than 60 kVp.

2.3.3.6 S distortion

S distortion is a spatial warping of the image in an S shape through the image. This type of distortion is usually subtle, if present, and is the result of stray magnetic fields and the earth's magnetic field. On fluoroscopic systems capable of rotation, the position of the S distortion can shift in the image due to the change in the system's orientation with respect to the earth's magnetic field.

2.3.4 Optical Coupling

2.3.4.1 Distribution Mechanism

The output image on an II is small, and for over-table II's, a ladder would be needed to view the output window directly. Consequently, a video camera is usually mounted above the II and is used to relay the output image to a TV monitor for more convenient viewing by the operator. In addition to the TV camera, other image recording systems are often connected to the output of the II. The optical distributor (Fig. 2.3.8) is used to couple these devices to the output image of the II. A lens is positioned at the output image of the II, and light rays travel in a parallel (non-diverging) beam into the light-tight distributor housing. A mirror or a prism is used to reflect or refract the light toward the desired imaging receptor. Figure 2.9 illustrates a video camera and a 105-mm roll film camera mounted on the distributor. Mirrors can be motorized, and can shunt the light to any of the accessory ports on the distributor. When only two imaging receptors are present, a stationary partially silvered mirror can be used to split the light beam so that it is shared between the two cameras.

2.3.4.2 Lenses

The lenses used in fluoroscopy systems are identical to high-quality lenses used in photography. The lenses focus the incoming light onto the focal plane of the camera. The lens assemblies include a variable aperture, basically a small hole positioned between individual lenses in the

lens assembly. Adjusting the size of the hole changes how much light gets through the lens system. The *f-number* is (inversely) related to the diameter of the hole ($f = \text{focal length}/\text{aperture diameter}$), but it is the area of the hole that determines how much light gets through. Because of this, the standard *f-numbers* familiar to anyone who owns a camera progress by multiples of $\sqrt{2}$: 1.0, 1.4, 2.0, 2.8, 4.0, 5.6, 8, 11, 16. Changing the diameter of the hole by a factor $\sqrt{2}$ changes its area by a factor of 2, and thus increasing the *f-number* by one *f-stop* reduces the amount of light passing through the aperture by a factor of 2. At $f/16$, the aperture is tiny, little light gets through, and the overall gain of the II and optics combined is reduced. At $f/5.6$, more light gets through, and the overall gain of the II-optics subsystem is eight times higher than at $f/16$.

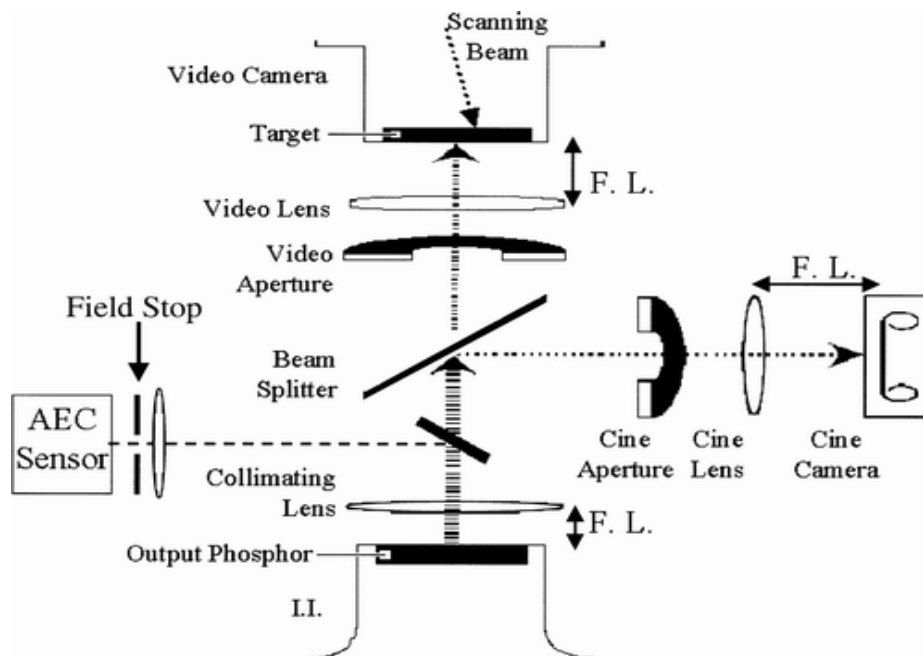


Figure 2.8 The optical distributor. The output window of the image intensifier, which is the source of the optical image, is also shown (bottom). Parallel rays of light enter the optical chamber, are focused by lenses, and strike the video camera where an electronic-image is produced. A partially silvered mirror (or motorized mirror in some instances) is used to shunt the light emitted by the image intensifier to an accessory port (left). A roll film camera is shown mounted on the optical distributor. The separate apertures for the two imaging devices (video camera and roll film camera) allow adjustment for the differing sensitivity of the two devices.

Adjustment of the aperture markedly changes the effective gain of the II-optics subcomponents of the imaging chain. This adjustment has an important affect on the performance of the

fluoroscopy system. By lowering the gain of the II optics, a higher x-ray exposure rate is used, and lower noise images will result. Increasing the gain reduces the x-ray exposure rate and lowers the dose, but reduces image quality. This will be discussed more fully below (see Automatic Brightness Control).

2.3.5 Video Cameras

2.3.5.1 General Operation

The closed-circuit video system transfers the signal from the output of the II to the video monitors in the room. The operation of a video system is shown schematically in Fig. 2.9. In the video camera, patterns of light (the image data) are incident upon the TV target (Fig. 2.9A). The target is swept by a scanning electron beam in a raster scan pattern. The TV target is made of a photoconductor, which has high electrical resistance in the dark, but becomes less resistive as the light intensity striking it increases. As the electron beam (electrical current) scans each location on the target, the amount of current that crosses the TV target and reaches the signal plate depends on the resistance of the target at each location, which in turn is related to the local light intensity. Thus the electrical signal is modulated by the local variations in light intensity, and that is physically how the video system converts the image to an electronic signal.

The video signal, which is represented as voltage versus time (Fig. 2.9B), is transferred by wire to the video monitor. Synchronization pulses are electronically added to the signal to keep the raster scanning in the video camera and video monitor synchronized. At the monitor, the raster scan pattern on the target is replicated by an electron beam scanning the monitor phosphor. The video signal voltage modulates the beam current in the monitor, which in turn modulates the luminance at that location on the monitor.

Analog video systems typically have 30 frame/sec operations, but they work in an interlaced fashion to reduce flicker, the perception of the image flashing on and off. The human eye-brain system can detect temporal fluctuations slower than about 47 images/sec, and therefore at 30 frame/sec flicker would be perceptible. With interlaced systems, each frame is composed of two fields (called odd and even fields, corresponding to every other row in the raster, with the odd field starting at row 1, and the even field starting at row 2), and each field is refreshed at a rate of 60 times per second (although with only half the information), which is fast enough to avoid the perception of flicker.

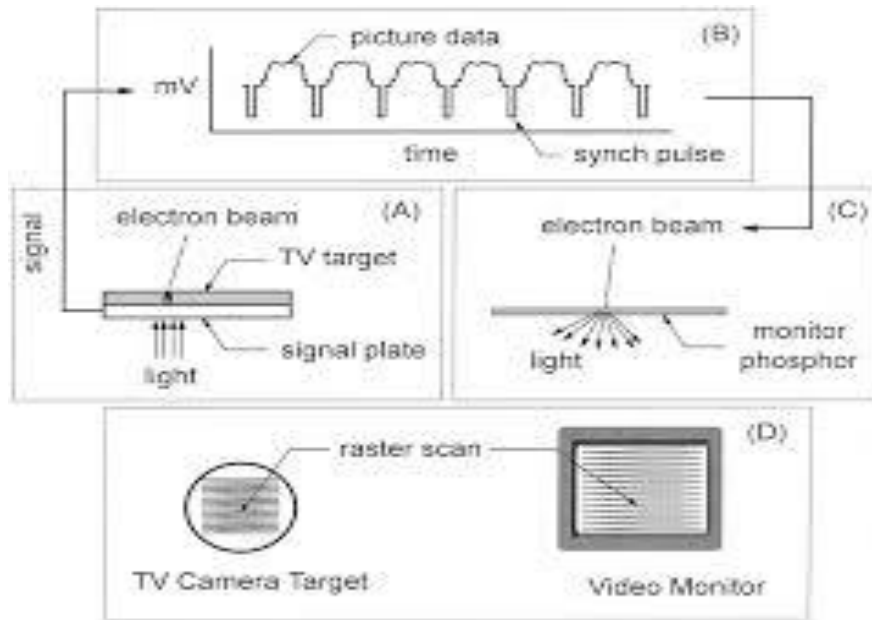


Figure 2.9 The closed circuit TV system used in fluoroscopy. At the TV camera (A), an electron beam is swept in raster fashion on the TV target (e.g., SbS03). The TV target is a photoconductor, whose electrical resistance is modulated by varying levels of light intensity. In areas of more light, more of the electrons in the electron beam pass across the TV target and reach the signal plate, producing a higher video signal in those lighter regions. The video signal (B) is a voltage versus time waveform that is communicated electronically by the cable connecting the video camera with the video monitor. Synchronization pulses are used to synchronize the raster scan pattern between the TV camera target and the video monitor. Horizontal sync pulses (shown) cause the electron beam in the monitor to laterally retrace and prepare for the next scan line. A vertical sync pulse (not shown) has different electrical characteristics and causes the electron beam in the video monitor to reset at the top of the screen. Inside the video monitor (C), the electron beam is scanned in raster fashion, and the beam current is modulated by the video signal. Higher beam current at a given location results in more light produced at that location by the monitor phosphor. (D) The raster scan on the monitor is done in synchrony with the scan of the TV target.

2.3.5.2 Video Resolution

The spatial resolution of video in the vertical direction is determined by the number of video lines. Standard video systems use 525 lines (in the United States), but larger IIs (>23 cm) require *high line rate* video to deliver adequate resolution, which is typically 1,023 lines, but this varies

by vendor. For a 525-line system, only about 490 lines are usable. In the early days of television, a man named Kell determined empirically that about 70% of theoretical video resolution is appreciated visually, and this psychophysical effect is now called the Kell factor. Thus, of the 490 video lines, about $490 \times 0.7 = 343$ are useful for resolution, and 343 *lines* are equivalent to about 172 *line pairs*, since one line pair constitutes two lines. If 172 line pairs scan a 229-mm (9-inch) field, the resulting spatial resolution will be $172 \text{ line pairs} / 229 \text{ mm} = 0.75 \text{ line pairs/mm}$. In 17-cm (7-inch) and 12-cm (5-inch) modes, this calculation yields resolutions of 1.0 and 1.4 line pairs/mm, respectively.

The horizontal resolution is determined by how fast the video electronics can respond to changes in light intensity. This is influenced by the camera, the cable, and the monitor, but the horizontal resolution is governed by the *bandwidth* of the system. The time necessary to scan each video line (525 lines at 30 frames/sec) is 63 μsec . For standard video systems, 11 μsec are required for the horizontal retrace (the repositioning of the electron beam at the beginning of each horizontal raster scan), so that 52 μsec are available for portraying the picture data. To achieve 172 cycles in 52 μsec (to match the vertical resolution), the bandwidth required is $172 \text{ cycles} / 52 \times 10^{-6} \text{ sec} = 3.3 \times 10^6 \text{ cycles/sec} = 3.3 \text{ MHz}$. Higher bandwidths ($\sim 4\times$) are required for high-line rate video systems.

2.3.5.3 Flat panel Digital fluoroscopy

Flat panel devices are thin film transistor (TFT) arrays that are rectangular in format and are used as x-ray detectors. TFT systems are pixilated devices with a photodiode at each detector element, which converts light energy to an electronic signal. Since the TFT array is sensitive to visible light (and is not very sensitive to X-rays), a scintillator such as CsI is used to convert the incident X-ray beam energy into light, which then strikes the TFT detector. For fluoroscopic applications, the flat panel imager replaces the image intensifier and video camera, and directly records the real-time fluoroscopic image sequence. The pixel size in fluoroscopy is usually larger than radiography, and some flat panel systems have the ability to adjust the pixel size by binning four pixels into one larger pixel. Such dual-use systems have pixels small enough to be adequate for radiography (e.g. 100 to 150 μm), but the pixels can be binned to provide a detector useful for fluoroscopy (e.g., 200 to 300 μm). Flat panel imagers (Fig. 2.3.10) can therefore replace the II, video camera, digital spot film device, and cine camera in a much lighter and smaller package. Because a vacuum environment is not required (because there are no electron optics), the cover

to the flat panel can be -1 mm of carbon fiber, and this improves the quantum detection efficiency compared to the image intensifier as shown in Fig. 2.3.7.

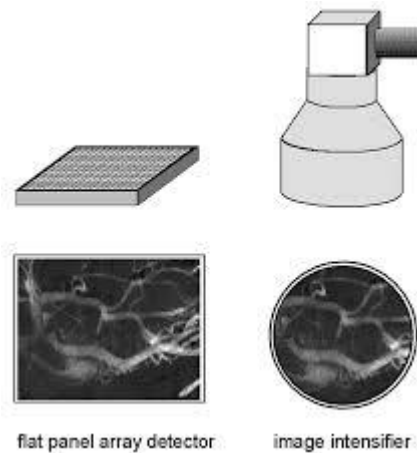


Figure 2.10 The flat panel imaging system and the image intensifier with its mounted video camera and optimal distributor. The flat panel detector produces a rectangular image, well matched to the rectangular format of TV monitors. The image produced by the image intensifier is circular in format, resulting in less efficient utilization of rectangular monitors for fluoroscopic display. The flat panel detector is substantially less bulky than the image intensifier and TV system, but provides the same functionality.

2.3.3 Peripheral equipment

There are many imaging cameras that are commonly used with fluoroscopic systems. Most of these are mounted on accessory ports of the optical distributor.

2.3.3.1 Photo-Spot Cameras

A photo-spot camera is used to generate images on photographic film, taken from the output of the II. The most common formats are 100-mm cut film, or 105-mm roll film. Spot film cameras are convenient; fluoroscopists can archive an image during the fluoroscopic examination by simply stepping on a floor pedal. The mirror in the optical distributor swings into the optical path, redirecting light rays toward the spot-film camera (or a partially silvered mirror is already in place). The X-ray generator produces a radiographic pulse of X-rays, the camera shutter opens briefly, and the image is recorded on film. The film is advanced and stored in a take-up magazine. Photo-spot images are made directly from the output phosphor of the II, through lenses, and therefore enjoy the full resolution of the II systems, unencumbered by the resolution

constraints of the video system. An entrance exposure to the II of 75 to 100 $\mu\text{R}/\text{image}$ is typically required for photo-spot cameras operating with a 23-cm (9-inch) FOV II.

2.3.3.2 Digital photo-spot

Digital photo-spot cameras are high-resolution, slow-scan TV cameras in which the TV signal is digitized and stored in computer memory. Alternately, digital photo-spot cameras are charge coupled device (CCD) cameras with 10242 or 20482 pixel formats. The digital photo-spot camera allows near-instantaneous viewing of the image on a video monitor. The real-time acquisition of the permanent archive images allows the fluoroscopist to quickly assemble an array of images demonstrating the anatomy pertinent to the diagnosis. The digital images can be printed on a laser imager if hard-copy viewing is necessary.

2.3.3.3 Spot-Film Devices

A spot-film device attaches to the front of the II, and allows the acquisition of radiographic screen-film images using a few button presses on the device. When an image acquisition is requested by the operator, the spot-film device transports a screen-film cassette from a lead-lined magazine to a position directly in front of the II. A radiographic pulse of x-rays is used, and spot-film devices typically have their own anti-scatter grids and automatic exposure control. Most systems automatically collimate to a variety of formats. For example, one 30-cm x 30-cm cassette can be exposed with four different 15-cm x 15-cm radiographic images. Although bulky, spot-film devices are convenient when large FOV images are routinely required, as in GI/GU studies. Spot film devices produce conventional screen-film images, with somewhat better spatial resolution than images produced by the II (e.g., photo-spot cameras).

2.3.3.4 Cine-Radiography Camera

A cine camera attaches to a port on the optical distributor of an II, and can record a very rapid sequence of images on 35-mm film. Cine is used frequently in cardiac studies, where a very high frame rate is needed to capture the rapid motion of the heart. The frame rates of cine cameras run from 30 frames/see to 120frames/see or higher. Cine radiography uses very short radiographic pulses, and therefore special generators are needed. The opening of the cine camera shutter is synchronized with the X-ray pulses. The X-ray tube loading is usually quite high, so high heat capacity x-ray tubes are used in the cardiac catheterization laboratory. An entrance exposure to the input phosphor of approximately 10 to 15 $\mu\text{R}/\text{frame}$ (23-cm-diameter II) is used for cine-radiography studies. Digital cine cameras are typically CCD-based cameras that produce a rapid

sequence of digital images instead of film sequence. Digital cine is increasingly used in the cardiology community.

2.3.4 Fluoroscopy Modes of Operation

With the computerization of X-ray generators and imaging systems, a great deal of flexibility has been added to fluoroscopy systems compared to what was available in the 1970s. Some systems come with enhanced features, and some of these alternate modes of operation are described below.

2.3.4.1 Continuous fluoroscopy

Continuous fluoroscopy is the basic form of fluoroscopy. It uses a continuously on X-ray beam using typically between 0.5 and 4 mA (depending on patient thickness). A video camera displays the image at 30frames/sec, so that each fluoroscopic frame requires 33 milliseconds (1/30 second). Any motion that occurs within the 33-msec acquisition acts to blur the fluoroscopic image, but this is acceptable for most examinations. In the United States, the maximum entrance exposure to the patient is 10 R/min.

2.3.4.2 High Dose Rate Fluoroscopy

Some fluoroscopy systems have high dose rate options, usually called specially activated fluoroscopy. This mode of operation allows exposure rates of up to 20 R/min to the patient in the U.S. The high dose rate mode is enabled by stepping on a different pedal than the standard fluoroscopy pedal. An audible signal is required to sound when specially activated fluoroscopy is being used. Unless a practice sees an exceptionally high proportion of obese patients, the need for high dose rate fluoroscopy is questionable.

2.3.4.3 Variable frame Rate Pulsed Fluoroscopy

In pulsed fluoroscopy, the X-ray generator produces a series of short x-ray pulses. Let's compare this with continuous fluoroscopy with 33-msec frame times, operating continuously at 2 mA. The pulsed fluoroscopy system can generate 30 pulses per second, but each pulse can be kept to ~10 msec and 6.6 mA. This would provide the same X-ray exposure rate to the patient (using 0.066 mAs per frame in this example), but with pulsed fluoroscopy the exposure time is shorter (10 msec instead of 33 msec), and this will reduce blurring from patient motion in the image. Therefore, in fluoroscopic procedures where object motion is high (e.g., positioning catheters in highly pulsatile vessels), pulsed fluoroscopy offers better image quality at the same dose rates.

Many fluoroscopists practice aggressive dose-saving measures, a commendable goal. Variable frame rate pulsed fluoroscopy can be instrumental in this. During much of a fluoroscopic procedure, a rate of 30 frames per second is not required to do the job. For example, in a carotid angiography procedure, initially guiding the catheter up from the femoral artery to the aortic arch does not require high temporal resolution, and perhaps 7.5 frames per second can be used—reducing the radiation dose for that portion of the study to 25% (7.5/30). Pulsed fluoroscopy at variable frame rates (typically 30, 15, and 7.5 frames/sec) allows the fluoroscopist to reduce temporal resolution when it is not needed, sparing dose in return. At low frame rates, the fluoroscopic image would demonstrate intolerable flicker unless measures were taken to compensate for this. Using a digital refresh memory, each image is digitized and shown continuously at 30 frames per second (or faster) on the video monitors until it is refreshed with the next pulsed image. In this way, a sometimes jerky temporal progression of images can be seen by the human observer at low frame rates, but the image does not suffer from on/off flicker.

2.3.4.4 Frame Averaging

Fluoroscopy systems provide excellent temporal resolution, and it is this feature that is the basis of their clinical utility. However, fluoroscopy images are also relatively noisy, and under some circumstances it is beneficial to compromise temporal resolution for lower noise images. This can be done by averaging a series of images, as shown in Fig. 2.11. Frame averaging is performed by digitizing the fluoroscopic images and performing real-time averaging in computer memory for display. Appreciable frame averaging can cause very noticeable image lag (reduced temporal resolution), but the noise in the image is reduced as well. The compromise between lag and image noise depends on the specific fluoroscopic application and the preferences of the user. Aggressive use of frame averaging can allow lower dose imaging in many circumstances. Portable fluoroscopy systems use X-ray tubes with limited output, and consequently frame averaging is a feature commonly found on these systems.

Different averaging algorithms can be used, but a common approach to frame averaging is called *recursive filtering*. In this approach, the image just acquired, I_n is added with the last image (I_{n-1}) using

$$I_{displayed} = \alpha I_n + (1 - \alpha) I_{(n-1)} [1]$$

The parameter α ranges from 0 to 1; as α is reduced, the contribution of the current image (I_n) is reduced, the contribution of previous images is enhanced, and thus the amount of lag is

increased. As α is increased, the amount of lag is reduced, and at $\alpha = 1$, no lag occurs. The current displayed image $I_{displayed}$ becomes the I_{n-1} image for the next frame, and because of this the weighted image data from an entire sequence of images (not just two images) is included (Fig. 2.11).

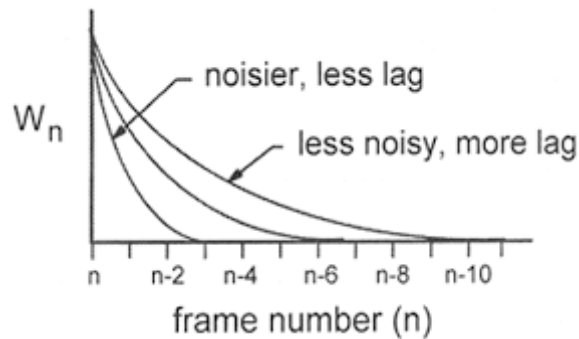


Figure 2.11 The concept of frame averaging. The individual frames occurring as a function of time are weighted and averaged into a single display image, and typically "older" frames are weighted less than newer frames.

2.3.4.5 Last-Frame-Hold

When the fluoroscopist takes his or her foot off of the fluoroscopy pedal, rather than seeing a blank monitor, last-frame-hold enables the last live image to be shown continuously. The last frame-hold circuit merely is a video digitizer, a fast analog to digital converter that converts the video signal to a digital image. As the fluoroscopy pedal is released, a signal is generated that causes the last image with X-rays on to be captured, and this image is displayed continuously on the video monitor(s) until the fluoroscopy pedal is depressed again. Last-frame-hold is very convenient and can reduce the dose to the patient. While especially useful at training institutions where residents are developing their fluoroscopy skills, last-frame-hold is a convenient feature that even seasoned fluoroscopists should and do use. Rather than orienting oneself with the pedal depressed and X-rays on, last-frame-hold allows the fluoroscopist to examine the image for as long as necessary using no additional radiation.

2.3.4.6 Road Mapping

Road mapping is really a software-enhanced variant of the last-frame-hold feature. Two different approaches to road mapping can be found on fluoroscopic systems. Some systems employ side-by-side video monitors, and allow the fluoroscopist to capture an image (usually with a little

contrast media injection), which is then shown on the monitor next to the live fluoroscopy monitor. In this way, the path of the vessel can be seen on one monitor, while the angiographer advances the catheter in real time on the other monitor. Another approach to road mapping is to allow the angiographer to capture a contrast injection image (or subtracted image), but then that image is displayed as an overlay onto the live fluoroscopy monitor. In this way, the angiographer has the vascular "road map" right on the fluoroscopy image, and can angle the catheter to negotiate the patient's vascular anatomy. Road mapping is useful for advancing catheters through tortuous vessels.

2.3.5 Automatic Brightness Control (ABC)

The exposure rates in modern fluoroscopic systems are controlled automatically. The purpose of the *automatic brightness control* (ABC) is to keep the brightness of the image constant at the monitor. It does this by regulating the X-ray exposure rate incident on the input phosphor of the II. When the II is panned from a thin to a thick region of the patient, the thicker region attenuates more of the X-rays, so fewer X-rays strike the II and less light is generated. The system senses the reduction in light output from the II and sends a signal to the X-ray generator to increase the X-ray exposure rate. Fluoroscopic systems sense the light output from the II using a photodiode or the video signal itself. This control signal is used in a feedback circuit to the X-ray generator to regulate the X-ray exposure rate. Automatic brightness control strives to keep the number of X-ray photons used for each fluoroscopic frame at a constant level, keeping the signal-to-noise ratio of the image approximately constant regardless of the thickness of the patient.

The fluoroscopic ABC circuitry in the X-ray generator is capable of changing the mA and the kV in continuous fluoroscopy mode. For pulsed-fluoroscopy systems, the ABC circuitry may regulate the pulse width (the time) or pulse height (the mA) of the X-ray pulses. For large patients, the X-ray exposure rate may hit the maximum legal limit (10 R/min) yet the image will still not be appropriately bright. Some X-ray fluoroscopic systems employ ABC circuitry which can then open the aperture to increase the brightness of the image. The video camera also has electronic gain, which is increased when X-ray exposure rates are at a maximum. These last two approaches will increase the visible noise in the image, since the X-ray fluence rate (photons/mm²/sec) is no longer being held constant at the input phosphor.

Any particular generator changes the mA and the kV in a predetermined sequence; however, this sequence varies with different brands of generators and is sometimes selectable on a given

fluoroscopic system. How the mA and kV change as a function of patient thickness has an important effect on patient dose and image quality. When the fluoroscopist pans to a thicker region of the patient, the ABC signal requests more X-rays from the generator. When the generator responds by increasing the kV, the subject contrast decreases, but the dose to the patient is kept low because more X-rays penetrate the patient at higher kV. In situations where contrast is crucial (e.g., angiography), the generator can increase the mA instead of the kV; this preserves subject contrast at the expense of higher patient dose. In practice, the mA and kV are increased together, but the curve that describes this can be designed to aggressively preserve subject contrast, or alternately to favor a lower dose examination (Fig. 2.12). Some fluoroscopy systems have "low dose" or "high contrast" selections on the console, which select the different mA/kV curves shown in Fig. 2.12.

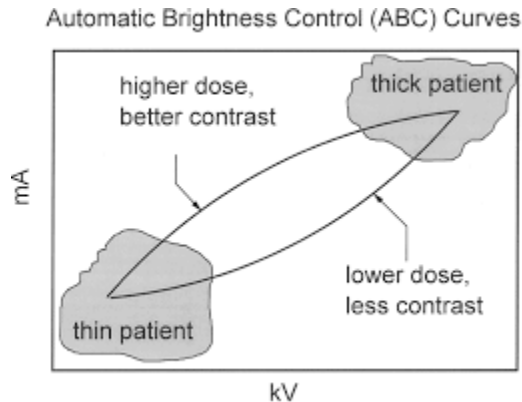


Figure 2.12 Automatic brightness control (ABC) changes the exposure rate as the attenuation of the patient between the X-ray tube and the image intensifier changes. The exposure rate can be increased by increasing either the mA, the kV, or both. Two possible curves are illustrated. The top curve increases mA more rapidly than kV as a function of patient thickness, and preserves subject contrast at the expense of higher dose. The bottom curve increases kV more rapidly than mA with increasing patient thickness, and results in lower dose, but lower contrast as well.

2.3.6 Image quality

2.3.6.1 Spatial Resolution

The spatial resolution of the II is best described by the modulation transfer function (MTF). The limiting resolution of an imaging system is where the MTF approaches zero (Fig. 2.3.13). The limiting resolution of modern IIs ranges between 4 and 5 cycles/mm in 23-cm mode. Higher magnification modes (smaller fields of view) are capable of better resolution; for example, a 14-

cm mode may have a limiting resolution up to 7cycles/mm. The video imaging system degrades the MTF substantially, so that the resolution performance of the image intensifier is not realized. Table 2.3.1 lists the typical limiting resolution of video-based fluoroscopy for various image intensifier field sizes.

Film-based imaging systems (photo-spot and cine cameras) coupled directly to the output of the image intensifier will produce spatial resolution similar to that of the image intensifier, since the spatial resolution of the optics and of the film are typically much better than that of the II. Digital imaging systems such as digital photo-spot and digital subtraction angiography (DSA) systems will usually demonstrate limiting resolution determined by the pixel size for 5122 and 10242 matrix systems. For example, for a 10242 DSA system in 27-cm FOV with the width of the digital matrix spanning the circular FOV of the II, the pixel size would measure about $270 \text{ mm}/1024 \text{ pixels} = 0.26 \text{ mm/pixel}$. The corresponding limiting spatial resolution (Nyquist equation, see Chapter 10) is about 1.9cycles/mm.

2.3.6.2 Contrast Resolution

The contrast resolution of fluoroscopy is low by comparison to radiography, because the low exposure levels produce images with relatively low signal-to-noise ratio (SNR). Contrast resolution is usually measured subjectively by viewing contrast-detail phantoms under fluoroscopic imaging conditions. Contrast resolution is increased when higher exposure rates are used, but the disadvantage is more radiation dose to the patient. The use of exposure rates consistent with the image quality needs of the fluoroscopic examination is an appropriate guiding principle. Fluoroscopic systems with different dose settings (selectable at the console) allow the user flexibility from patient to patient to adjust the compromise between contrast resolution and patient exposure.

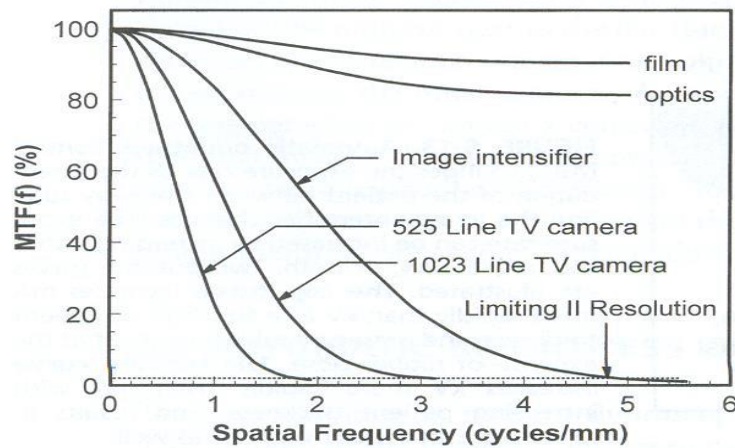


Figure 2.13 The modulation transfer function (MTF) of the components in the fluoroscopic imaging chain. The film (for example in a photo-spot camera) has very good resolution, and the optics in the optical distributor also has excellent resolution. The MTF of the image intensifier is shown with a limiting resolution of approximately 4.8 cycles per mm. This MTF is typical for a 23 cm image intensifier mode. The TV camera MTF is the worst in the imaging chain, and limits the MTF of the overall image during live fluoroscopy and videotaped imaging sequences. Image acquisition devices that bypass the video chain (photo spot and cine) enjoy the native resolution of the image intensifier.

Table 2.1 Typical Limiting Spatial Resolution in Fluoroscopy

| Field of View: cm (inches) | 1,023-Line Video: Line Pairs/mm | 525-Line Video: Line Pairs/mm |
|----------------------------|---------------------------------|-------------------------------|
| 14 (5.5) | 2.7 | 1.4 |
| 20 (7.9) | 2.0 | 1.0 |
| 27 (10.6) | 1.6 | 0.7 |
| 40(15.7) | 1.3 | 0.5 |

2.3.6.3 Temporal Resolution:

The excellent temporal resolution of fluoroscopy is its strength in comparison to radiography, and is its reason for existence. Blurring phenomena that occur in the spatial domain reduce the spatial resolution, and similarly blurring in the time domain can reduce temporal resolution. Blurring in the time domain is typically called image *lag*. Lag implies that a fraction of the image data from one frame carries over into the next frame. In fact, image information from several

frames can combine together. Lag is not necessarily bad, as mentioned previously in the section on frame averaging. Video cameras such as the vidicom (SbS3 target) demonstrate a fair amount of lag. By blurring together several frames of image data, a higher SNR is realized because the contribution of the x-ray photons from the several images is essentially combined into one image. In addition to the lag properties of the video camera, the human eye produces a lag of about 0.2 sec. At 30frames/sec, this means that approximately six frames are blurred together by the lag of the human eye-brain system. Combining an image with six times the x-ray photons increases the SNR by $\sqrt{6} \approx 2.5$ times, and thus the contrast resolution improves at the expense of temporal resolution. As mentioned above, some systems provide digital frame averaging features that intentionally add lag to the fluoroscopic image.

Whereas some lag is usually beneficial for routine fluoroscopic viewing, for real-time image acquisition of dynamic events such as in digital subtraction angiography, lag is undesirable. With OSA and digital cine, cameras with low-lag performance (e.g. plumbicons or CCO cameras) are used to maintain temporal resolution.

2.3.7 Fluoroscopy Suites

The clinical application strongly influences the type of fluoroscopic equipment that is needed. Although smaller facilities may use one fluoroscopic system for a wide variety of procedures, larger hospitals have several fluoroscopic suites dedicated to specific applications, such as GI/GU, cystography, peripheral vascular and cardiac angiography, and neurovascular examinations.

2.3.7.1 Gastrointestinal Suites

In GI fluoroscopic applications, the radiographic/fluoroscopic room (commonly referred to as an Rand F room) consists of a large table that can be rotated from horizontal to vertical to put the patient in a head-down (Trendelenburg) or head up position (Fig. 2.3.14A). The II can be either over or under the table, but is usually above the table. The table has a large shroud around it, hiding the X-ray tube or the II and providing radiation shielding. The table usually will have a Bucky tray in it, to be used with an overhead X-ray tube, mounted on a ceiling crane in the room. A spot film device or photo-spot camera often accompanies this table configuration.

2.3.7.2 Remote Fluoroscopy Rooms

A remote fluoroscopy room is designed for remote operation by the radiologist. The fluoroscopic system is motorized and is controlled by the operator sitting in a lead-glass shielded control

booth. In addition to the normal movement of the II (pan, zoom, up, down), remote rooms typically have a motorized compression paddle that is used to remotely palpate the patient. Remote rooms use a reverse geometry, where the X-ray tube is above the table and the image intensifier is below the table. These systems reduce the radiation exposure to the physician operating it, and allow the procedure to be done sitting down without a lead apron on. Remote rooms require more patience and operator experience than conventional rooms.

2.3.7.3 Peripheral Angiography Suites

In the angiographic setting, the table does not rotate but rather "floats"-it allows the patient to be moved from side to side and from head to toe (Fig. 2.14 B). The fluoroscopy system (the X-ray tube and II) can also be panned around the stationary patient. The fluoroscopic system is typically mounted on a C-arm or U-arm apparatus, which can be rotated and skewed, and these motions provide considerable flexibility in providing standard posteroanterior (PA) and lateral as well as oblique projections. Because of the routine use of iodinated contrast media, power injectors are often table- or ceiling mounted in angiographic suites. For peripheral angiography and body work, the image intensifier diameters run from 30 to 40 cm. For neuroangiography rooms, 30-cm image intensifiers are commonly used.

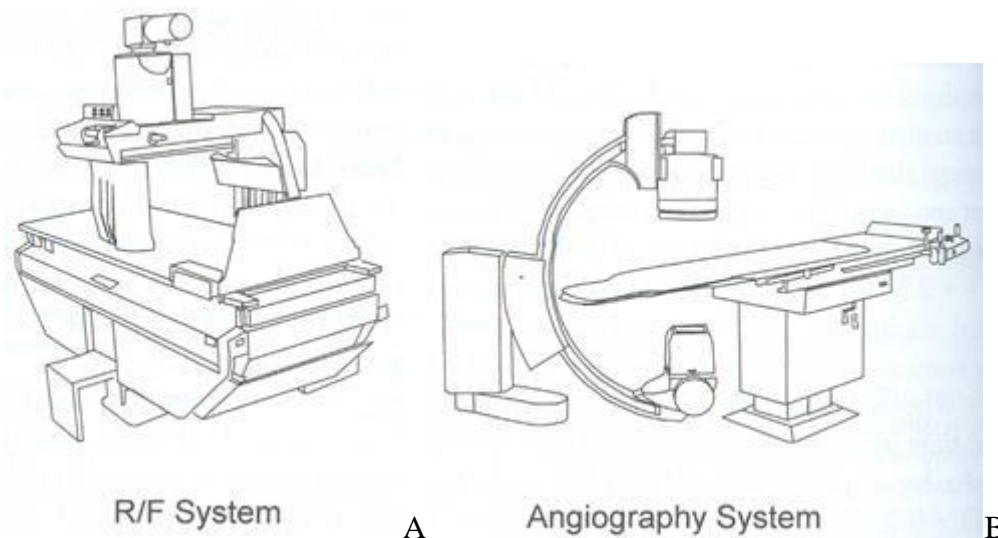


Figure 2.14 A: A radiographic/fluoroscopic (R/F) system. R/F systems allow different table angulations to facilitate the movement of contrast agents (typically barium-based) upward or downward in the patient. B: Angiography systems typically use a table that does not angulated, but rather floats left to right and top to bottom, which allows easy adjustment of the patient's anatomy with respect to the imaging chain for following a catheter as it is advanced. The X-ray

tube (below) and image intensifier (above) are commonly mounted on a (-arm or U-arm configuration, which allows easy adjustments between the lateral and postero-anterior (PA) imaging positions.

2.3.7.4 Cardiology Catheterization Suite

The cardiac catheterization suite is very similar to an angiography suite, but typically 23-cm image intensifiers are used. The smaller IIs permit more tilt in the cranial caudal direction, as is typical in cardiac imaging. Cine cameras, either film based or digital is also mandatory features of the cardiac catheterization suite. Many cardiac catheterization systems are *biplane*.

2.3.7.5 Biplane Angiographic Systems

Biplane angiographic systems are systems with one table but with two complete imaging chains; there are two generators, two image intensifiers, and two X-ray tubes. Two complete X-ray tube/II systems are used to simultaneously record the anteroposterior and lateral views of a single contrast injection. The simultaneous acquisition of two views allows a reduction of the volume of contrast media that is injected into the patient. During biplane angiography, the X-ray pulse sequence of each plane is staggered so that scattered radiation from one imaging plane is not imaged on the other plane. Biplane suites usually allow one of the imaging chains to be swung out of the way, when single plane operation is desired.

2.3.7.6 Portable Fluoroscopy-C Arms

Portable fluoroscopy systems are C-arm devices with an x-ray tube placed opposite from the II. Many C-arm systems are 18-cm (7-inch), but 23-cm (9-inch) systems are available as well. Portable C-arm systems are used frequently in the operating room and intensive care units (Bushberg 2001).

2.4 Radiation Dosimetry for patient method dose measurement (DAP)

2.4.1 Patient Dose

The mean absorbed dose in a tissue or organ DT is the energy deposited in the organ divided by the mass of that organ - except for invasive methods, no organ doses can be measured. The only way in radiography is:

- ❖ Measure the Entrance Surface Air Kerma (ESAK).

- ❖ Use mathematical models based on Monte Carlo simulations (the history of thousands of photons is calculated) to estimate internal dose.
- ❖ Dose to the organ tabulated as a fraction of the entrance dose for different projections.
- ❖ Since filtration, field size and orientation play a role: long lists of tables (See NRPB R262 and NRPB SR262).

2.4.2 Factors influencing dose in radiography

2.4.2.1 Beam energy

Depending on peak kV and filtration; regulations require minimum total filtration to absorb lower energy photons, added filtration reduces dose (use of highest kV resulting in acceptable image contrast).

2.4.2.2 Grids

Reduce the amount of scatter reaching image receptor, but at the cost of increased patient dose, typically 2-5 times: “Bucky factor” or grid ratio.

2.4.2.3 Patient size

Thickness, volume irradiates, etc, and dose increases with patient size, technique charts with suggested exposure factor for various examinations and patient thickness helpful to avoid retakes.

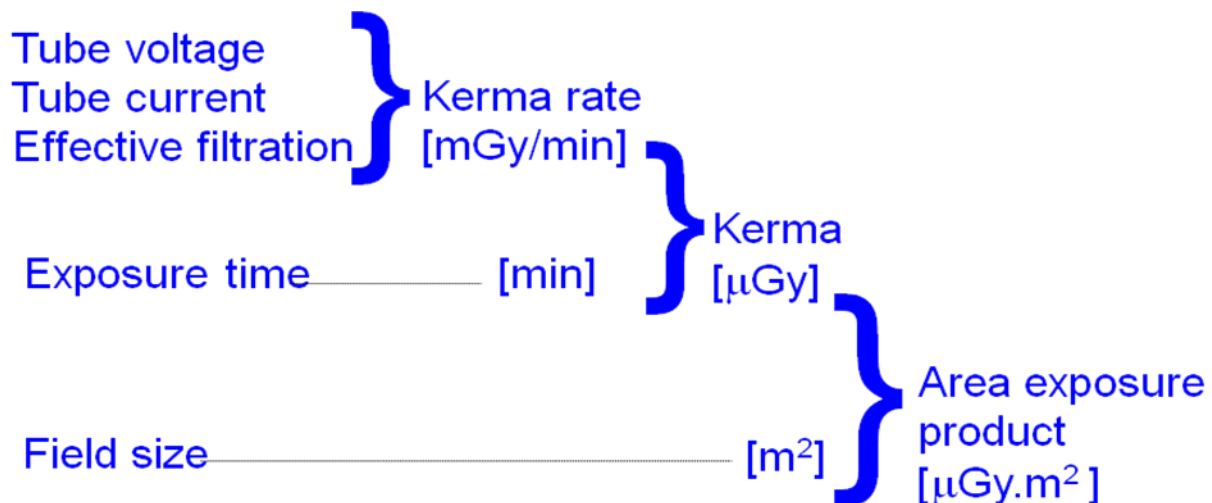


Figure 2.15 Essential parameters influencing patient exposure

2.4.3 Operational dose quantities

Quantities related to patient dose:

- ❖ Radiation output of X-ray tubes.
- ❖ Entrance surface dose.
- ❖ Dose-Area Product (DAP)

2.4.3.1 KERMA and Dose

KERMA (Kinetic Energy Released in a Material) is the sum of the initial kinetic energies of all charged ionizing particles liberated by uncharged ionizing particles in a material of mass. Absorbed dose is the energy absorbed per unit mass. In diagnostic radiology, Kerma and Dose are equal; the SI unit of kerma and dose is the joule per kilogram, (J/kg), termed gray (Gy).

2.4.3.2 Incident Air Kerma (iAK)

Incident air kerma is the air kerma from the incident beam on the central X-ray beam axis at the focal-spot to surface distance at the skin entrance plane. Only primary radiation incident on the patient or phantom and not backscattered radiation is included.

2.4.3.3 Entrance-surface air kerma (ESAK)

Entrance-surface air kerma (ESAK) is the air kerma on the central X ray beam axis at the point where X ray beam enters the patient or phantom. The contribution of the backscattered radiation is included.

2.4.4 Effect of scatter

Radiation is scattered from any surface, lighter materials such as tissue scatter more radiation than heavier ones such as lead, and this may affect dose measurements recorded. If the radiation detectors are placed directly on any surface, it will be exposed to backscattered radiation.

2.4.4.1 Influence of (Back Scattered) BS radiation on measurements

The contribution of scattered radiation to the air kerma at the point of measurement is below 3% (5%) if there is no material in the beam in the space of 1 m (0.7 m) behind the point of measurement.

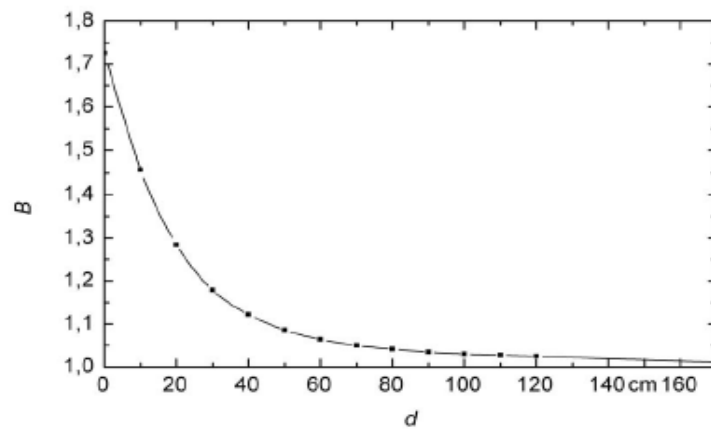


Figure 2.16 10 cm PMMA, 60x60 cm², beam quality RQR10

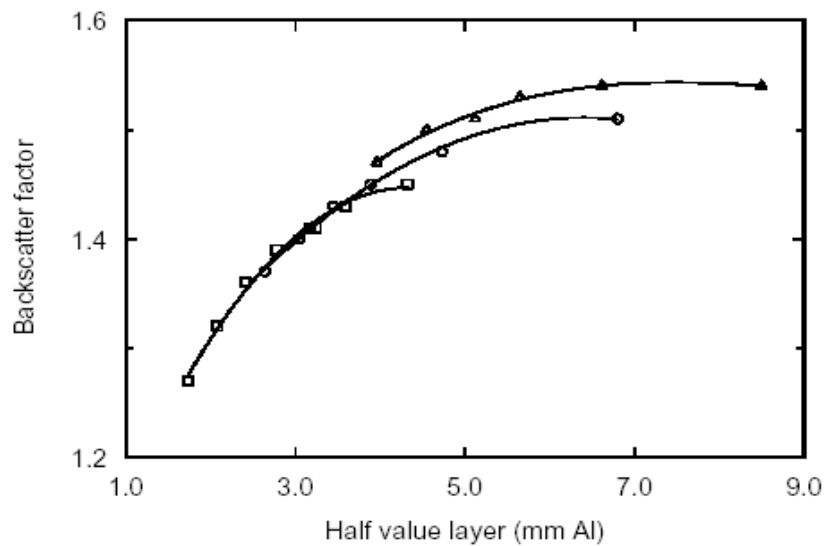


Figure 2.17 Backscatter factors; 25x25 cm²; 2.5 mm total filtration

Table 2.2 Backscatter factors (water)

| HVL (mm AL) | Field size (cm x cm) | | | | |
|-------------|----------------------|---------|---------|---------|---------|
| | 10 x 10 | 15 x 15 | 20 x 20 | 25 x 25 | 30 x 30 |
| 2.0 | 1.26 | 1.28 | 1.29 | 1.30 | 1.30 |
| 2.5 | 1.28 | 1.31 | 1.32 | 1.33 | 1.34 |
| 3.0 | 1.30 | 1.33 | 1.35 | 1.36 | 1.37 |
| 4.0 | 1.32 | 1.37 | 1.39 | 1.40 | 1.41 |

2.4.5 Absorbed dose in soft

Values of absorbed dose to tissue will vary by a few percent depending on the exact composition of the medium that is taken to represent soft tissue. The following value is usually used for 80 kV and 2.5 mm Al of filtration:

$$F_c = [\mu_{n/p}]_{\text{water}} / [\mu_{n/p}]_{\text{air}}] \approx 1.06$$

2.4.6 Detectors for X-Ray dose measurements

- ❖ Ionization chambers
- ❖ Semiconductor detectors

2.4.6.1 Ionization Chambers

Collect ions produced by interactions in air, atomic Numbers similar to tissue › similar interactions. Different sizes › also related to dose and dose rate (larger sizes of chambers used for measurement of low doses, which produce less charge). Ionization Chambers (IC) are sensitive to radiation incident from all directions and this has an influence on scatter radiation detected, ionization chambers are thin walled and usually detect radiation from all directions.



Figure 2.18 Ionization Chambers



Figure 2.19 Cylindrical shape

Cylindrical shape; two electrodes: the external wall of the chamber constitutes the cathode; the anode is a filament placed in the centre of the volume. Cap material is air-equivalent (same absorption as the same mass of air); electrons used to measure change in charge are produced in cap. Cap thickness is important; too thin is an insufficient electron enters the chambers, and too thick is too much radiation absorbed, response is symmetrical with respect to the chamber axis.

2.4.6.1.1 Parallel Plate Ionization Chamber

Most common type of IC used for diagnostic radiological measurement of air kerma (to improve spatial resolution at least in one dimension).

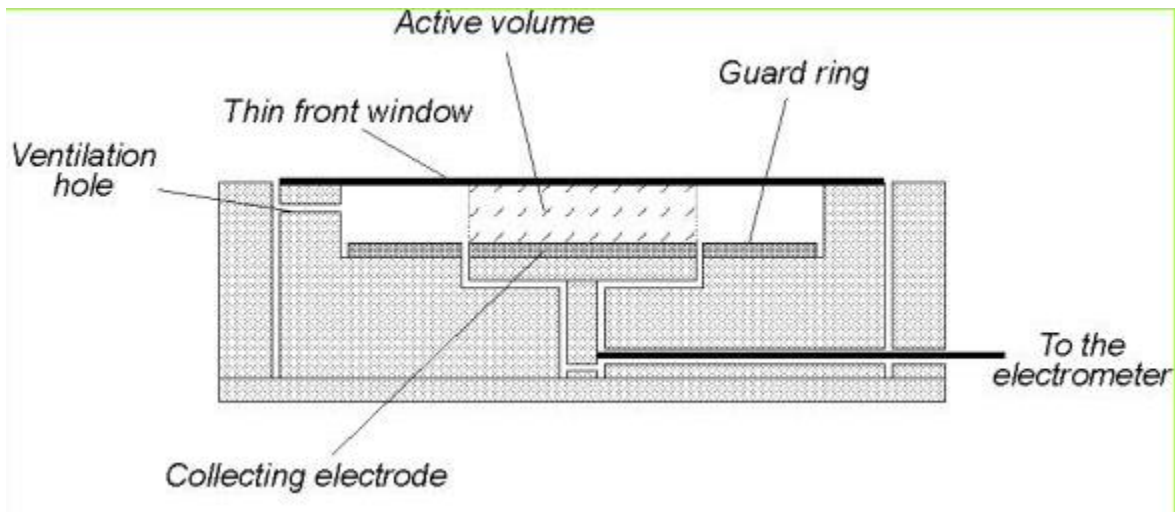


Figure 2.20 Parallel Plate Ionization Chamber

Two parallel flat electrodes separated by few millimeters. The chamber window thickness should be sufficient to allow full buildup of the secondary electron spectrum. Size of IC is important; it should be large enough to collect sufficient charge to give a measurement (1Gy produces approximately 36 nC in 1cc of air) but taking into account x-ray beam size. IC is calibrated with plates oriented perpendicularly to the beam axis; if parallel plate IC has different entrance and exit windows, it's important that the entrance window faces the focal spot. IC chambers are calibrated at the calibration laboratories in term of free in air kerma.

2.4.6.1.2 Transmission chamber

Detector is “transparent” to X-rays: attenuation can be neglected, generally consists of layers of PMMA coated with conducting material; graphite could not be used because is not transparent to light. Used materials contain elements of high atomic number (indium, tin) > energy dependence, used as KAP meters.

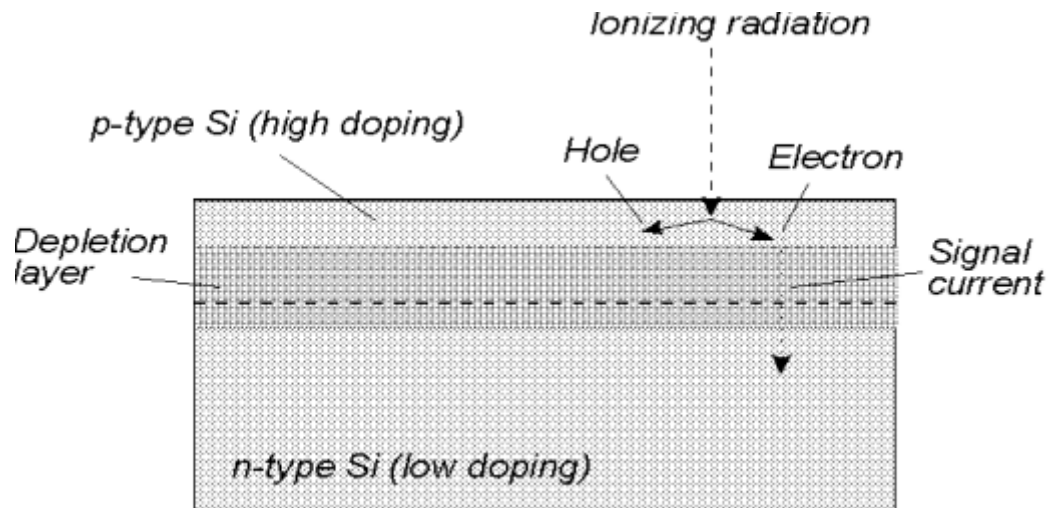


Figure 2.21: Cut through a silicon diode radiation detector



Figure 2.22: Semiconductors dosimeter

2.4.6.2 Semiconductors dosimeters

Diode: simplest semiconducting devices (based on a p-n junction). X-rays excite electrons in semiconductor, atomic numbers (Si), significantly higher atomic number than tissue » different mechanism of interactions.

Similar response with photon energy is achieved through using 2 or more detector elements with one or more positioned behind a thin metal filter. Readings are combined using an algorithm to give a similar response with photon energy to tissue » with this technique accuracy within +5% over the range of X-ray beam energies (50÷150 kV) (C. Martin).

Detectors are placed on lead backing plate to attenuate radiation incident from the rear, which would alter the ratios of radiations incident on the different elements. Lead backing plates affect the angular responses of the detectors » angles ranged from 40° to 120°.

2.4.6.2.1 Polar response of different detectors

Ionization Chamber (IC) Keithley, Semiconductor Detectors (SDs); Unfors Xi, 512L and Barracuda are mounted on lead backing plates.

2.4.6.2.2 Multi-meters

Multi-meters produced by different manufacturers allow measurement of dose, kVp and other parameters such as exposure time with one meter.



Figure 2.23 A: Unfors and B, RADCHECK Multi-meters

2.5 X-Ray System

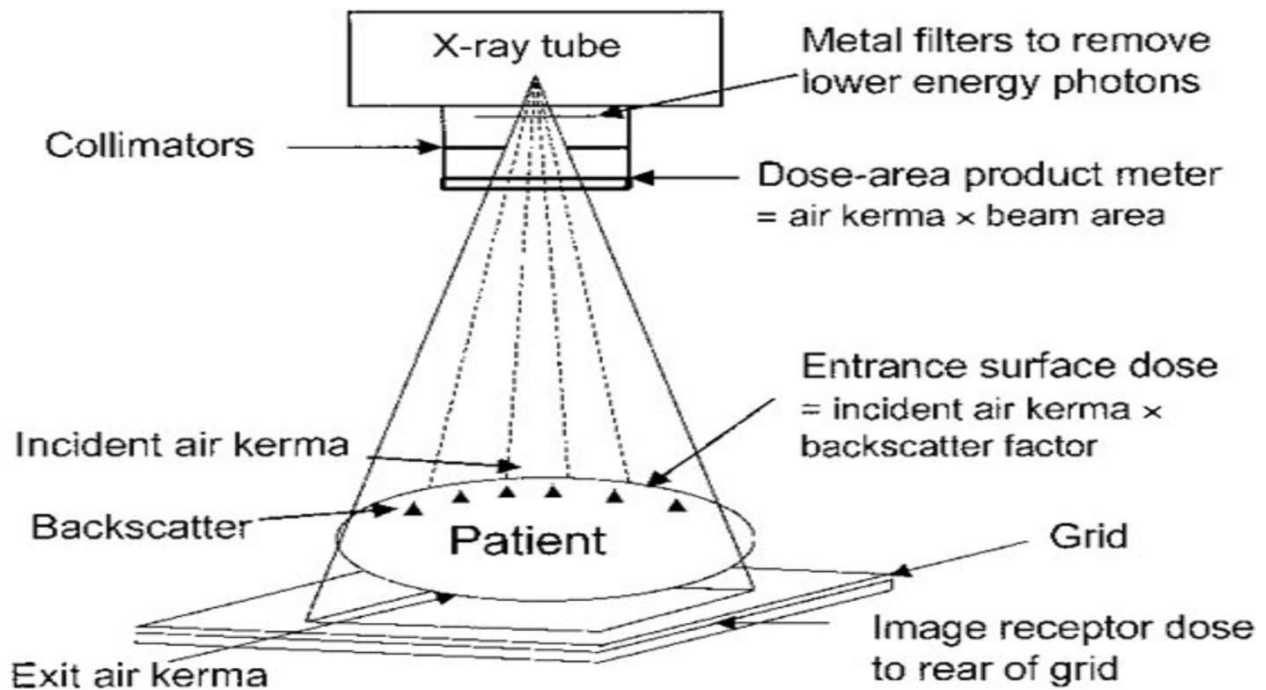


Figure 2.24 X-ray system

2.5.1 X-Ray Tube Output

The X-ray tube output is the air kerma at a specified distance from the X-ray tube focal spot, divided by the *mAs* (tube-current exposure-time product).

2.5.2 Measurement set-up

- Detector at a known distance from the x-ray tube focuses (FFD normally 50 cm).
- Away from objects which might scatter radiation
- Radiation field size at least $10 \times 10 \text{ cm}^2$.
- Measurement repeated for different kV values
- *mAs* setting depends on tube loading and conditions of normal use.
- Air kerma measurements are made with the detector positioned entirely within the X-ray beam.

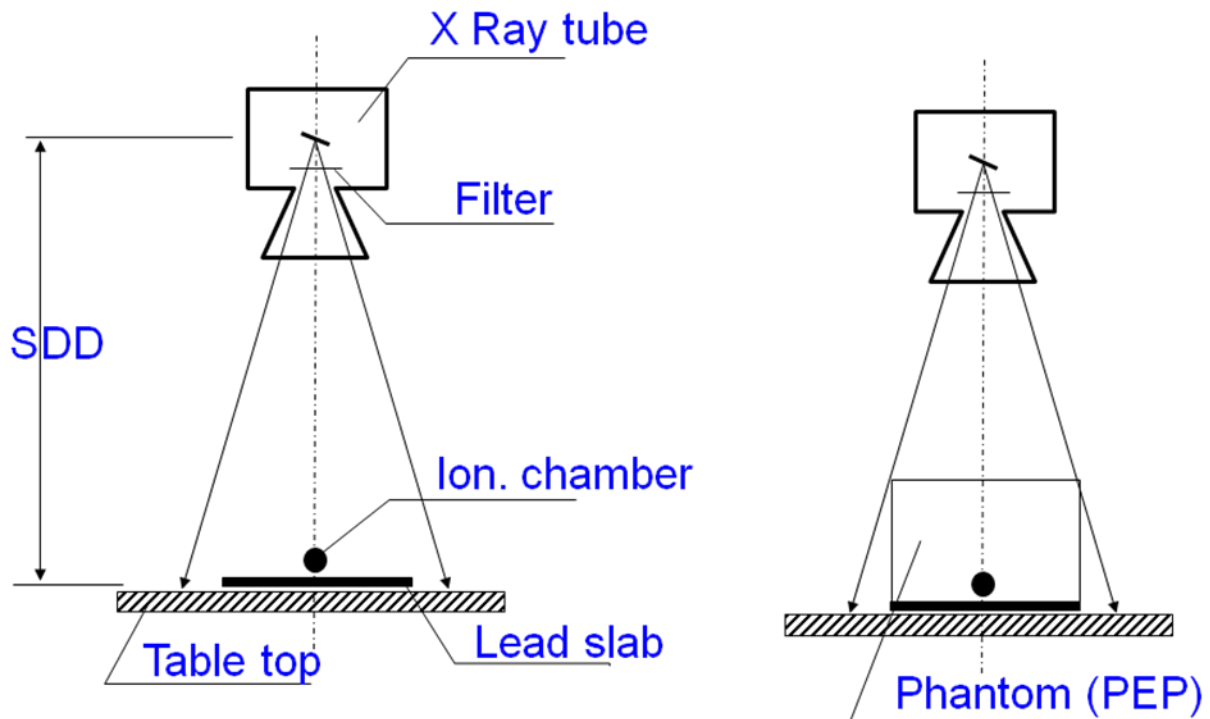


Figure 2.25 measurements with ionization chamber setup

2.5.3 Measurements with diodes

Detectors should be positioned with detector elements aligned perpendicular to x-ray tube axis; this avoids variation in air kerma along the axis due to the ‘anode heel effect’.

X-Ray Tube Output; Air Kerma K_a (FDD) = $M \cdot N_k \cdot k_Q$

M = dosimeter reading

N_k = Air kerma calibration factor

k_Q = Energy calibration adjustment

Tube output Y (kVp, FDD) = K_a / mAs

2.5.4 Dependence of Output on kVp

Tube output is proportional to kVp^2 . Air kerma at intermediate kVps may be calculated using a square adjustment:

$$K_{a\text{ exp}} = K_{a\text{ meas}} \cdot (kVp_{\text{exp}}/kVp_{\text{meas}})^2$$

$$K_{a\text{ exp}} = K_a \text{ Exposure required}$$

$$K_{a\text{ meas}} = K_a \text{ Measurement}$$

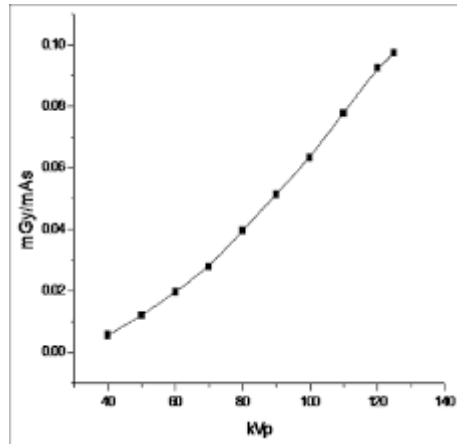


Figure 2.26 Tube output is proportional to kVp^2

2.5.5 Incident Air Kerma

Air kerma is inversely proportional to the distance from the tube focus; an inverse square law adjustment is applied to derive the air kerma incident on the patient.

$$- K_a \cdot [FDD - (tp + d)]^2 / FDD^2,$$

tp = patient thickness

d = couch to film distance

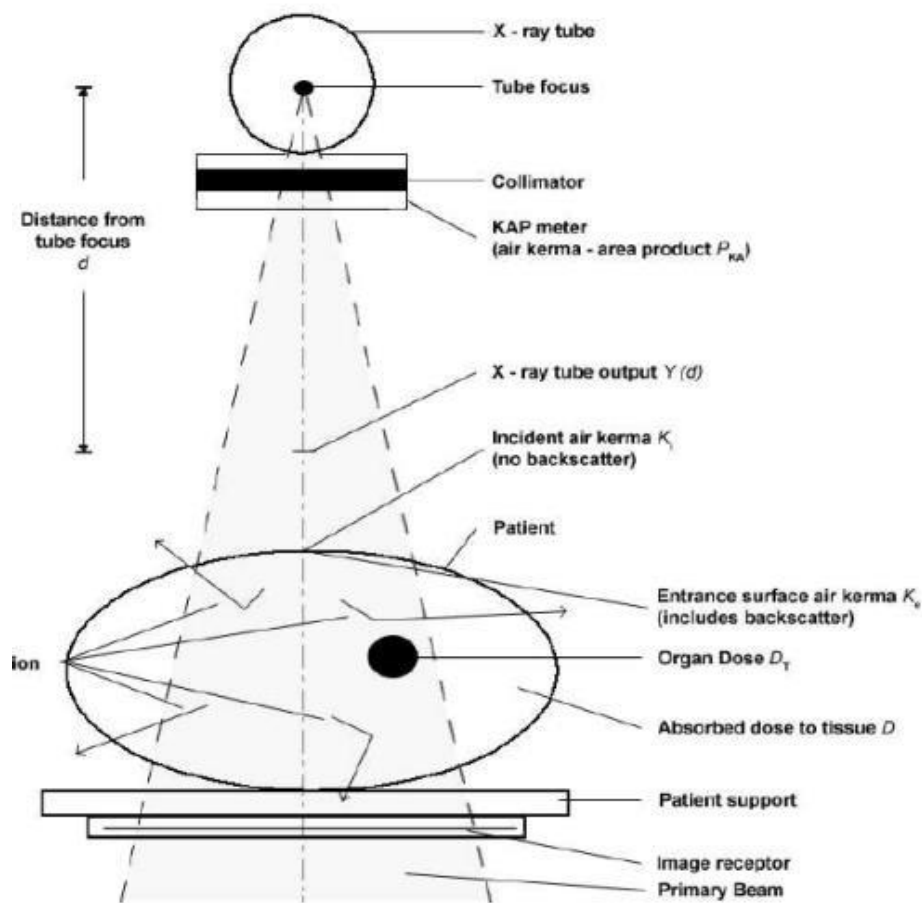


Figure 2.27: Radiation dose quantities and units

2.5.6 Entrance Surface Air Kerma

The dose to the skin surface includes backscattered radiation, Perspex (PMMA) or water phantom can be used for measurement of entrance surface dose with an ionization chamber; this provides an assessment of the dose rate received by the skin of a patient, a 20 cm thick phantom may be used as standard, but other thicknesses used in evaluating equipment performance.

$$\text{ESAK} = iAK * \text{BSF}$$

$$= Y(kVp, \text{FDD}) * \text{mAs} * \{ \text{FDD} / (\text{FFD} - (\text{tp} + d)) \}^2 * \text{BSF}$$

FDD = Focus detector distance

FFD = Focus film distance

tp = patient thickness + couch to film distance

BSF = backscatter factor (approx. 1.3 – 1.4)

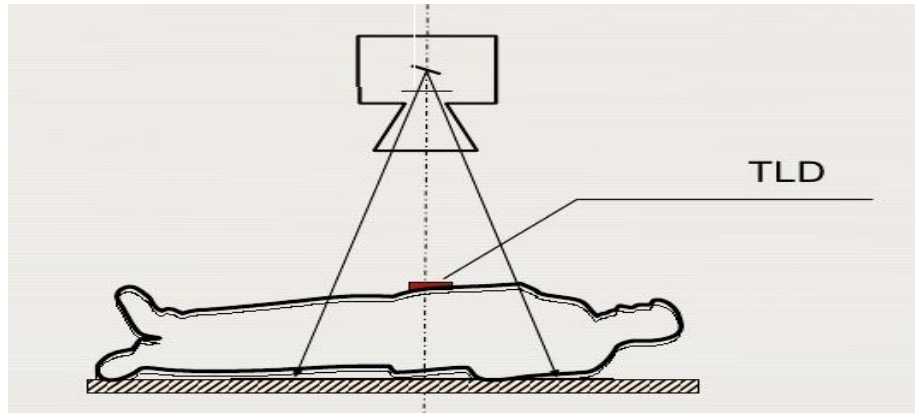


Figure 2.28: Patient dose measurement with TLD

2.5.7 Half Value Layer

Similar criteria apply to the measurement of the half value layer (HVL), the HVL is the thickness of Aluminium required to halve the air kerma. Measurement of the HVL for an X-ray beam at a particular tube potential is used to assess the amount of filtration in the X-ray beam.

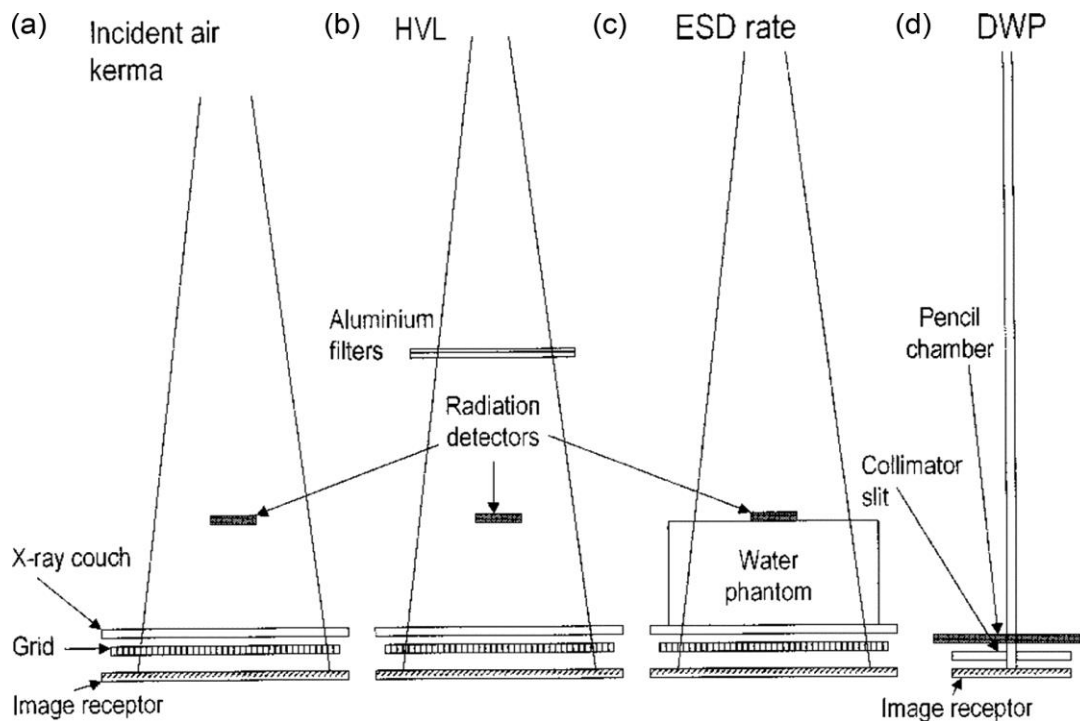


Figure 2.29: radiation dose measurement

2.5.8 Air Kerma-Area Product

The air kerma-area product (KAP) is defined as the air kerma in a plane, integrated over the area of interest, KAP is a measure of the total amount of radiation incident on a patient, and KAP can be related to effective dose since KAP can be assessed for multiple projections, field sizes.



Figure 2.30 Transmission ionization chamber

The KAP ($\text{cGy}\cdot\text{cm}^2$ or $\text{Gy}\cdot\text{cm}^2$ or $\mu\text{Gy}\cdot\text{m}^2$) is constant with distance since the cross section of the beam is a quadratic function which cancels the inverse quadratic dependence on dose; this is true neglecting absorption and scattering of radiation in air and even for X-ray housing near the couch table.

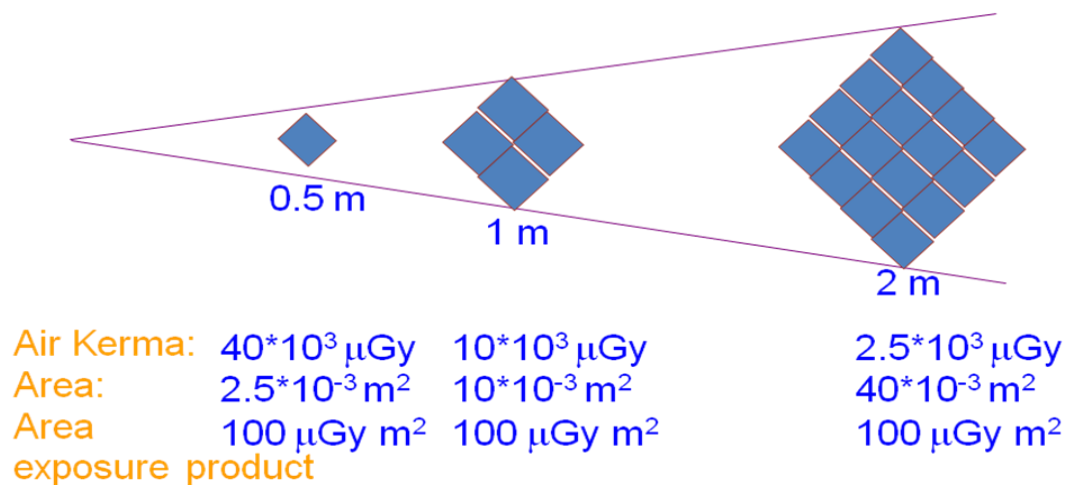


Figure 2.31: Dose area Product (DAP)

2.6 Calibration of KAP meter

It is always necessary to calibrate and to check the transmission chamber for the X-ray installation in use, in some European countries, it is compulsory that new equipment is equipped with an integrated ionization transmission chamber or with automatic calculation methods. It is convenient, in this case, also to check the read-out as some systems overestimate the real KAP value.

Measure air-kerma at a defined point using an appropriate radiation detector, measure the X-ray field size at a defined point. $KAP = \text{measured air-kerma} \cdot \text{field size}$ (assumes that the X-ray field is uniform).

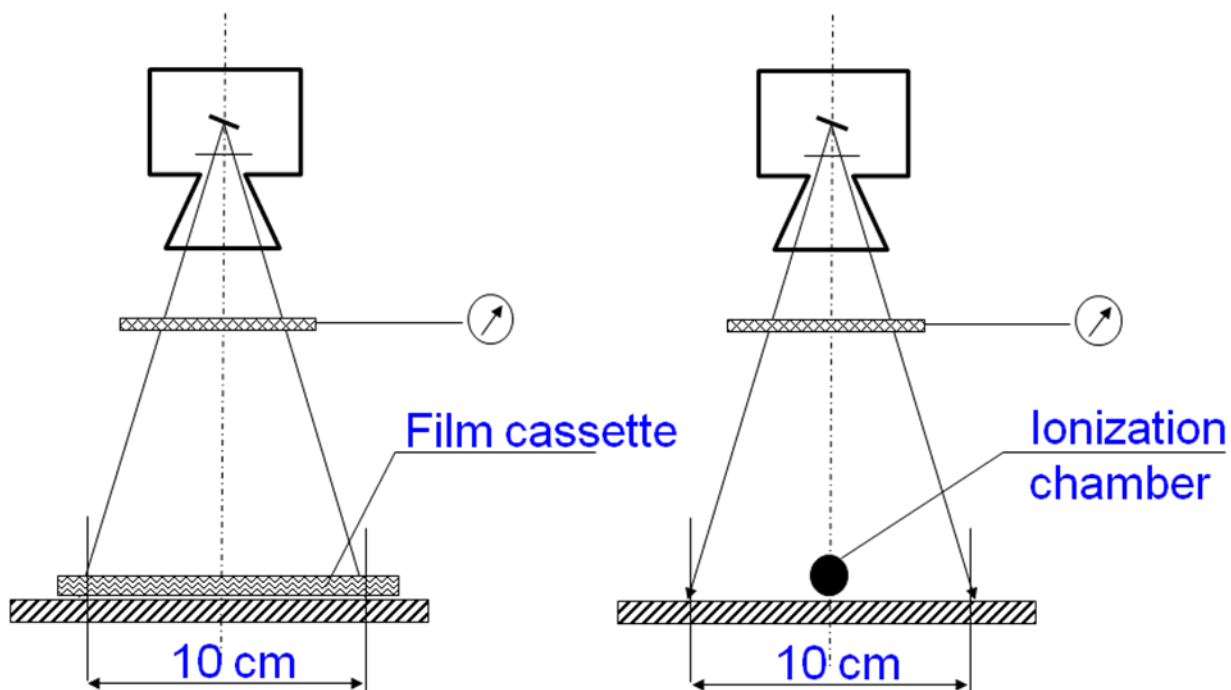


Figure 2.32 KAP meter

2.6.1 X-ray field

Field size measurements are influenced by penumbra and scatter. Film (of any kind) may be difficult to obtain, many digital systems apply electronic shutters. These limit the visibility of the edges of the X-ray field on video monitors. Problem if collimator is not properly aligned. (Bigger problem for collimator limited max FS).

2.6.2 Parameters and conditions

Air kerma area product (KAP) defined under low scatter conditions, all removable attenuators (e.g. table-top) are removed from the beam while testing. Common EU practice is measure

through the table; some systems may have a manufacturer's factor to account for the "through the table" fraction.

2.6.3 Accuracy and stability

Accuracy limits (IEC and FDA) are $\pm 35\%$, based on an IEC accuracy of $\pm 25\%$ for a physical DAP chamber. Precision of a specific system's readings is usually better than $\pm 5\%$ over many years. This assumes:

- No equipment failures.
- No changes in service procedures.

Individual systems median values vary; increased accuracy is needed (proposed $\pm 10\%$).

2.6.4 Correction Factor (CF)

$CF < 1.0$ means that the system over-reads, $CF > 1.0$ means that the system under-reads.

$$CF = \text{truth/display}$$

2.6.5 AAPM TG - 190

Accuracy and Calibration of Integrated Radiation Output Indicators in Diagnostic Radiology. Included equipment:

- Interventional Fluoroscopes
- Conventional (and Multipurpose) R/F rooms
- Mobile C-arm Fluoroscopy
- Portable (and Fixed) Radiographic Units

Collect information on "the calibration procedure" from major x-ray equipment manufacturers.

2.6.6 Working measurement proposal

Single measuring point is likely to work provided that manufacturers use this data to maintain accuracy of their systems over their entire working range, and physicists will occasionally test using other conditions. For now, DICOM and IEC standards should provide slots for multiple correction factors. Include indicators of validity (e.g. kV/filter range), Consider TG-190 as an IEC standard.

2.7 Radiation risks in Interventional radiology

2.7.1 COMMENTARY

The number, diversity and complexity of interventional radiological examinations have all increased markedly in recent years, and it is widely recognized that some of these procedures

carry greater risks than many other radiological procedures. This Commentary uses a meeting on “Radiation Protection in Interventional Radiology” held at the British Institute of Radiology on 28 March 2007 as a template to discuss recent progress in this area, some current problems and plans for the future.

It is widely recognized that some procedures in interventional radiology (IR) carry greater radiation risks than many other radiological examinations. There are increased stochastic risks to the patient from long screening procedures and a greater risk of deterministic effects, generally to the skin, especially when the radiation beam is directed at the same area on the skin surface for most, if not all, of the examination. There are also increased stochastic risks, and possibly deterministic risks, to staff who are close to the patient from scattered radiation. For all of these reasons, the European Council Directive of 30 June 1997 on “Health protection of individuals against the dangers of ionizing radiation to medical exposure, and repealing Directive 84/466 Euratom” [97/43/EURATOM 1997] identified IR as a “Special Practice” requiring special attention to be given to quality assurance programs, quality control measures and patient dose assessment.

Several publications give information and/or guidance on radiological protection in IR. However, in the past 4 years, the number, diversity and complexity of IR examinations have all increased markedly. Therefore, it is timely to review recent progress, current problems and plans for the future. This Commentary is based on a meeting held at the British Institute of Radiology on 28 March 2007 to address these issues. The multidisciplinary nature of many of them was emphasized.

2.7.2 Current trends in interventional radiology-the radiologists’ viewpoint

To put the subject into a clinical context, it is helpful to review the state of the art in IR. The first interventional procedure is generally attributed to [Dotter 1964] who used dilators to relieve arterial stenosis. Since that time, proliferation of IR procedures has proceeded apace, often driven by technical advances. By 2000, the compound annual rate of increase in IR across all service settings in the UK was, 10%.

Some recent trends in IR were identified by Hamish Ireland (Edinburgh):

- *A major reduction in angiograms* - at Edinburgh Royal Infirmary, the number of femoral arteriograms fell from 566 cases in 1999 to 42 in 2006. This demise results primarily from 3D imaging techniques, notably MR angiography, duplex ultrasound and CT angiography. Space in

angiographic rooms has been filled by interventional procedures, which are generally more complex, take longer to perform and involve more radiation.

- Multimodality guidance - e.g. the combined use of ultrasound and fluoroscopy for venous access, abscess and nephrostomy. The technique is precise, real time, and uses less ionizing radiation.
- Pre-intervention - other modalities are being used for the diagnostic aspect of the interventional procedure, e.g. CT angiography to localize gastrointestinal haemorrhage prior to embolization.
- Increasing jugular/neck/arm access.
- Increasing liver access - biliary stents and portal vein embolization.
- More IR procedures performed by non-radiologists - e.g. cardiologists and surgeons.

Ireland also indicated some drivers for change in the use of IR procedures:

- Changes in incidence of disease - the ageing population and increasing obesity are both leading to increased vascular disease and cancers, resulting in more peripheral angioplasty and stents, more biliary Ureteric stents and more radiofrequency (RF) ablation. Increasing alcohol intake and hepatitis C have increased cirrhosis of the liver, resulting in more chemo-embolization processes and transjugular intrahepatic portosystemic shunts (TIPS).
- Perceived effectiveness-new procedures and drugs are often received with great enthusiasm and their benefits overstated. This is followed by a period of realization that the efficacy is not as high as claimed. Hopefully, the “effectiveness” stabilizes at a lower level, from which it can improve steadily. Many IR procedures are in the first phase of this cycle. This raises the problem that it is very difficult to get sufficient patient numbers for rigid verification of the benefit of a new technique, and “justification” within the framework of ionizing radiation regulations may need re-appraisal.
- Fashion - this is related to the enthusiasm noted above.
- New technology - better imaging, e.g. ultrasound and CT guidance to aid targeting, and better procedure kits for endovascular aneurism repair (e.g. RF ablation) will be developed. Gradual introduction of robotic systems can be expected, especially in view of their potential for savings on staff doses if the operator can be further from the patient.

Using endovascular techniques as a specific example of IR procedures, Anthony Nicholson (Leeds) expanded on some important issues in radiation protection for the radiologist. IR plays a major role in accident/trauma and is becoming an increasing part of emergency work [Surash et

al 2003, Funaki 2006]. In some situations, the technique is far more effective than surgery for stopping massive bleeding. Significant doses of radiation are involved, including top-to-toe CT scanning beforehand, a flush aortogram to find the exact site of bleeding and CT scans to check that all is well subsequently, in addition to the radiation required for the interventional procedure itself. Is all this ionizing radiation necessary? Nicholson said that in some cases it was, and suggested that a simple working definition of optimized dose in IR was “the least amount of radiation to get the job done”. However, interventionalists must not get carried away by their enthusiasm to utilize fully this new technology now available to them. For example, it may be feasible to follow up a TIPS using ultrasound, with no further need for CT digital subtraction angiography.

For the radiologist, there is uncertainty and some confusion over the most suitable measure of doses to patients in IR. Two points need to be kept in mind. Firstly, the measure required to assess stochastic risk will normally be different from the measure best-suited to assess deterministic risk. Secondly, the pattern of exposure on the skin surface may be entirely localized to one area, e.g. in neuro work, or spread over a larger area, e.g. cardiology. For comparison of performance, cumulative dose (CD) is often preferable to dose-area-product (DAP), and Nicholson expressed concern at the wide range of CDs reported in the literature. For example, as part of a large multi-centre study, Miller et al [8] recorded CDs from 135 TIPS cases. The range was 0.1–8 Gy, with 26%, 1 Gy but 21% .3 Gy. This wide range in recorded doses has been reported many times for several different procedures. Setting aside equipment related factors, several contributing factors can be identified: patient factors (including complexity of the procedure), poor or no training of the interventionalist, experience of the interventionalist, high/low volume case load, and poor technique. However, in the final analysis, it is difficult to tease out the dominant causes of variation from this list.

2.7.3 Doses to patients

Elisio Van~ o´ (Madrid) gave an overview of doses to patients. After reviewing the relevant recommendations e.g. [ICRP 2000; 30, Malaga, Spain 2001, IPEM UK 2002], he made some important points.

Firstly, DAP, which is a measure of the total energy imparted to the patient as ionizing radiation, correlates reasonably well with the stochastic risks of induced cancer probability or hereditary effects. Variations in total energy absorbed with kVp, filtration and tissue weighting factors (w_T)

have a relatively minor effect. Conversely, for many interventional procedures, DAP is a poor measure of the risk of deterministic effects, especially for cardiology where there tends to be several non-overlapping fields. Therefore, it is important to record the CD or cumulative air KERMA (kinetic energy released per unit mass) at the interventional reference point (IRP). Note that manufacturers' data will normally be given in terms of air KERMA dose rate under specified output conditions in a scatter-free measurement at the IRP, chosen to approximate the skin surface. For a system with an isocentre, the IRP is a point on the reference axis 15 cm from the isocentre in the direction of the focal spot [BS EN 6060; 2001].

Secondly, the beneficial uses of diagnostic reference levels in plain film radiology are now well established:

- to compare the practice, in terms of level of radiological risk, with that in other centers.
- to decide if there is a margin for optimization in terms of the X-ray system settings or protocols
- to detect abnormal situations with high radiological risk for the patient.

Can the principle of reference levels (RLs) be transferred to interventional procedures and would this be an aid to optimization in IR? The starting point is to collect detailed information on a wide range of procedures from a number of different centers. Some preliminary data, using equipment supplied by only one manufacturer, are shown in Table 1 for both DAP and CD.

Information on the spread of doses can be used to propose RLs for different interventional procedures. However, the exercise is more difficult than for plain film radiography. Variations in dose will arise because of equipment factors, exposure settings and all of the factors noted by Nicholson. Bernadi et al [Bernardi et al 2000] reported a twofold difference in DAP between simple and complex procedures in percutaneous transluminal coronary angioplasty (PTCA). If RLs are adopted for IR procedures, then they may have to be graded for each type of procedure, according to simple, medium and complex.

Further information on patient skin dose monitoring was given by Rachel Morrell (Nottingham). A review of the advantages and limitations of the various methods available shows that none is ideal:

- DAP is measured with an ionization chamber that covers the whole beam area. It is easy to use and measures the total energy deposited. However, it may not indicate localized skin dose.

- Fluoroscopy time has the merit of convenience but gives no information on dose distribution and is not a good indicator of dose, as the dose from screening is usually small compared with the dose from digital image acquisition.
- A skin dose indicator gives the cumulative dose to a fixed point in the X-ray beam, so it is the highest possible value of the dose to a fixed point on the skin. Again, it is convenient to use but gives no information about dose distribution.
- Thermoluminescent dosimeters (TLDs) are accurate, linear over a wide range of doses and re-usable, but may miss the peak dose (depending on position). They are also easily damaged and time-consuming to use.
- Scintillation monitors and diodes have the advantages of real-time read-out but have poor area coverage and are likely to be visible on the image.

Table 2.2: Radiation doses in interventional radiology procedures: the data are abstracted from the RAD-IR study [Miller et al 20003]

| Procedure | Cases | Mean DAP (Gy.cm2) | DAP range (Gy.cm2) | Mean CD (Gy) | CD range (Gy) |
|--------------------------------|-------|----------------------|-----------------------|--------------|------------------|
| TIPS | 135 | 335.0 | 14–1364 | 2.00 | 0.1–7.2 |
| Biliary drainage | 123 | 70.7 | 3–386 | 0.91 | 0.02–4.8 |
| Renal stent | 103 | 190.0 | 9–724 | 1.61 | 0.1–7.2 |
| Iliac stent | 93 | 212.0 | 11–886 | 1.34 | 0.2–4.6 |
| Hepatic chemoembolization | 126 | 282.0 | 17–904 | 1.41 | 0.06–6.2 |
| Pelvic fibroid embolization | 90 | 298.0 | 4–815 | 2.46 | 0.02–7.0 |
| Vertebroplasty | 98 | 78.1 | 6–335 | 1.25 | 0.1–4.0 |

DAP, dose-area-product; CD, cumulative dose; TIPS, transjugular intrahepatic portosystemic shunt.

International Commission on Radiological Protection (ICRP) Report 85 [Ann ICRP 2000; 30] recommends that the magnitude and position of the maximum skin dose should be recorded in the patient's notes if it exceeds 1 Gy for procedures that are likely to be repeated, or 3 Gy for all

procedures. Patients receiving more than 1 Gy to the same skin area can be considered to be “at risk” from deterministic effects and should be informed about potential symptoms and appropriate action they should take if any skin changes occur.

[Morrell and Rogers 2006] have made a detailed study of the use of Kodak EDR 2 film (Eastman Kodak Company, Rochester, NY) for skin dose monitoring. Measurements were made for 20 coronary angiography and 32 PTCA procedures. The film gives good information on the pattern of irradiated fields across the patient’s back, with variations in radiation blackening. For coronary angiography, all skin doses were well below 1 Gy. However, 23% of PTCA patients received skin doses of 1 Gy (the dose at which the film saturated) or more. The authors concluded that practical compliance with ICRP recommendations requires a robust method for skin dosimetry that is more accurate than DAP and applicable over a wider range of doses than EDR2 film. Gaf chromic films (International Specialty Products, Wayne, NJ) have higher dose ranges than EDR2 film and do not require processing, but at present they are prohibitively expensive for routine dosimetric use. There are indications that the problem of comprehensive and relevant dosimetry may be amenable to solution by mathematical modeling. For example, a mathematical model developed by Morrell and Rogers [Morrell and Rogers 2006] uses exposure and projection data from the acquisition runs stored in the DICOM image files to estimate skin doses.

Early work showed that maximum skin doses calculated by this model correlated well with those measured on EDR2 film. Three methods for including the relatively smaller dose contribution from fluoroscopy were investigated and all successfully identified patients receiving skin doses in excess of 1 Gy. Two advantages over film dosimetry are that doses above the saturation point of film can be assessed and there is less staff involvement. Furthermore, in theory, the method can be combined both with data on doses to organs and wT values to give an estimate of effective dose to patients, and with data on room scattering to provide information on staff doses. Some of the technology that would be required for a comprehensive dosimetric system is not yet available, but this might be a fruitful area for discussion with manufacturers.

2.7.4 Staff doses

Van o’ emphasized that “appropriate” staff dosimetry is essential, but what is “appropriate”? There are several possibilities:

- one personal dosimeters (usually under the apron).

- two personal dosimeters (one under, one over the apron).
- additional dosimeters for the extremities.
- electronic dosimetry.
- research occupational dosimetry (with several TLDs).

There are also practical problems with occupational dosimetry:

- staff forget to wear their dosimeters.
- there are mistakes in the use of dosimeters above and below the apron - perhaps they are interchanged?
- dosimeters are worn that were assigned to other Interventionalists.
- there may be uncertainty over whether protective devices have been in place or worn, e.g. lead curtains, thyroid shields, protective goggles.

Nicholson commented that, in the UK, the Regulations did not make it easy for staff to monitor themselves and cited the problem of “Radiation Passports” for interventionalists who work at more than one location. There is general agreement that the interventionalist will be giving 100% of their attention to the patient with little thought for the radiation dose to themselves. However, this should not prevent the wearing of dosimeters as directed.

Mark Whitby (Glasgow) gave further information on staff dose and monitoring requirements. Many factors will influence the amount of scattered radiation reaching staff, including the size of the patient, the equipment and its set-up, the type of procedure (especially its complexity and length), tube geometry, position of staff (especially their hands) relative to the patient, the skill and experience of the operator and the effective use of radiation protection principles and devices.

Given the uncertainties, it is not surprising that Whitby’s data showing indicative doses for IR/cardiology covered wide ranges (Table 2.3). It is clear that, at the upper ends of these ranges, staff will need to be “Classified Radiation Workers” and some form of monitoring is essential. The challenge is to ensure that it is both relevant and proportionate to the risk. For whole body monitoring, there is still uncertainty as to whether two monitors (one below the apron at, for example, chest level and one above the apron at collar/eye level) are necessary. Whitby suggested that one monitor should suffice for a low work load, with two monitors for a higher work load. The boundary between low and high workloads should be set in the region of 1-5 mSv per annum for body doses. The second monitor will also be necessary if eye doses are high,

i.e. with a boundary in the range 10–50 mSv per annum. Unfortunately, it is difficult to specify the boundary in terms of readily available machine output data such as DAP, because the precise position of the operator is also a factor. Therefore, a conservative approach to monitoring must be taken initially. This can often be relaxed when real monitoring data become available.

Doses to the hands are highly dependent on their position relative to the beam and the different hand movements in different procedures. For example, this may be a prodding action (advancing/withdrawing the catheter) used in the percutaneous approach, or a combination of prodding and twisting actions used in, for example, the femoral or internal jugular vein approaches. For a mixed work load, a ring dosimeter worn on the ring or fifth finger is a good compromise. For the percutaneous approach, a finger stalls at the top of the middle finger might be preferable, with a ring dosimeter worn on the ring or little finger still providing a good estimate of maximum dose.

Because of the uncertainties involved, the hands should always be monitored when a procedure in which the hands have to be close to the main beam is used for the first time. Subsequently, monitoring might be relaxed to “periodic” if the estimated annual hand dose is less than 50 mSv per annum, or stopped altogether if below 10 mSv per annum. For further information on recommended extremity monitoring at different dose levels, see Martin and Whitby [Martin and Whitby 2003].

Proper use of protective measures can have a big impact on staff doses and is essential e.g. [Vanó E et al 2006]. In the example cited, nine staff radiologists and eight interventional cardiology fellows working in a centre performing 5000 procedures a year were monitored using personal dosimeters - below and outside lead aprons - over a period of 15 years. At the start of the study, maximum doses of 100–300 mSv per month above the apron and 5–11 mSv per month (mean 10.2 mSv per year) below the apron were recorded. In the past 5 years, after a program of optimization, mean occupational doses under the lead apron have fallen to 1.2 mSv per year (14% of those in 1989 to 1992), whereas doses recorded outside the lead apron have fallen by a factor of 14. The most effective actions for reducing the radiation risk were (I) training in radiation protection, (II) a program of patient dose reduction, and (III) the systematic use of radiation protection facilities, specifically ceiling-suspended protective screens.

Table 2.3: Indicative staff dose summary for radiology/cardiology [DENDY 2008]

| | Whole body | Eye | Extremities | |
|---------------------|------------|----------|-------------|--------|
| | | | Hands | Feet |
| Per-procedure (mSv) | 1–50 | 1–500 | 5–3500 | 5–3000 |
| Monthly (mSv) | 0.05–1.0 | 0.05–6.0 | 0.5–15 | 0.5–15 |
| Annually (mSv) | 0.5–4 | 0.5–20 | 5–200 | 5–200 |
| Annual limit (mSv) | 20 | 150 | 500 | 500 |

This table was shown at the British Institute of Radiology meeting on 28 March 2007 and is reproduced here with the permission of the author.

2.7.5 Equipment factors and program set-up

Taking the title “Designing radiation protection into the system”, Nick Marshall (London) gave an excellent review of the importance of well-designed equipment in dose reduction. Features of the equipment that are known to affect dose include:

- *Spectral filtration* - 0.1 mm Cu can reduce skin dose rate by 40% (but has less impact on effective dose), increases tube loading and reduces contrast. A range of filters should be available for different program, and the spectral filtration should be displayed to help with trouble-shooting and optimization.

- *Pulsed fluoroscopy* - is virtually essential for interventional work. In modern systems, the high tension is kept constant and a third grid controls the flow of electrons to the anode. Optimization of fluoroscopy pulse widths and careful choice of entrance exposure/ pulse during calibration of equipment is important. Hernanz-Schulman [Schulman 2006] reported that, in paediatrics, grid-controlled pulsed fluoroscopy at 3.75 pulses s⁻¹ can reduce dose by ten-fold without significant reduction of contrast or spatial resolution.

Organ curves - the X-ray set can respond to demand for increased output by increasing kV, mA or a combination of both. A range of options will be available so it is important to know the impact of each on contrast and dose.

- *Image receptor*-there is increasing emphasis on solid state detectors (flat panel detectors (FPDs)), using either direct conversion with amorphous selenium or indirect conversion using cesium iodide, in preference to image intensifiers. The FPDs have a better dynamic range because there is no television camera. Also, the manufacturers claim a better detective quantum efficiency, which could be used either for dose reduction or to give better signal-to-noise ratio. However, Marshall displayed data showing little difference in input dose rate at the image receptor under automatic exposure control for image intensifier and FPD systems. He suggested that the failure to demonstrate any advantage might be due to electronic noise in the FPDs.

Marshall also made some important general remarks on radiation protection implications of the interface between radiology staff and manufacturers:

- Before entering the market, the radiology department should specify, as fully as possible, the scope of interventional procedures the equipment will be performing. A system can only be “well-designed, reliable, flexible, everyone likes using it” if it is fit for the clinical purpose for which it is intended. Manufacturers often have very little data on dose but the “Safe Specs” system provided by KCARE (King’s Centre for the Assessment of Radiological Equipment) contains a useful questionnaire to aid evaluation. “Homework” at this stage is likely to have a pay-back in terms of exposure times and dose rates.

- The architecture of the program set-up system must be fully understood. For example, is it a free-standing system in which the fluoroscopy mode is completely separate from the examination type or does the choice of examination pre-define the acquisition and fluoroscopy parameters? In either case, a wide range of operational modes and examination pre-sets (input dose rates, pulsed fluoroscopy setting, spectral filtration) must be correctly set up to ensure adequate image quality and doses as low as possible for all examinations.

- For pre-defined studies, proper liaison must be maintained between the radiology department, the applications specialist employed by the manufacturer and the medical physicists involved in commissioning. The commissioning physics tests are often based on factory default settings and are performed before the applications specialist adjusts the software for specific clinical applications. Further commissioning should be done, for example, 6 months later to establish actual clinical baselines.

Careful attention to detail in setting parameters and clinical observations can aid in optimization and indicate further areas of study. These principles were well illustrated in two case studies in interventional neuroradiology presented by Halina Szutowicz (Cambridge).

A Siemens Axiom Artis BA was installed in Cambridge in May 2004, and each of the factory settings was challenged with alternative options. For example, 15 pulses s^{-1} was reduced to 7 pulses s^{-1} but gave jerky movements and was rejected. Dose rates per pulse were reduced from 23 mGy, 32 mGy and 45 mGy per pulse to 15 mGy, 18 mGy and 23 mGy per pulse, respectively. Arrangements were made to put the dose record file with the stored images, and a total dose record was placed in the patient's radiology record.

The first case was a long procedure, lasting a total of 9 h, to embolize a single large occipital arterio/venous malformation. 2.5 weeks later, the patient reported sudden loss of hair from the back of the head, but no apparent erythema at this stage. Subsequently, marked erythema and almost complete epilation developed.

A number of actions were taken:

- The entrance field from the postero-anterior (PA) plane was accurately matched.
- Dose readings were retrieved - the PA entrance skin dose (ESD) was 8.1 Gy.
- The radiation protection advisor and radiotherapy colleagues were contacted.
- ESD was checked against published threshold doses for deterministic effects.
- Embolization programs were re-programmed to lower dose rates.
- Radiation protection survey reports were checked
- DAP meters were recalibrated to a tighter tolerance band (5%)
- Post-procedure patient visits were introduced when the estimated skin dose exceeded 2 Gy.

3 months later, the patient's hair had regrown. This is consistent with temporary epilation. Perhaps there was early erythema that went unnoticed?

Fewer details were given on the second case, except that it was a spinal embolization. The lateral plane ESD was off scale (maximum 999 mGy) and had to be estimated from the DAP reading at 11.3 Gy. At 10 months, telangiectasia was visible, with perfect collimation to the irradiated site, but the patient had not noticed any of the early effects he had been told to expect.

The work raises some interesting questions for future study:

- How accurate are deterministic time scales? Much of the available data comes from radiotherapy with fractionated exposures.

- In both cases, why were minor effects not more apparent earlier?
- Can anything be done in advance to minimize deterministic effects in such patients, e.g. vitamin C as an antioxidant?

2.7.6 Education and training

Several other matters that deserve mention will be grouped together under this heading. As Claire Cousins (Cambridge) pointed out, very few radiologists or interventionalists will see a radiation injury during their working lifetime and will never know if their use of radiation has caused cancer. However, the fact that “these things happen to someone else” is not an acceptable reason for ignoring radiation doses.

Long-term follow-up of atomic bomb survivors has shown that an excess risk of cancer is associated with a few tens of mSv [Preston et al 2003]. At the much lower doses associated with many diagnostic procedures, e.g. those comparable with annual background radiation, extrapolation is more uncertain, not least because homeostatic mechanisms may reduce the radiation effect [Dendy P and Brugmans 2003]. However, at the level of effective dose (E) typical of IR, the analysis of Brenner and Elliston [Brenner and Elliston 2004] is pertinent. They assumed an E value of 12 mSv for a single full whole-body CT examination (lung organ dose, 15 mGy) and estimated a cancer risk of 861024 for a 45-year-old, which falls slightly with age. Adequate information must be given to all relevant staff on such levels of radiation risk, which are typical of many IR procedures, but it is important to emphasize that there are very large sources of error in using the effective dose concept for risk estimation [Martin 2007]. The 95% confidence interval on the Brenner and Elliston risk estimation [Brenner and Elliston 2004] was about a factor of three each way, and so numerical estimates of excess risk of fatal cancer derived from E should not be included in patient reports.

A further important aspect of training is to put the radiation risk into perspective with other everyday risks. For example, the risk of death in a car accident in the US in 1999 was about a quarter that of the hypothetical CT scan discussed above, but clearly a series of whole-body CT scans, or comparable IR studies, will accrue a significant risk.

If risk estimation in IR is difficult, then estimating the benefit is infinitely more difficult. Clearly, there are often massive benefits for the patient but we have not even begun to quantify the level at which benefits and radiation risk might be of a similar magnitude. In the absence of a sound methodology, it is difficult to know what to teach. Because, in general, the radiation is being

used as an aide to therapy in IR, there is perhaps something to learn from the approach adopted in radiotherapy.

Van't Hof discussed the work that has been done in Europe on the theoretical training required [DENDY 2008]. A syllabus has been prepared and a recommended teaching time allocated to each subject for different staff groups, e.g. diagnostic radiology specialists, IR specialists, other medical doctors using X-ray systems, radiographers and maintenance engineers. Total teaching varies from 10 h to 60 h. The International Atomic Energy Agency (IAEA) has produced specific training material for cardiologists and held regional courses in several continents. An ICRP Working Party is currently preparing definitive recommendations with a tentative title “Radiation protection training for physicians that conduct or order diagnostic and interventional procedures using ionizing radiation”.

On the practical side, Nicholson expressed concern that too many doctors are becoming involved in IR without proper structured training. Ensuring low doses to patients and staff should be an integral part of good technique, and it is a little surprising that there was no mention of radiation dose or radiation risk in a 2002 publication on IR education in *Seminars in Interventional Radiology*. [Kaufman and Rösch 2002] The article on “Virtual Reality Training in Interventional Radiology” in that issue would have been a good opportunity to discuss how the technical variables that affect patient and staff doses might be factored into such training.

Another problem is accreditation. It may be feasible for training centers to be accredited by National Professional Bodies but how will the “students” be assessed and how does one decide the level at which they can be considered competent? Multiple choice questions seem entirely inadequate.

There is also much to learn for the radiographer in the IR room. Kevin Walker (Stirling) suggested that because of their background and previous training, the radiographer is best suited to be the Radiation Protection Supervisor (RPS). This could be a good arrangement provided that the radiographer is experienced and has a “hands-on” role in the interventional room on a regular basis. He or she must not only be responsible for their own training, i.e. the equipment, quality assurance, optimization of procedures and importance of interdisciplinary work, but must also supervise the training of others. New staff needs to know about stochastic and deterministic effects, scattered radiation, protective devices, how to wear their dosimeters and dose limits. The RPS must also ensure that other staffs, who are preoccupied with the procedure and the patient,

do not inadvertently and unnecessarily increase their own doses, and must be generally proactive in radiation protection matters. With the future developments in “skill mix”, other individuals may be better equipped to be the RPS in certain situations.

2.7.7 Conclusions and future work

To sum up briefly:

- Demographic changes and changes in patterns of disease will ensure that the number of IR procedures, and sometimes their complexity, will continue to increase. Occasionally, this will result in higher doses to individual patients. It will certainly increase the radiation burden to the population as a whole.
- Better imaging equipment, procedure kits and dose saving devices will be introduced by the manufacturers, perhaps with an emphasis on robotics.
- Work on patient doses will continue, not least because this is a legal requirement. Manufacturers should ensure that digital technology is exploited for management of the data.
- ICRP will be widening the use of reference levels and the British Institute of Radiology will be setting up a Working Party to look at skin doses. DAP and CD are useful quantities when comparing doses for similar procedures.
- Careful follow-up of patients undergoing lengthy procedures may provide important new information on deterministic effects.
- Greater efforts should be made to relieve the operator of the responsibility for their own monitoring. Perhaps, as a starting point, the mathematical modeling described by Morrell and Rogers could be used to produce maps of scattered radiation.
- The concept of effective dose should be used with caution for estimating radiation risk because of the large errors and uncertainties involved.
- Training and education will continue to receive the highest priority. ICRP will finalize its recommendations for training doctors and the IAEA will continue to promote programs in staff training, but some key issues need to be addressed: (i) how does one quantify the clinical outcome, i.e. the “benefit” in IR, and (ii) how should the practical competence of new operators be verified?

2.7.8 Dose Area Product (DAP)

Dose area product (DAP) is a quantity used in assessing the radiation risk from diagnostic X-ray examinations and interventional procedures. It is defined as the absorbed dose multiplied by the area irradiated, expressed in gray-centimetres squared ($\text{Gy}\cdot\text{cm}^2$ [Kim et al 2008] - sometimes the prefixed units $\text{mGy}\cdot\text{cm}^2$ or $\text{cGy}\cdot\text{cm}^2$ are also used). Manufacturers of DAP meters usually calibrate them in terms of absorbed dose to air. DAP reflects not only the dose within the radiation field but also the area of tissue irradiated. Therefore, it may be a better indicator of the overall risk of inducing cancer than the dose within the field. It also has the advantages of being easily measured, with the permanent installation of a DAP meter on the X-ray set. Due to the divergence of a beam emitted from a "point source", the area irradiated (A) increases with the square of distance from the source ($A \propto d^2$), while radiation intensity (I) decreases according to the inverse square of distance ($I \propto 1/d^2$). Consequently, the product of intensity and area, and therefore DAP, is independent of distance from the source.

2.7.8.1 How is DAP measured

An ionization chamber is placed beyond the X-ray collimators and must intercept the entire X-ray field for an accurate reading. Different parameters of the X-ray set, such as peak voltage (kVp), tube current (mA), exposure time, or the area of the field, can also be changed. For example, a $5\text{ cm} \times 5\text{ cm}$ X-ray field with an entrance dose of 1 mGy will yield a $25\text{ mGy}\cdot\text{cm}^2$ DAP value. When the field is increased to $10\text{ cm} \times 10\text{ cm}$ with the same entrance dose, the DAP increases to $100\text{ mGy}\cdot\text{cm}^2$, which is four times the previous value. [CRCPD/10-01_QA_DAP]

Kerma area product (KAP) [Kim et al 2008] is a related quantity which for all practical radiation protection purposes is equal to dose area product. However, strictly speaking where g is the fraction of energy of liberated charged particles that is lost in radiative processes in the material, [Seltzer and Stephen 1998] and the dose is expressed in absorbed dose to air. The value of g for diagnostic X-rays is only a fraction of a percent.

Adult coronary angiography and PCI procedures expose patients to an average DAP in the range of 20 to $106\text{ Gy}\cdot\text{cm}^2$ and 44 to $143\text{ Gy}\cdot\text{cm}^2$ respectively. [Raza 2006]

2.7.8.2 The Cardiovascular System: Anatomy, Physiology, Pathology

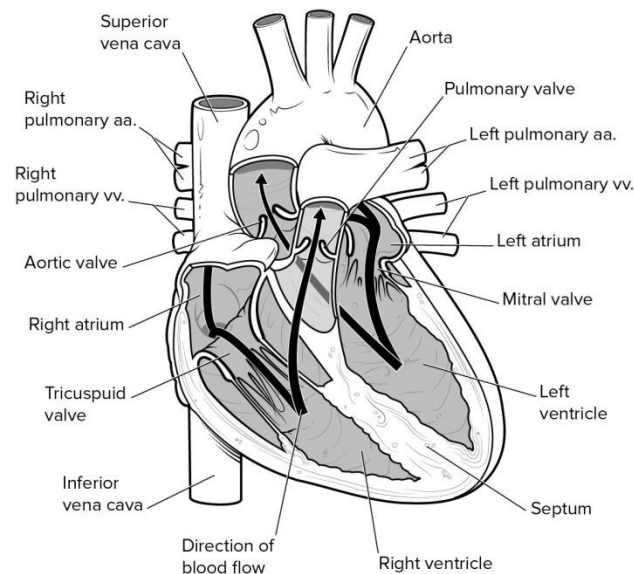
2.7.8.2.1 Anatomy and Physiology

The heart consists of two pumps working synchronously side by side and sharing an inner wall in common. Although these two pumps are intimately allied in structure and function, each handles a different component of the total blood volume, and (except in the presence of structural abnormality) mixing of the two circulations does not occur. Each pump consists of two chambers: a relatively thin walled collecting chamber, or atrium, and the pump proper, or ventricle. Each contraction of a ventricle propels blood through a single large vessel, which branches into increasingly smaller vessels and eventually into vessels of microscopic caliber called capillaries. Each ventricle is equipped with two valves. One of these prevents backflow of blood into the atrium when the ventricle contracts and the other prevent backflow of expelled blood into the ventricle while it is relaxed and refilling for the next contraction.

Contraction of a chamber is called systole, and relaxation is called diastole. Systole occurs when a wave of electrical activity, beginning at the pacemaker (sinoatrial node) in the right atrium, spreads over the heart muscle, stimulating first the atria and then the ventricles to contract. During the fraction of a second that elapses before the next impulse from the pacemaker, the heart muscle relaxes in diastole and refilling of the chambers occurs. [John 2011]

Venous blood, low in oxygen and high in carbon dioxide, is collected by the superior and inferior venae cavae and delivered to the right atrium and hence to the right ventricle. Right ventricular systole sends this blood through the pulmonary artery to the lungs, in whose capillaries the blood picks up fresh oxygen from inspired air and discharges excess carbon dioxide into air that is about to be expired. During systole the tricuspid valve prevents blood from leaking back into the right atrium, and during the succeeding diastole the pulmonic valve keeps blood from leaking back into the right ventricle. Oxygenated and purified blood is returned to the heart by the pulmonary veins, which deliver it to the left atrium. Passing from the left atrium to the left ventricle, the blood is now pumped through the aorta into the arteries of the systemic circulation. During left ventricular systole, the mitral valve prevents blood from being driven back into the left atrium; during diastole, the aortic valve prevents blood from leaking back into the ventricle. The arteries branch into increasingly smaller vessels and eventually break up into capillaries in

the tissues, where oxygen is released and carbon dioxide and other wastes are taken up. The blood then passes through peripheral veins back to the venae cavae and the circuit is complete.



2.7.8.2.2 Pathology of the heart:

1. **Hypertension:** is defined arbitrarily as systolic blood pressure above 140 mmHg or diastolic blood pressure above 90 mmHg. The annual toll of deaths due directly to hypertension in the United States is about 35,000, and it is recognized as a contributing factor in another 180,000 deaths.

2. **Atherosclerosis:** the arteries of older persons often lose their elasticity and become narrowed in caliber, are often associated with ischemia of the tissues supplied, and are thus the underlying mechanism of many serious health problems, including myocardial ischemia (causing angina, cardiac failure, and myocardial infarction), cerebrovascular disease (causing stroke and dementia), and peripheral vascular disease (causing intermittent claudication and gangrene of extremities).

3. **Myocardial infarction (MI):** also known as coronary thrombosis and heart attack, is defined as death (irreversible damage) of a segment of heart muscle (myocardium) caused by obstruction to blood flow in one or more branches of the coronary system. Myocardial infarction is currently recognized as the most common cause of death in this country. About 800,000 persons annually sustain first heart attacks; with a mortality rate of 30%, and 450,000 persons sustain recurrent heart attacks, with a mortality rate of 50%. The usual cause of MI is formation of a thrombus in a

coronary artery at the site of an atherosclerotic plaque. Less frequent causes are anatomic anomalies or inflammatory disease (vasculitis) involving the coronary arteries and arterial spasm induced by drugs, particularly cocaine.

The classical symptoms of myocardial infarction are crushing anterior chest pain radiating into the neck, shoulder, or arm, lasting more than 30 minutes, and not relieved by nitroglycerin.

4. Congestive Heart Failure: Congestive heart failure is an extremely common complication of a broad range of disorders, not all of them primarily affecting the heart. Even with aggressive treatment, the five year survival rate for persons with congestive heart failure is only 50%. Death most commonly results from progressive ventricular dysfunction, arrhythmia, or thrombo-embolism. [John 2011]

2.8 Literature Review:

Optimization of the radiation dose in the interventional radiology mainly in cardiac catheterization is a research area where different results were determined and ideas were recommended to achieve the ALARA principle has been studied by several researchers; for example; **Nada and Nayel** 2016 (Sudan). They aimed to assess radiation doses and the associated hazards to pediatric during cardiac catheterization procedures (112pts). The median KAP in Gy.cm², CK in mGy, number of frames and FT were (4.6, 29.0, 340.4, 13.5) and (6.0, 35.0, 318, 9.8) for the diagnostic and therapeutic cardiac procedures, respectively. The median (KAP in Gy.cm², effective dose in mSv) for different age, 1≤5 years, 5≤10 years and 10-15 years old were (2.2, 4.4), (2.5, 5.0), (4.2, 5.1) and (8.5, 4.1) respectively. Including all the procedures using the multiplicative model of ICRP 60, the mean attributable lifetime risk for stochastic effect was 0.08 and 0.05% for girls and boys, respectively. Training is needed to raise staff awareness about radiation protection. **Heilmaier** et al 2016 they aimed to determine the effect on patient radiation exposure of the combined use of a patient dose monitoring system and real-time occupational dose monitoring during FGIs. Patient radiation exposure, in terms of KAP - Gy.cm², was measured in period 1 with a patient dose monitoring system, and a real-time occupational dose monitoring system was additionally applied in period 2. Mean/median KAP in 19 different types of FGIs was analyzed in both periods for two experienced interventional radiologists combined as well as individually. Patient dose and occupational dose were correlated, applying Pearson and Spearman correlation coefficients. Although FGIs were similar

in numbers and types over both periods, a substantial decrease was found for period 2 in total mean \pm SD/median KAP for both operators together (period1, $47 \text{ Gy}\cdot\text{cm}^2 \pm 67/41 \text{ Gy}\cdot\text{cm}^2$; period2, $37 \text{ Gy}\cdot\text{cm}^2 \pm 69/34 \text{ Gy}\cdot\text{cm}^2$) as well as for each individual operator (for all, $P < .05$). Overall, KAP declined considerably in 15 of 19 types of FGIs in period 2. Mean accumulated dose per intervention was $4.6 \text{ }\mu\text{Sv}$, and mean dose rate was 0.24 mSv/h . There was a strong positive correlation between patient and occupational dose ($r = 0.88$). They concluded that the combined use of a patient dose monitoring system and real-time occupational dose monitoring significantly lessens patient and operator doses in different types of FGIs. **Leyton et al 2016** Aimed to report scattered radiation doses at the height of the operator's eye in an interventional cardiology facility without considering radiation protection devices and to correlate these values with different angiographic projections and operational modes. The ICRP recommends a new threshold for opacities and a new radiation dose to eye lens limit of 20 mSv/year for occupational exposure. Scatter dose rate increases linearly with patient ESAK rate, at AP projection for FL, FN and cine modes were 13 ± 1 ; 39 ± 3 and $282\pm26 \text{ mGy min}^{-1}$, respectively. Scatter radiation dose at the eye lens depends on C-arm angulations. The factors of increase for scatter doses at the height of the operator's eye was approximately between 10 to 12 times greater for an X-ray tube running from AP to LAO, spider or LAO45CRA30 projections. The factor of increase for the other projections was approximately 1. Large ranges of scatter radiation dose rate at the height of the operator's eye were found, from 0.37 ± 0.04 to $60.19 \pm 6.02 \text{ mSv h}^{-1}$. There is a strong linear correlation between scattered radiation doses at the height of the operator's eye and patient KAP. Experimental correlation factor of $8.3 \text{ }\mu\text{Sv}$ at the eyes of the cardiologist for 1 Gy cm^2 with a $R^2=0.8272$ and an equation scatter radiation dose (μSv) = $5.159\cdot\text{KAP (Gy}\cdot\text{cm}^2) + 3.144$ were found. Experimental correlation factors of 2.3; 12.0; 12.2 and $17.6 \text{ }\mu\text{Sv/Gy cm}^2$ were found for the AP, LAO45CRA30, spider and LAT projections, respectively. A conservative estimate of the scatter dose values at the height of cardiologist's eyes was calculated; varied from 0.106 to 1.452 mSv per procedure when protection tools have not been used. Therefore, cardiologists may exceed the threshold for lens opacities if protective tools are not used. **Harbron et al 2016**. A review was conducted of these studies, gathering data on KAP, FT, air kerma, and estimates of effective dose and organ doses. The majority of studies focus on KAP and FT with no estimation of dose to the patient. A greater than ten-fold variation in average KAP was found between different studies, even where data were stratified by patient age or

weight. Typical values of KAP were 0.6-10 Gy.cm² (16 years). KAP was lowest for heart biopsy (0.3–10 Gy.cm² for all ages combined) and atrial septostomy (0.4-4.0 Gy.cm²), and highest for pulmonary artery angioplasty (1.5-35 Gy.cm²) and right ventricular outflow tract dilatation (139 Gy.cm²). Most estimates of patient dose were in the form of effective dose (typically 3-15 mSv) which is of limited usefulness in individualized risk assessment. Despite advances in radiation protection, recent publications have reported surprisingly large doses, as represented by KAP and air kerma. There is little indication of a fall in these dose indicators over the last 15 years. Nor is there much suggestion of a fall in doses associated with the use of flat panel detectors, as opposed to image intensifiers. An assessment of the impact of radiation dose in the context of overall patient outcome is required. **Lefterova** 2016 aimed to estimate paediatric dose in IC (54pts; 42 CA, 12 CA+PCI) and radiology practice in (Bulgaria); sex, age, weight, and height, frame rate, total (FT), number of acquired series/images, DAP, BMI and kerma at IRP were used, they made correlation between the DAP and weight values ($r_2 = 0.627$). Large variation of the dose parameters were found within the groups. The average DAP values for CA procedures were 137.6 (range 54.9–285.04) cGy.cm² for age group (0–12 months), 269.8 (48.4–830.2) cGy.cm² for (1–4 years), 275.8 (54.5–751.0) cGy.cm² for (5–9 years) and 878.7 (313.6–1766.4) cGy.cm² for (10–15 years). Data for CA + PCI procedures was analyzed for groups (1–4 years) and (10–15 years). The average DAP values were 457.8 (177.2 –1037.2) cGy.cm² and 948.2 (703.9–1318.4) cGy.cm² respectively. The average FT for CA was: (0–12 m)–12.0 (6.7–26.6) min; (1–4 y)–15.7 (1.7–40.6) min; (5–9 y)–10.1 (0.9–30.3) min; (10–15 y)–11.6 (2.9–31.0) min. The average kerma at IRP values for CA were: 16.0 (7.6–41.52) mGy for (0–12 m); 18.5 (4.2–54.2) mGy for (1–4 y); 17.2 (2.6–45.7) mGy for (5–9 y) and 51.0 (15.1–126.3) mGy for (10–15 y). The average FT for CA + PCI was: 25.8 (4.8–65.7) min for (1–4 y) and 17.5 (7.6–27.1) min for (10–15 y). The average kerma at interventional reference point (IRP) values for CA + PCI were: 37.1 (15.1–77.7) mGy for (1–4 y) and 50.2 (39.2–77.1) mGy for (10–15 y). Concluded that the dose values are lower than the typical doses for adult patients but higher than reported from other studies which show the potential for optimization of the radiology practice. **Varghese** et al 2016. This study intends to evaluate radiation doses and estimated risk from angiographic projections during CA procedure performed using novel flat detector (FD) system with improved image processing and noise reduction techniques. Real-time monitoring of radiation doses using KAP was performed for 140 patients. Mean FT, KAP, and reference air kerma ($K_{a,r}$), for CA

procedure were 3.24 min (0.5–10.51), 13.99 Gy.cm² (4.02–37.6), and 231.43 mGy (73.8–622.15), respectively. Effective dose calculated using Monte Carlo-based PCXMC software was found to be 4.9 mSv. Left anterior oblique (LAO) 45° projection contributed the highest radiation dose (28%) of the overall KAP. Radiation-induced risk was found to be higher in females compared to males with increased risk of lung cancer. An increase of 10%–15% in radiation dose was observed when one or more additional projections were adopted along with the seven standard projections. A 14% reduction of radiation dose was achieved from novel FD system when low-dose protocol during fluoroscopy and medium-dose protocol during cine acquisitions were adopted, compared to medium-dose protocol. **Abdoelrahman** et al 2015 (Sudan). 206 patients underwent four types of (IC) procedures which are (CA, PCI, PTMC and pacemaker) the number patients for each procedure were 145, 39, 4 and 18 respectively. The mean age of patients was 59.9±14.1 (3-100 yrs). The mean value of kVp was 78.2±11.4 (50 - 109), mAs was 7.1 ±0.72 (3 - 10.2). The mean FT was 6.9±7.1 min. KAP, and FT were registered. For CA, PCI, PTMC and pacemaker the mean and median KAP values demonstrated as higher and lower values were found to be (63.69, 52 Gy.cm²) (18.78, 15.5 Gy.cm²) for PCI and pacemaker respectively. The higher mean and median fluoroscopy time in minutes (11.43, 9.70) as registered for PCI procedure was reported in this study which may considered relatively higher value than reported in the literature. **Aly** et al 2015 studied information about PSD, DAP, FT, and CD from PTCA CA. The range of maximum photon energy was 50 - 125 kVp and FT was 0.6 - 52 sec. Values of up to 143 Gy.cm² for DAP and 0.752 mGy for CD were found in CA. Otherwise the DAP and CD for PTCA were found to be 143 Gy.cm² and 2.287 mGy respectively in 3rd Quartile. The relation between FT and DAP is also considered. The aim of this study is also to assess the radiation dose received by patients undergoing IR procedures, by identifying the procedures that deliver the highest doses. Radiation doses for 1132 patients were collected include patients age, sex, FT, total DAP reading. The range of kVp used in these procedures was 50 - 125 kVp and the fluoroscopy time 0.18 - 52 minutes. For CA procedures, DAP values reached 72.14 Gy.cm² and CD values reached 752 mGy. On the other hand, the DAP for and CD for PTCA procedures were found to be 143 Gy.cm² and 2287 mGy respectively. CD was of the order of 2 Gy, the dose limit for radiation injuries. a strong correlation was found between the (DAP) and (PSD), Conversely, there is a poor correlation between the Total FT and the PSD. It is noticed that the DAP value for CA in Diamond RLs exceeded the HMC DRLs by almost 20%

for 3rd quartile values. However DAP is a poor indicator of onset of deterministic effects. A much better indicator is skin entrance. In this study, a strong correlation was found between the (DAP) and (PSD). Conversely, there is a poor correlation between the Total Fluoroscopy Time (FT) and the PSD, so DAPs can be used as an indicator for PSD. On the other hand, Fluoroscopy Time was found to be a much less reliable indicator of the Peak Skin Dose. The proposed reference levels based on DAP readings are thus about 100 Gy.cm^2 , corresponding to PSD of about less than 2 Gy. **Ubeda** et al 2015. Studied the local patient dose diagnostic reference levels in pediatric interventional cardiology in Chile to correlate patient dose values with patient weight. Sample sizes by age group were 120 for <1 yr; 213 for 1 to <5 yr; 82 for 5 to <10 yr; and 102 for 10 to <16 yr. The third quartile values obtained for DAP by diagnostic and therapeutic procedures and age range were 1.17 and 1.11 Gy cm² for <1 yr; 1.74 and 1.90 Gy cm² for 1 to <5 yr; 2.83 and 3.22 Gy cm² for 5 to <10 yr; and 7.34 and 8.68 Gy cm² for 10 to <16 yr, respectively. The third quartile value obtained for the DAP/body weight ratio for the full sample of procedures was 0.17 (Gy cm²/kg) for diagnostic and therapeutic procedures. **Hwang** et al 2015. Radiation Exposure in Coronary Angiography: A Comparison of Cineangiography and Fluorography. 55 patients were prospectively enrolled and divided into two CAG groups, in accordance with the operator's professional discretion: a conventional cineangiography group versus a fluorography group. The total AK and DAP were significantly lower in the fluorography group ($159.3 \pm 64.9 \text{ mGy}$ and $1337.9 \pm 629.6 \text{ }\mu\text{Gy.m}^2$, respectively) than in the cineangiography group ($326.9 \pm 107.5 \text{ mGy}$ and $2341.1 \pm 849.9 \text{ }\mu\text{Gy.m}^2$, respectively; $p=0.000$ for both). The total procedure time (cineangiography vs. fluorography, 12.8 ± 4.7 vs. $12.5 \pm 2.9 \text{ min}$; $p=0.779$) and contrast agent amount (136.1 ± 28.3 vs. 126.3 ± 25.7 , $p=0.214$) were comparable between the two groups. They concluded that the fluorography is a useful method to decrease the radiation exposure in selected patients requiring CAG. **Livingstone** et al 2015 studied the transition from II to FPD in IC and their impact on radiation dose. This study intends to compare radiation doses from II and FPD systems for CAG and PTCA performed. Radiation doses were measured using DAP in CAG ($n = 222$) and PTCA ($n = 75$) performed using FPD angiography system. The DAP values from FPD were compared with earlier reported data using II systems from the same referral center where the study was conducted. The mean DAP values from FPD system for CAG and PTCA were 24.35 and 63.64 Gy.cm² and those from II system were 27.71 and 65.44 Gy.cm². Transition from II to FPD system requires stringent dose optimization strategies right

from the initial period of installation. To achieve improved patient dose reduction, it is advisable to strictly adhere to low dose protocols with high filtration in FPD systems. In addition, more attention for staff doses is warranted especially for interventionalists when this stringent patient dose reduction is employed. It is recommended to follow stringent dose reduction strategies right from the period of initial installation when there is a transition from II to FPD systems. Shah et al 2015. They studied an effectiveness of fluorography versus cineangiography at reducing radiation exposure during diagnostic coronary angiography. Fluorography (n=25) or Cineangiography (n=25) group. Patients in the Fluorography group underwent coronary angiography using retrospectively-stored fluorography with repeat injection under cineangiography only when needed for better resolution per operator's discretion. Patients in the Cineangiography group underwent coronary angiography using routine cineangiography. The primary endpoint was patient radiation exposure measured by radiochromic film. Secondary endpoints included the radiation output measurement of kerma-area product (KAP) and air kerma at the interventional reference point ($K_{a,r}$), and operator radiation exposure measured by dosimeter. Patient radiation exposure (158.2 mGy (76.5-210.2) vs. 272.5 mGy (163.3-314.0), KAP ($1323\mu\text{Gy}\cdot\text{m}^2$ (826-1765) vs. $3451\mu\text{Gy}\cdot\text{m}^2$ (2464-4818), and $K_{a,r}$ (175 mGy (112-252) vs. 558 mGy (313-621) was significantly lower in the Fluorography compared with Cineangiography group (42%, 62%, and 69% relative reduction, respectively). Operator radiation exposure trended in the same direction though statistically non-significant (Fluorography $2.35\mu\text{Gy}$ [1.24-6.30] vs. Cineangiography $5.03\mu\text{Gy}$ [2.48-7.80], $p=0.059$). They concluded that the use of fluorography in a select group of patients during coronary angiography with repeat injection under cineangiography only when needed was efficacious at reducing patient radiation exposure. **Wassef** et al 2014 they reported the results a novel radiation reduction protocol (RRP) system for CA and PCI procedures and the determinants of radiation dose. Separate analyses were done for conventional 15 frames/s (FPS) and at reduced 7.5 FPS post-RRP groups. A total of 605 patients underwent CA (309 before RRP and 296 after RRP), with 129 (42%) and 122 (41%) undergoing PCI before and after RRP, respectively. With RRP, a 48% dose reduction ($1.07 \pm 0.05\text{ Gy}$ vs. $0.56 \pm 0.03\text{ Gy}$, $p < 0.0001$) was obtained, 35% with 15 FPS RRP ($0.70 \pm 0.05\text{ Gy}$, $p < 0.0001$) and 62% with 7.5 FPS RRP ($0.41 \pm 0.03\text{ Gy}$, $p < 0.001$). Similar dose reductions for DCA and PCIs were noted. There was no change in the number of stents placed or vessels intervened on. Increased dose was associated with male sex, radial approach, increasing body mass index, cine

runs, and frame rates. Using a multivariable model, a 48% relative risk with RRP ($p < 0.001$), 44% with 15 FPS RRP and 68% with 7.5 FPS RRP was obtained. We demonstrate a highly significant 48.5% adjusted radiation dose reduction using a novel algorithm, which needs strong consideration among interventional cardiology practice. **Pasciak** et al 2014 they purposed to determine whether C-arm rotation reduces the PSD in IC procedures and, if so, under what circumstances. The authors used simulations to perform using a numerical ray-tracing algorithm to analyze the effect of C-arm rotation on PSD across a range of patient sizes, C-arm configurations and procedure types. Specific data from modern fluoroscopes and patient dimensions were used as inputs to the simulations. They found that small patients may not benefit from C-arm rotation as a procedural modification. They concluded that with the exception of rotation to steep craniocaudal angles, rotating the C-arm reduces PSD in IC procedures when used as either a procedural modification or a prophylactic strategy, and tight collimation of the X-ray field increases the benefit of C-arm rotation, and has the added benefits of increasing image contrast and reducing patient and operator dose. **Abdelaal** et al 2014. They intended to determine the efficacy of low rate fluoroscopy at 7.5 frames/s (FPS) versus conventional 15 FPS for reduction of operator and patient radiation dose during DCA and PCI via the Transradial approach (TRA). Low rate fluoroscopy has the potential to reduce radiation exposure. Primary endpoints were operator radiation dose, patient radiation dose, and fluoroscopy time. 363 patients, 184 underwent DCA and 179 underwent PCI. Overall, fluoroscopy at 7.5 FPS compared with 15 FPS was associated with a significant reduction in operator dose (30%), and in patient's dose area product (19%). When stratified by procedure type, 7.5 FPS compared with 15 FPS was associated with significant reduction in operator dose during both DCA (40%) and PCI (28%). Fluoroscopy at 7.5 FPS, compared with 15 FPS, was also associated with substantial reduction in patients' dose-area product during DCA (26%) and during PCI (19%). Fluoroscopy time was similar in 7.5 FPS and 15 FPS groups for DCA (3.4 ± 2.0 min vs. 4.0 ± 4.7 min) and PCI (11.9 ± 8.4 min vs. 13.3 ± 9.7 min), respectively. Fluoroscopy at 7.5 FPS, compared with 15 FPS, is a simple and effective method in reducing operator and patient radiation dose during TRA DCA and PCI. They concluded that the low rate fluoroscopy at 7.5 FPS offers a simple, cost-free, yet a very effective measure to reduce both operator and patient radiation exposure during TRA in real-world situations, without any effect on procedural duration, fluoroscopy time, or contrast use, and suggested that operators should routinely adopt

this method to minimize radiation exposure. Sample size calculations were based on observational data from our cardiac catheterization laboratories over a 12-month period. Average operator radiation doses per procedure were 30 ± 20 mSv for DCA and 65 ± 25 mSv for PCI. The average patient's DAP during the same period was 30 ± 14 Gy.cm² for DCA and 75 ± 35 Gy.cm² for PCI. We estimated that a sample size of 350 patients would be required to demonstrate a $\geq 20\%$ dose reduction in operator and patient exposure with 7.5 FPS compared with 15 FPS during DCA and/or PCI with a power of 80% at alpha level of 0.05. **Arif** et al 2014. Aimed to compare the radiation dose in PCI vs. peripheral interventions in one centre with a uniform system of protection methods. A total of 352; 217 PCI (single and multiple stenting) and 135 patients undergoing PTA (in lower extremities, carotid artery, renal artery, and subclavian artery). Radiation dose, FT, and total procedural time were reviewed. CD was measured in gray (Gy) units. The total procedural time was significantly higher in PTA (PCI vs. PTA: 60 (45–85) min vs. 75 (50–100) min), $p < 0.001$. The radiation dose for PCI procedures was significantly higher in comparison to PTA (PCI vs. PTA: 1.36 (0.83–2.23) Gy vs. 0.27 (0.13– 0.46) Gy), $p < 0.001$. There was no significant difference in the fluoroscopy time (PCI vs. PTA: 12.9 (8.2–21.5) min vs. 14.4 (8.0–22.6) min), $p = 0.6$. The analysis of correlation between radiation dose and fluoroscopy time in PCI and PTA interventions separately shows a strong correlation in PCI group ($r = 0.785$). However, a weak correlation was found in PTA group ($r = 0.317$). ‘Concluded that the radiation dose was significantly higher during PCI in comparison to PTA procedures despite comparable fluoroscopy time and longer total procedure time in PTA. Fluoroscopy time is a reliable parameter to control the radiation dose exposure in coronary procedures. The increasing complexity of endovascular interventions has resulted in the increase of radiation dose exposure during PCI procedures. **Lefterova** et al (2014) The purpose of this study is to estimate typical patient doses in angiography rooms in two university hospitals in Sofia, and to compare them with the established national diagnostic reference levels (DRL) and published data. Prospective patient study was performed for five X-ray units of four different manufacturers. Four most common procedures were included: coronary angiography (CA), percutaneous coronary intervention (PCI), lower limb arteriography (LLA) and stent placement in iliac/femoral artery. Totally 285 procedures were recorded, and for each the following information was collected: sex, age, weight, and height of patient, frame rate, fluoroscopy time (FT), total number of series/images, and total dose area product (DAP). DAP in cine mode and cumulative

doses were recorded for two of the systems. In addition, entrance surface air kerma (ESAK) rates in fluoroscopy and acquisition mode were measured with a PMMA phantom. Image quality was assessed using DICOM images by calculation of signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR). Large variations were observed in procedure protocols, resulting in variations in patient dose: DAP ranges were 5.9-172, 31-498, 2.7-78 and 12-326 Gy.cm² for CA, PCI, LLA and iliac/femoral artery stent placement respectively. The mean DAP values varied by a factor of 2 for CA and a factor of 3 for PCI. Two times difference in mean value of cumulative dose was found due to the 3.6 fold ESAK rate difference. The mean values of DAP were higher than national DRL (40 Gy.cm² for CA and 140 Gy.cm² for PCI) in three of the rooms and lower for only one room. The mean DAP values of 34 Gy.cm² for LLA and 65 Gy.cm² for stent placement were lower compared to the national and published DRLs. The mean FT was higher than the auxiliary reference intervals for only one system. A possible explanation of the higher doses is the higher number of acquired images. Image quality was better for the system with higher doses but sufficient for all systems. Patient dose recording, establishment of typical doses and comparison with national DRL demonstrated to be good tool to find potential for optimization. Egan 2014 the study reviewed patient radiation doses DAP with respect to two of the more prevalent exams; CA (N=518) & PCI (N=116). The results also reviewed cases per cardiologist to determine any discrepancies between practices. As the data included individual cases, it was useful to look at dose not only in terms of the individual cases but also individual patients, especially as many patients attend the Cath Lab more than once. This means single and accumulated dose can be compared to the trigger levels proposed in SIR Guidelines (2009).

Shah et al 2014 made a comparison about an effectiveness of fluorography versus cineangiography at reducing radiation exposure during diagnostic coronary angiography. Patients in the fluorography group underwent CA using retrospectively-stored fluorography with repeat injection under cineangiography only when needed for better resolution per operator's discretion. Patients in the Cineangiography group underwent coronary angiography using routine cineangiography. The primary endpoint was patient radiation exposure measured by radiochromic film. Secondary endpoints included the radiation output measurement of KAP and air kerma at the interventional reference point ($K_{a,r}$), and operator radiation exposure measured by dosimeter. Patient radiation exposure (158.2mGy [76.5-210.2] vs. 272.5mGy [163.3-314.0],

$p=0.001$), KAP ($1323\mu\text{Gy m}^2$ [826-1765] vs. $3451\mu\text{Gy m}^2$ [2464-4818], $p<0.001$), and $K_{a,r}$ (175 mGy [112-252] vs. 558 mGy [313-621], $p<0.001$) was significantly lower in the fluorography compared with cineangiography group (42%, 62%, and 69% relative reduction, respectively). Operator radiation exposure trended in the same direction though statistically non-significant (fluorography $2.35\text{ }\mu\text{Gy}$ [1.24-6.30] vs. cineangiography $5.03\mu\text{Gy}$ [2.48-7.80], $p=0.059$). They concluded that the use of fluorography in a select group of patients during coronary angiography with repeat injection under cineangiography only when needed was efficacious at reducing patient radiation exposure. **Abdelaal** et al 2014 they sought to determine the efficacy of low rate fluoroscopy at 7.5 FPS (FPS) vs. conventional 15 FPS to reduce operator and patient radiation dose during DCA and PCI via TRA. TRA for cardiac catheterization is potentially associated with increased radiation exposure; low rate fluoroscopy has the potential to reduce radiation exposure. Patients undergoing TRA DCA ad-hoc PCI were randomized to fluoroscopy at 7.5 FPS versus 15 FPS prior to the procedure. Both 7.5 and 15 FPS fluoroscopy protocols were configured with a fixed dose per pulse of 40 nGy. 363 patients (184 DCA & 179 PCI). 7.5 FPS compared with 15 FPS was associated with a significant reduction in operator dose (30% relative reduction [RR], $p < 0.0001$); and in patient's DAP (19% RR; $p = 0.022$). When stratified by procedure type, 7.5 FPS compared with 15 FPS was associated with significant reduction in operator dose during both DCA (40% RR; $p < 0.0001$) and PCI (28% RR; $p = 0.0011$). Fluoroscopy at 7.5 FPS, compared with 15 FPS, was also associated with substantial reduction in patients' DAP during DCA (26% RR; $p = 0.0018$) and during PCI (19% RR; $p = 0.13$). Fluoroscopy time was similar in 7.5 FPS and 15 FPS groups for DCA (3.4 ± 2.0 min vs. 4.0 ± 4.7 min; $p = 0.42$) and PCI (11.9 ± 8.4 min vs. 13.3 ± 9.7 min; $p = 0.57$), respectively. They concluded that the fluoroscopy at 7.5 FPS, compared with 15 FPS, is a simple and effective method in reducing operator and patient radiation dose during TRA DCA and PCI. **Eitidal** et al 2013 (Sudan) The aim of this study was to assess effective dose to a patient during cardiac procedures, such as coronary angiography (CA), percutaneous coronary interventions (PCI), percutaneous Trans venous mitral Commissurotomy (PTMC) and pacemaker. Measurements were performed on 206 patients in hospital in Khartoum using the Dose Area Product (DAP). Calculations of surface and effective dose were performed with Monte-Carlo-based program PCXMC. The mean DAP value per procedure determined in all workplaces ranged between 1.0 and 167.0 Gy cm^2 for CA, 1.0–194.0 Gy cm^2 for PCI, 1.0-69 Gy cm^2 for

PTMC and 1.0-56 Gy cm^2 for pacemaker. The effective dose was estimated in the study by using the PCXMC software, the higher and lower values were found to be (11.95, 3.32) for PCI and PTMC respectively. The results presented are comparable with those published by other authors. This study has shown that the doses received by patients during IC procedures could be high, especially since these patients could be exposed several times according to the chronic evolution of the coronary disease. **Sun et al 2013**. In recent years, intensive efforts have been initiated to reduce the radiation dose associated with interventional cardiology. There is increasing concern about the potential deleterious effects from radiation arising from intervention cardiology due to two reasons: first, cardiac procedure volumes have grown tremendously. Second, the radiation doses received by interventional cardiologists and patients can vary by more than an order of magnitude for the same type of procedure. Increased workload, complexity of the interventional procedures, and acute patient conditions contribute significantly to the amount of radiation exposure to both patients and medical staff. Non-cancer risks of radiation in interventional cardiology that have been discussed in different scenarios emphasize the importance of reducing radiation dose to patients. A final general recommendation is that being aware of the radiological protection of your patient will also be improving your own occupational protection. **Wang et al 2013**. This study was designed to measure PSD, DAP, CD and FT for IC procedures and to evaluate whether patient doses were higher than that in other published data. CAG, PTCA and RFA, were entered into the study. For every procedure, data about PSD were resulted from six TLD arrays and DAP, CD and FT were collected from the displayed monitor. There was wide variation in the doses observed for different instances of the same procedure. PSD for PTCA and RFA ranged from 0.1 Gy to more than 3 Gy. Of 238 instances, there were 22 (9.2 %) with PSDs greater than 2 Gy and 4 (1.7 %) than 3 Gy. PTCA had exceeded the DIMOND preliminary reference levels by 41.1 % in DAP and 25.0 % in FT. Mean DAP was in the range of reported values for CAG procedure, but higher than all data obtained in literatures for PTCA. Data from this study are in the range of most reported values for CAG and RF ablation procedure, while higher than that obtained in some literatures for PTCA. **Mattos et al 2013**. Patients were analyzed according to the access route: femoral or radial. 1197 pts (782 FAA and 415 RAA). The median radiation dose received by the patients was higher with the radial approach, both for DCA (621.6 mGy vs. 445.7 mGy; $P < 0.01$) and PCI (1241.6mGy vs. 990.9mGy; $P < 0.01$). Less experienced operators in the radial approach exposed patients to higher radiation doses (1463

mGy vs. 1196 mGy; $P = 0.02$), which did not occur with the more experienced operators (1311 mGy vs. 1449 mGy; $P = 0.84$). Concluded that the patients undergoing invasive cardiologic procedures are exposed to higher radiation levels when the radial access is used.

Taghi et al 2013. The mean values of MSD and DAP for DCA were 68.51 mGy and 20.96 Gy.cm², respectively and for PCI 344.18 mGy and 70.94 Gy.cm², respectively. A good correlation was found between MSD and DAP ($R=0.88$) but correlation between MSD and CDIRP was stronger ($R=0.90$). They concluded that MSD values did not exceed the 2000 mGy dose threshold for deterministic effects. The highest MSD obtained for DCA was 229.40 mGy and for PCI it was 820.50 mGy. The results show that CDIRP can be a fairly good estimate of MSD. **Sun** et al, 2013 they reviewed radiation-induced non-cancer risks in interventional cardiology to optimize staff and patient dose reduction. There is increasing concern about the potential deleterious effects from radiation arising from intervention cardiology due to two reasons: first, cardiac procedure volumes have grown tremendously. Second, the radiation doses received by interventional cardiologists and patients can vary by more than an order of magnitude for the same type of procedure. Increased workload, complexity of the interventional procedures, and acute patient conditions contribute significantly to the amount of radiation exposure to both patients and medical staff. Non-cancer risks of radiation in interventional cardiology that have been discussed in different scenarios emphasize the importance of reducing radiation dose to patients and medical staff. This can be achieved through implementing necessary strategies such as continual improvements in protocols and equipment, implementation of guidelines proposed by professional bodies into daily practice and attending training programmes to ensure best practice. A final general recommendation is that being aware of the radiological protection of your patient will also be improving your own occupational protection. Another study conducted by **Ahmed NA** et al (2012) they measured the patient doses in interventional cardiology procedures in Sudan, namely CA, PTCA, percutaneous transvenous mitral commissurotomy (PTMC) and pacemaker. For CA, PTCA, PTMC and pacemaker the mean and median kerma area product values in Gy.cm² were found to be (20, 17.9), (56.5, 50.3), (21.6, 19.6) and (15.3, 9.6), respectively. They found that the radiation doses delivered to 461 patients were as follows; mean and median cumulative kerma in mGy were (143.7, 120.5), (418.4, 371.4), (119.8, 102) and (88.7, 59.8) as measured for CA, PTCA, PTMC and pacemaker,

respectively. Furthermore, mean and median total fluoroscopy time in minutes were (5.2, 3.39), (17.6, 14.8), (18, 15) and (10.2, 7.16) as registered for CA, PTCA, PTMA and pacemaker, respectively. Maximum skin dose was estimated for 13 patients during PTCA and CA procedures. Dose exceeded 2 Gy in PTCA for one patient. In comparison with the guidelines for coronary examinations suggested by SENTINEL Consortium, a higher fluoroscopy time for PTCA procedure is reported in this study. It is realized that proper selection of irradiation area, technique modes, fluoroscopy time and conducting special training on radiation protection to the operators are the main factors for potential optimization. **Journy** et al 2012. The mean MSD and DAP were respectively 389 mGy and 65 Gy.cm² for CAs, and 916 mGy and 69 Gy.cm² for PTCAs. For 8% of the procedures, the MSD exceeded 2 Gy. Although a linear relationship between the MSD and the DAP was observed for CAs (r²=0.93), a simple extrapolation of such a model to PTCAs would lead to an inadequate assessment of the risk, especially for the highest dose values. For PTCAs, the body mass index, the therapeutic complexity, FT and the number of cine frames were independent explanatory factors of the MSD, whoever the practitioner was. Moreover, the effect of technical factors such as collimation, cinematography settings and X-ray tube orientations on the DAP was shown. MSD is largely the result of the technical options chosen by the operator (II field size, beam collimation, wedge filter, frame rate, dose rate and focus–detector distance) as their modality. The study illustrates the impact of operator behavior on dose, which probably results in a complex attitude that integrates all these technical options. Alarm may also be supported to warn the practitioner when the dose may exceed specified thresholds. **Bernier** et al 2012 studied patient cumulative radiation exposure in interventional cardiology. Organ doses to the lung, oesophagus, bone marrow and breast were mathematically evaluated. The median age of patients was 70 years. Their median cumulative DAP value was 48.4 Gy.cm² for the whole year and the median effective dose was 9.7 mSv. The median organ doses were 41 mGy for the lung, 31 mGy for the oesophagus, 10 mGy for the bone marrow and 4 mGy for the breast. Levels of doses close to the heart appear to be rather high in the case of repeated IC procedures. This study has shown that the doses received by patients during ICP could be high, especially since these patients could be exposed several times according to the chronic evolution of the coronary disease. Health monitoring as well as long-term epidemiological studies of the most exposed patients undergoing ICP should help to assess the radiation-induced cancer risk of the radiosensitive organs around the heart, but need to take into

account the clinical specificities of the target population. **Walsh** et al 2012. They aimed to measure and optimize the patient radiation doses in Endovascular Aneurysm Repair (EVAR). Two types of patient dose were estimated; effective dose (ED), which allows estimation of radiation risk to the EVAR patient population; and Peak Skin Dose (PSD), which allows us assess the potential for an individual patient to receive a radiation skin injury. Based on 111 EVAR cases we estimated average ED as 12.4 mSv. Cumulative patient dose in our centre was lower than other studies because the follow up of EVAR patients is based on ultrasound rather than CT. PSD calculated using a published conversion formula closely matched measurements with calibrated gafchromic film. 99% of patients had an estimated PSD of 2Gy. Results indicate that skin injuries are possible, but very unlikely in EVAR procedures at our centre. EVAR is a high dose procedure and emphasis on dose optimization is important. We broke the EVAR procedure into 15 steps and, in a phantom study, showed how skin dose changes as procedure steps are varied. The resulting dose matrix has the potential to be used as an educational tool to promote dose optimization. **A. Sulieman** et al (2011) (Sudan). They had been evaluated the level of radiation dose received by the patients in order to introduce local diagnostic reference levels. They found that the average ($KAP \pm SD$) of PCI and DCA procedure were $(46.4 \pm 21.1) \text{ Gy.cm}^2$ and $(22.4 \pm 2) \text{ Gy.cm}^2$, respectively, and the average ($FT \pm SD$) of both were (24.1 ± 16.8) minutes and (37.2 ± 20.0) min respectively. Their study had revealed that estimated patient dose rate was found to be 125 mGy/min which considered higher than the recommended DRL for the continuous high mode fluoroscopy used in interventional radiology (100 mGy/min). They concluded the fact that the patients received relatively high dose than previously reported studies. **Fetterly** et al, 2011, they intended to establish the primary clinical determinants of patient radiation dose associated with PCI to identify opportunities for dose reduction. Median patient age was 68.6 years, median body mass index was 29.7 kg/m², and median weight was 88 kg. Median Cumulative skin dose (CSD) was 1.64 Gy per procedure for male and 1.15 Gy for female patients. They found that an increasing of body mass index, patient sex, lesion complexity, lesion location, and performing physician were significantly associated with CSD. Physicians who performed more procedures were associated with lower CSD. Several primary determinants of radiation burden to patients undergoing PCI were identified. Complexity, number, and location of lesions were associated with radiation skin dose. Skin dose correlated with patient size, increasing significantly with increasing BMI and decreasing for female versus

male patients. Notably, this work demonstrates that patient radiation dose varies substantially among physicians and that there is an inverse correlation of patient dose with operator volume. **Dragusin** et al 2011. Optimization of radiation dose and image quality and implementation of ALARA principle in catheterization laboratories are tasks that involve all actors: interventional cardiologists, auxiliary staff, medical physicist, and applications specialists. However, in daily practice some tactics for radiation dose reduction and image quality improvement should be known by all interventional cardiologists. We create a list of little steps that have an impact in radiation safety in daily practice. *Use the lowest acceptable clinical protocols during fluoroscopy and cineangiography.* Pulsed fluoroscopy and cineangiography at lowest radiation level should be used. If the equipment allows, different protocols must be created and used in function on the type of structure that is being imaged (venous vs. arterial, fast-moving vs. slow-moving). *Correct placement of the patient in the isocenter on the table.* Having the patient correct positioned in the isocenter facilitates keeping the heart at the center of the X-ray field. In this way there is no need of prolonged fluoroscopy to adjust the patient's position with each change in angiographic projection. *Avoid the use of fluoroscopy to make changes to the patient position or collimators.* Fluoroscopy should be used very briefly to check the patient position. Movements to the correct position should be avoided by using fluoroscopy constantly. Modern units have "virtual" markers that enable the positioning of the collimators. The correct position of collimators should be checked by brief fluoroscopy rather than constant visualization. *Remove unnecessary instruments and body parts from the X-ray field.* Presence of the patient's arm, operator's hands or any external instruments should never be visible on a cardiac study. These structures or objects result in an overall increase in radiation dose to the patient because of the demand of AEC system to compensate with increased radiation output. *Minimize the number of angiograms.* Limit the number of projections to provide an overview of the status of the coronary arterial tree and identify the ideal projections to be used for coronary angioplasty. Always performs test injection of a small amount of contrast material using fluoroscopy prior to acquiring an angiogram. This approach prevents the wasted angiogram that is taken with the catheter inadvertently wedged deeply in a vessel. Also fluoroscopy of test injection can aid in determining the correct magnification mode. Keep in mind that few seconds of fluoroscopy and little quantity of contrast material are less irradiating the patient than a full wasted angiogram. During complicated interventions, limit the use of magnification, because of the substantial

increase in radiation dose. *Keep the detector (II or FD) as close to the patient as possible.* The X-ray tube should be as far away as possible. If the detector is far from patient, the input doses will be higher and the scatter radiation increases. *Decrease beam on time.* This is probably one of the most important rules. Fluoroscopy must not be applied when discussing or doing other manoeuvre. If the eye is not on the screen, the foot should not be on the fluoroscopic pedal. Use stored images rather than live images for studying the case. *Use angiographic projections that reduce operator exposure whenever possible.* For right oblique projections, the X-ray tube moves away from the operator, while for left anterior oblique projection moves it closer. Kuon et al., 2004 published an interesting paper focused on identification of less-irradiation tube angulations in invasive cardiology. Di Mario & Sutaria, 2005 published a review of techniques to obtain optimal views of all segments of the coronary arterial system. *Remove anti-scatter grid when imaging small children.* New cardiac X-ray systems have possibility to remove the grid. In pediatric patients a significant reduction in radiation dose is possible without compromising image quality. *Know your own cardiac X-ray equipment and its features.* Work with radiation physicist, the manufacturer to regularly test and maintain the equipment in optimal working conditions. *Ensure protection of laboratory staff.* Before starting fluoroscopy, ensure that everyone in the room use radiation protection shielding. Ask of laboratory staff to keep distance during cine angiography. Remember the inverse square law: doubling the distance from a point source reduces the radiation exposure to one-quarter. Keep the proper use and storage of lead aprons. Aprons that are not proper storage might develop cracks, compromising their effectiveness. Always use personal dosimeters. Technology of X-ray cardiac system is continuously adapting and optimization of radiation doses with less compromise on image quality is possible. On the other side, activity in cardiac catheterization laboratories increases and more complex procedures are performed. All the actors involved in catheterization laboratory should be trained and familiar with the basic principles of radiation safety. Developing a radiation safety culture should be a priority. Attention to the simple rules of radiation safety and the planning of an interventional procedure should enable the interventional cardiologist to produce high quality images at low radiation level to the patient. **Sanchez** (2011) they aimed is to propose a set of national diagnostic reference levels (DRLs) for patients as recommended by the International Commission on Radiological Protection and to initiate several optimization actions to improve radiological protection of both patients and staff. Six hospitals have joined the

programme and accepted to submit their data to a central database. First to be acquired were the quality control data of the X-ray systems and radiation doses of patients and professionals. The results from 9 X-ray systems, 1467 procedures and staff doses from 43 professionals were gathered. Provisional DRLs resulted in 44 Gy cm² for coronary angiography and 78 Gy cm² for interventions. The X-ray systems varied up to a factor of 5 for dose rates in reference conditions. Staff doses showed that 50 % of interventional cardiologists do not use their personal dosimeters correctly. **Ying and Kandaiya 2010** Patients' dose measurements were carried out by using Gafchromic XR-RV2 films. For patient dose measurements, the films were placed on the table underneath the patient for an under-couch tube position. This study included a total of 44 patients. Values of 35–2442 mGy for peak skin dose (PSD) and 10.9–344.4 Gy.cm² for dose–area product (DAP) were obtained. DAP was found to be a poor indicator of PSD for PTCA procedures but there was a better correlation ($R^2 = 0.7344$) for CA + PTCA procedures. The highest PSD value in this study exceeded the threshold dose value of 2 Gy for early transient skin injury recommended by the Food and Drug Administration. The XR-RV2 radiochromic film is a good dosimetric film for interventional cardiology examination to map patient skin doses. The results obtained in this study show that XR-RV2 is suitable to monitor patient skin doses and for predicting possible skin injury when the threshold dose levels are exceeded. DAP is not an adequate indicator of patient skin dose. The wide variation in DAP values could arise from long fluoroscopy time, variation in cineangiography time, patient weight and anatomy, operator skill, the number of lesions and the field size used. DAP readings can be useful in assessing potential skin dose for fluoroscopy times less than 15 min; this only gives PSD of less than 1 Gy.

Neil et al 2010 studied of PSDs during neuroradiology and CI procedures by using Gafchromic XR-RV2 film. The displayed CAK calibrated in terms of cumulative (CESD) and results indicate that this can provide a reliable indicator of the PSD in neuroradiology. Results linking PSD to CESD for interventional cardiology were variable, but CAK is still considered to provide the best option for use as an indicator of potential radiation-induced effects. A CESD exceeding 3 Gy is considered a suitable action level for triggering follow-up of patients in neuroradiology and cardiology for possible skin effects. Application of dose action levels defined in this way would affect 8% of neurological embolization procedures and 5% of cardiology ablation and multiple stent procedures at the hospitals where the investigations were carried out. A close

relationship was observed between CESD and DAP for particular types of procedure, and DAPs of 200-300 Gy.cm² could be used as trigger levels where CAK readings were not available. The DAP value would depend on the mean field size and would need to be determined for each application. Stevens et al, 2010. Timely identification of systematic changes in radiation delivery of an imaging system can lead to a reduction in risk for the patients involved. A two stage monitoring process employing individual and exponentially weighted moving average (EWMA) control charts was developed and used to identify unexpectedly high or low radiation exposure levels for individual patients, as well as detect persistent changes in the radiation output delivered by the imaging systems. To address this issue, they proposed the implementation of an ongoing monitoring process that utilizes procedural data to identify unexpected large or small radiation exposures for individual patients, as well as to detect persistent changes in the radiation output of imaging platforms. To increase sensitivity of the charts, they accounted the variation in DAP values due to other measured factors (patient weight, FT, and digital acquisition frame count) using multiple linear regression. They recommended that the retrospective application of this technique to actual clinical data identified a number of cases in which the DAP result could be considered unexpected, and found that this technique offers a valuable enhancement to existing quality assurance programs in radiology that rely upon the testing of equipment radiation output at discrete time frames to ensure performance security. **Miller** et al 2010. In their study Clinical Radiation Management for Fluoroscopically Guided Interventional Procedures (FGI) procedures are performed in large numbers in the United States and in Europe. They aimed to minimize radiation risk to the patient without increasing other risks, such as procedural risks, many FGI procedures, the potential for patient radiation doses high enough to cause radiation effects, so management of radiation exposure is therefore essential for these procedures. They concluded that the FGI procedures provide great benefit to patients, but also entail risks, including the risk of radiation effects. Minimizing the likelihood and severity of radiation effects requires appropriate and properly functioning equipment, a radiation management process that extends from pre-procedure planning through post-procedure follow-up, and a robust quality assurance and quality improvement program. Radiation injuries cannot always be avoided, but an informed and motivated physician can reduce their incidence and severity.

Olivera et al 2010. Monitored doses to patients in interventional cardiology in Serbian to investigate possibility for setting of trigger levels if dose quantities exceed certain levels. Information on annual workload was estimated based on number of CA procedures and PCI. Patients' doses were assessed in terms of KAP and air kerma in international reference point (KIRP). All three centers reported KAP values higher than 100 Gy.cm^2 and even values above 200 Gy.cm^2 , corresponding to 42% and 16% of all measurements. Measured KIRP value higher than 5 Gy was reported in one center, indicating that skin doses associated possibility of skin injuries were observed. KAP mean hospital values for CA ranged from 33 to 78 Gy.cm^2 and for PCI from 73 to 113 Gy.cm^2 , while associated values for KIRP were: 0.45-1.2 Gy and 1.1-1.8 Gy, respectively. Patient should be informed about possible skin effects, if dose level is higher than trigger. The presented results are valuable input for dose optimization strategies and for increasing awareness related to importance of dose management in interventional cardiology.

Karambatsakidou et al 2009. Conversion factors for effective dose ($\text{CF}_E = \text{effective dose/DAP}$ ($\text{mSv (Gy.cm}^2)$) in paediatric interventional cardiology were estimated retrospectively for 249 patients using DAP, irradiation geometry, exposure parameters and tissue-weighting factors (TWFs) from ICRP 60. The results showed that irradiation geometry had no significant impact on the CFE, and a single factor was defined for both diagnostic and interventional examinations. In addition, the effect of the new tissue-weighting factor for breast tissue (TWF_b) given in ICRP 103 on the effective dose was assessed. The CF_E was $3.7 \pm 0.2 \text{ mSv (Gy.cm}^2)$ (neonate), $1.9 \pm 0.2 \text{ mSv (Gy.cm}^2)$ (1 year), $1.0 \pm 0.1 \text{ mSv (Gy.cm}^2)^{-1}$ (5 years), $0.6 \pm 0.1 \text{ mSv (Gy.cm}^2)$ (10 years) and $0.4 \pm 0.1 \text{ mSv (Gy.cm}^2)$ (15 years). Applying these CFs to the individual DAP values of each patient yielded mean effective doses of 13.0 mSv (neonate), 8.6 mSv (1 year), 6.4 mSv (5 years), 8.6 mSv (10 years) and 12.7 mSv (15 years). The maximum estimated skin dose (15 patients) did not exceed 60 mGy. With the new ICRP value for TWF_b , increases in the CFs in the order of 10–30%, and in the effective dose of 10–20%, were indicated. The results indicated that the effective dose in paediatric interventional cardiology is of much greater concern than the skin dose. Furthermore, age-dependent CFE values are required so as not to underestimate the doses to very young patients.

Bor et al 2009 monitored patient doses and dosimetric evaluations in interventional cardiology. DAP and skin doses of 325 patients were measured using alternative dosimetric techniques for different cardiological examinations in five different. Mean DAP values measured with a transparent ion chamber were 49.1 Gy.cm^2 , 66.8 Gy.cm^2 , 106.9 Gy.cm^2

and 124.7 Gy.cm², respectively, for CA, PTCA or stent (PT-SI), CA and/or PTCA and/or stent (CA-PT-SI), and ablation examinations. Radiochromic films, TLD and point measurement of air kerma (AK) were carried out for skin dose assessments. Skin doses of 23 patients measured with radiochromic films were found to be between 2 Gy and 6 Gy. Although the complexity of the procedures was the major reason for these excessive doses, considerable contributions of high X-ray output of some fluoroscopy units were also noticed. Good correlations were found among the DAP results and also between the entrance skin doses calculated from AK measurements and direct DAP readings ($R(2) = 0.91$). A trigger DAP value of 130 Gy cm² for the 2 Gy of skin doses was derived from this relationship. In the case of coronary angiography examinations LAO 45 and RAO 30 were found as the dominant projections which may also simplify the dosimetric technique. **Brnić** et al, 2009, studied the patient radiation doses in the most common interventional cardiology (CA, PTCA, and stenting) procedures were included. Patient irradiation was measured in terms of KAP, FT and number of cine-frames (F). DRLs of KAP, FT and F were calculated as third quartile values rounded up to the integer. Skin doses were assessed on a selected sample of high skin dose procedures, using radiochromic films, and peak skin doses (PSD) were presented. A relative large range of doses in IC was detected. National DRLs were proposed as follows: 32 Gy.cm², 6.6 min and 610 frames for CA and 72 Gy cm², 19 min and 1270 frames for PTCA. PSD <1 Gy were measured in 72 % and PSD >2 Gy in 8 % of selected patients. The doses recorded in the study are acceptable when compared with the literature, but optimization is possible. Other authors Ioannis Pantos et al, 2009 they reviewed the derived doses at non-pediatric patients from 72 relevant studies published during the last 22 years in international scientific literature and found that patient radiation doses vary widely among the different interventional cardiology procedures but also among equivalent studies. Discrepancies of the derived results are patient, procedure, physician, and fluoroscopic equipment related. Nevertheless, interventional cardiology procedures can subject patients to considerable radiation doses. They recommended by efforts to minimize patient exposure should always be undertaken. **Stratis** et al (2009) Patient Dose in Cardiac Radiology Dose-area product (DAP), fluoroscopy time, number of sequences and frames per sequence were collected for each of 108 coronary angiography and 101 coronary angioplasty procedures, using the dedicated X-ray machine of the hospital's haemodynamic department, where more than 3000 procedures are performed per year. The median values of DAP were 19.96 and 40.17 Gy.cm² for coronary

angiography and angioplasty, respectively; fluoroscopy times were 7.7 and 23.4 minutes; and the numbers of frames were 457 and 641, respectively. There was a strong correlation between DAP and fluoroscopy time, the number of frames per sequence, and hence the cine recording time. Concluded that the entrance skin dose delivered to the patient in the haemodynamic department was lower than that of other studies, although the mean fluoroscopy time per patient was longer. The practices in use satisfy the diagnostic reference levels as far as DAP values and number of frames per patient are concerned, but not with regard to fluoroscopy time. We did not find the correlation between doctors' experience and DAP values reported in other studies, as we did not take into account the complexity index of the lesion. **Morrish** et al (2008) this study investigates patient doses by means of dose-area product (DAP) meters installed in six rooms in two hospitals. DAP measurements in each room ranged from 28.0- 39.3 Gy.cm² for coronary angiography and from 61.3-92.8 Gy.cm² for percutaneous transluminal coronary angioplasty, with the mean effective doses calculated to range between 5.1-6.6 mSv and 11.2-17.0 mSv, respectively. These values are comparable with those found in recent literature. DAP measurements were found to correlate strongly (correlation coefficient of 79%) with patient weight. The non-uniform scatter radiation fields surrounding the irradiated area during coronary angiography were also investigated using a tissue equivalent phantom and an ionization chamber. Exposure rates of scattered radiation from digital acquisition were found to be around 16 times higher than those generated from fluoroscopy, and oblique-angled imaging led to greater amounts of scatter owing to the increase in related exposure factors. The distribution of scatter from oblique projections confirms that X-ray photons in the diagnostic energy range are preferentially scattered backwards, toward the X-ray tube. These concepts are a major consideration when training individuals working in the angiography suite in order to keep doses "as low as reasonably practicable". **Domienik** et al 2008. Made a correlation of patient maximum skin doses in cardiac procedures used various dose indicators like DAP, CD and entrance dose at the patient plane (EFD). This study aimed at relating those dose indicators with doses ascribed to the most irradiated areas of the patient skin usually expressed in terms of local maximal skin dose (MSD). For CA procedures, the values of FT, total DAP and MSD were (0.7-27.3) min, (16-317) Gy.cm² and (43-1507) mGy, respectively, and for interventions, accordingly (2.1-43.6) min, (17-425) Gy.cm², (71-1555) mGy. Moreover, for CA procedures, CD and EFD were in the ranges (295-4689) mGy and (121-1768) mGy and for PCI (267-6524) mGy and (68-2279) mGy,

respectively. No general and satisfactory correlation was found for safe estimation of MSD. However, results show that the best dose indicator which might serve for rough, preliminary estimation is DAP value. In the study, the appropriate trigger levels were proposed for both facilities. **Dragusin et al 2008**, Radiation dose survey in a paediatric cardiac catheterization laboratory equipped with flat-panel detectors. A survey of 273 (126 diagnostic and 147 therapeutic) paediatric catheterizations was performed to investigate the radiation doses delivered by the new X-ray system. DAP and fluoroscopy times (FT) are reported for patients divided into six age groups: 0-30 d, >1-12 m, >1-3, >3-5, >5-10 and >10-15 y. For accurate risk estimation, effective dose (E) has been determined for all patients using the PCXMC software. For diagnostic procedures, the third quartile of E ranges from 11.3 mSv for newborns to 7 mSv for children of 10-15 y. Therapeutic procedures are more complex than diagnostic. Consequently, the third quartile of E is 22.6 mSv (0-30 d), 18.6 (>1-12 m), 13.3 (>1-3 y), 21.5 (>3-5 y), 17.8 (>5-10 y) and 34.1 mSv (>10-15 y). Dose conversion factors, which relate the DAP and E, have been estimated for each age group. The results of this study may serve as a first step in the optimization process, in order to make full use of the dose reduction potential of flat-panel systems. **Parizoti and Netto. 2008**. They aimed to analyze the optimization of fluoroscopic image quality and patient entrance surface air kerma rate in IR procedures. The authors utilized a phantom developed for evaluating conventional radiological images adapted for fluoroscopy through the addition of two catheters with different diameters, both of them utilized in IR. The patient ESAK rate was determined with the aid of this phantom. The evaluation of technical parameters for different exposure modes of a digital fluoroscopic imaging system has allowed the determination of the air kerma rate, enabling the optimization of the image quality in IR procedures. The decrease in the patient entrance surface air kerma rate may achieve 67%. They concluded that the optimization of fluoroscopic image quality achieved with a phantom allows reducing the patient entrance surface air kerma with no significant loss of diagnostic performance. Else investigator **Georges et al 2007** monitored the variations of radiation dosage delivered to patients undergoing interventional cardiological procedures. They evaluated DAP and Fluoroscopy time (FT) during CA and/or PTCA in 3600 consecutive patients from 2002 to 2005. Procedures were performed by five experienced physicians, using successively femoral and radial techniques. DAP and FT significantly correlated ($r = 0.73$; $p < 0.0001$). Median (25th-75th percentiles) values for DAP and for FT were 63 (40-101) Gy.cm²

and 6.3 (4-10) min for CA, 100 (62-178) Gy.cm² and 14.0 (9-22) min for elective PTCA, and 141 (90-219) Gy.cm² and 15.7 (11-23) min for CA immediately followed by ad hoc PTCA, respectively. They found there are differences between operators ranged from 50% (CA) to 70% (PTCA) for both DAP and FT ($p < 0.001$). They also observed that the moving from the femoral to the radial approach resulted in a 1.5 to 2-fold increase in DAP in 2002 ($p < 0.001$), and DAP and FT subsequently decreased toward the european DIMOND reference values (in 2005: 53.4 Gy.cm² and 5.5 min for CA, 104.64 Gy.cm² and 13.1 min for elective PTCA, 128.4 Gy.cm² and 13.6 min for PTCA). They concluded that the radiation exposure to patients and staff are strongly dependent on operators, time course, and the arterial access, the enhanced knowledge of radiation dose is the first step of a radiation dose-reduction program, and the definition of national reference values for DAP and fluoroscopy time would be helpful for appropriate comparisons. **Livingstone** et al (2007) they intended to audit and optimize radiation dose imparted to patients undergoing PTCA involving single or multiple stent placement guided under cardiovascular X-ray machine were included in their study by measuring DAP. A dose reduction of 27-47% was achieved using copper filters and optimal exposure parameters. They recorded the mean DAP values before optimization which are 66.16 and 122.68 Gy.cm² for single and multiple stent placement respectively and are 48.67 and 65.44 Gy cm² respectively after optimization. They saw that due to the increase in the number of PTCAs performed and the associated risk from radiation, periodical audit of radiation doses for interventional procedures are necessary, though the radiation dose imparted to patients does not present any alarming situation with regard to ill effects of radiation, it would be prudent to optimize radiation dose to patients undergoing PTCA and take efforts towards achieving reduction in radiation dose to the patients, since there is a frequent change in the various imaging modalities, reference dose levels should be audited on a time-to-time basis so as to keep the doses as low as reasonably practical, and enhanced knowledge of 'radiation dose'-reduction techniques significantly reduces patient radiation hazards in invasive cardiology. **Livingstone** et al 2007, they intended to audit and optimize radiation dose to patients undergoing CA by using spectral filters and by evaluating work practices of operators. The mean DAP values during CA before optimization was 55.86 Gy.cm² and after optimization was 27.71 Gy.cm². No ill-effects of radiation were reported in CA. Use of copper filtration may be recommended for procedures performed using cardiovascular machines. The optimization process of reducing radiation doses involved halving

the dose to 21.9 mGy/min⁻¹, 43.8 mGy/min⁻¹ and 87.5 mGy min⁻¹ for fluoro selection modes of low, normal and high respectively. This reduction was achieved by increasing the existing filtration of 0.1 mm Cu specified by the manufacturer to 0.4 mm Cu and by lowering the tube current and increasing the tube potentials. However, image quality was not adversely affected with the presence of additional copper filters and cardiologists did not find it difficult to perform the procedure. During the CA, operators selected the low fluoro mode, however for a caudal view, normal mode was selected. CA was performed under automatic brightness control in the tube potential and tube current was adjusted. The ages of patients ranged from 33 years to 78 years. The average height and weight of patients was 162.2 cm and 64.66 kg respectively. The number of frames acquired during cine runs ranged from 160 to 2378 and this depended upon the skill of the operator and the information needed to be elicited for the study. The fluoroscopy duration for a CA ranged from 0.4 min to 34.4 min. Reduction of radiation dose to patients and consequent minimization of overall radiation dose during CA in the current study was due to use of adequate copper filters with optimal exposure parameters. **Georges** et al 2007 they aimed to assess radiation exposure of patients in a large series of IC procedures. We evaluated DAP and FT during CA and/or PTCA in 3600 patients. DAP and FT significantly correlated ($r = 0.73$; $p < 0.0001$). Median values for DAP and for FT were 63 (40-101) Gy.cm² and 6.3 [4-10] min for CA, 100 [62-178] Gy.cm² and 14.0 [9-22] min for elective PTCA, and 141 [90-219] Gy.cm² and 15.7 [11-23] min for CA immediately followed by ad hoc PTCA, respectively. Differences between operators ranged from 50% (CA) to 70% (PTCA) for both DAP and FT ($p < 0.001$). Moving from the femoral to the radial approach resulted in a 1.5 to 2-fold increase in DAP ($p < 0.001$). DAP and FT then decreased toward the european DIMOND reference values (in 2005: 53.4 Gy.cm² and 5.5 min for CA, 104.64 Gy.cm² and 13.1 min for elective PTCA, 128.4 Gy.cm² and 13.6 min for ad hoc PTCA). They concluded that the radiation exposure to patients and staff are strongly dependent on operators, time course, and the arterial access, due in part to the learning curve for radial approach. The enhanced knowledge of radiation dose is the first step of a radiation dose-reduction program, likely to minimize patient and operator radiation hazards in interventional cardiology. **Chida** et al 2006 they aimed to make a correlation between the maximum radiation skin dose and FT for patients undergoing CI procedures to examine whether the correlations between MSD and body weight, FT, and DAP were useful for estimating MSD during CI procedures. 200 CI procedures (172 PCIs and 28 RFCA by using Care-graph with

skin-dose-mapping software. For the RFCA, we found a good correlation between the MSD and FT ($r = 0.801$, $p < 0.0001$), whereas we found a poor correlation between MSD and FT for the PCI ($r = 0.628$, $p < 0.0001$). There was a strong correlation between MSD and DAP in RFCA ($r=0.942$, $p < 0.0001$). There was also a significant correlation between MSD and DAP ($r=0.724$, $p<0.0001$) and weight-fluoroscopic time product (WFP) ($r=0.709$, $p <0.0001$) in PCI and Concluded that the correlation between the MSD with DAP is more striking than that with FT in both RFCA and PCI. **Dohatcu** et al (2006). Dose-related data was recorded for over 2000 cardiac catheterization and over 800 electrophysiology procedures. All procedures had a wide range of DAP values, ESD values and fluoroscopy times with distributions skewed toward the lower end. PCI procedures generally had the greatest ranges (216 to 88,971 cGy.cm² DAP, 2 to 726 cGy ESD, 1 to 96 minutes fluoroscopy) and the highest median values (16,000 cGy.cm², 130 cGy, 20 min). There was some correlation demonstrated between DAP values and fluoroscopy time and patient body mass index. ESD values calculated from DAP values had a large uncertainty primarily due to uncertainty in the exposure geometry. Although an inexact measure of skin exposure during interventional procedures, DAP values provide some guidance in identifying those patients with ESD values potentially above thresholds for deterministic effects. Tracking of this parameter can provide an indicator of when cautionary notes should be placed in the patient's chart for medical observation and follow-up. Also **Chu** et al (2006) performed a detailed monitoring on the skin entrance radiation exposure in lengthy interventional procedures. FT and DAP are readily available real-time measurements for each phase of the procedure or twenty cases, the means and standard deviations were 17.2 ± 6.4 min for x ray on-time, 256 ± 65 Gy cm⁻² for DAP, 94 ± 34 cGy for peak skin entrance dose in air kerma, and 19.2 ± 5.0 mSv for effective dose, respectively. The peak skin entrance dose was correlated to fluoroscopy duration, DAP, and effective dose with the r^2 -values of 0.48, 0.46, and 0.09, respectively. The correlation with DAP or fluoroscopy duration was not sufficiently strong to infer skin entrance dose from either of these parameters. Therefore, skin entrance dose should be determined directly.

Bacher 2005 Because of the higher radiosensitivity of infants and children compared with adults, there is a need to evaluate the doses delivered to pediatric patients who undergo interventional cardiac procedures. However, knowledge of the effective dose in pediatric interventional cardiology is very limited. Methods and Results-For an accurate risk estimation, a patient-specific Monte Carlo simulation of the effective dose was set up in 60 patients with

congenital heart disease who underwent DCA [n=28, DAP=548 (114–1461)] or PCI [n=32, DAP=472 (282–2044)] cardiac catheterization procedures. The dose-saving effect of using extra copper filtration in the x-ray beam was also investigated. For diagnostic cardiac catheterizations, a median effective dose of 4.6 mSv was found. Therapeutic procedures resulted in a higher median effective dose of 6.0 mSv because of the prolonged use of fluoroscopy. The overall effect of inserting extra copper filtration into the x-ray beam was a total effective dose reduction of 18% with no detrimental effect on image quality. An excellent correlation between the dose-area product and effective patient dose was found ($r=0.95$). Hence, dose-area product is suitable for online estimation of the effective dose with good accuracy. With all procedures included, the resulting median lifetime risk for stochastic effects was 0.08%. Because of the high radiation exposure, it is important to monitor patient dose by DAP instrumentation and to use additional beam filtration to keep the effective dose as low as possible in view of the sensitivity of the pediatric patients. They concluded skin doses are not problematic in pediatric interventional cardiology, but the calculated effective doses are as high as those for adult interventional cardiology, resulting in higher radiation risks. **Perisinakis** et al 2005. To establish radiation risks for patients undergoing fluoroscopically guided cardiac resynchronization device implantation. Cardiac resynchronization therapy (CRT) may be associated with extended fluoroscopic exposure. FT, DAP, exposure parameters, and percentage contribution of the fluoroscopic projections commonly used compared to corresponding data obtained from a control group of 20 patients who underwent a conventional rhythm device implantation operation. The DAP to peak skin dose, DAP to effective dose, and DAP to gonadal dose conversion factors were determined for biventricular pacing and conventional rhythm device implantation using a humanoid phantom and thermoluminescence dosimetry. The mean total fluoroscopy time and DAP values were 35.2 min and 4765 cGy.cm², respectively, for biventricular pacing and 8.2 min and 1106 cGy.cm², respectively, for conventional rhythm device implantation. Patient skin dose from biventricular pacing procedures requiring extended fluoroscopic exposure may exceed threshold dose for the induction of skin effects only if X-ray source-to-skin distance is kept low. The risk values for fatal cancer and severe hereditary disorders, respectively, associated with a typical CRT procedure were 273 per million and 0.2 per million treated patients. Radiation risks associated with fluoroscopically guided CRT procedures may be considerable. Present data may be used for the estimation of patient radiation risks from CRT procedures performed in other institutions.

Tsalafoutas et al 2005. They intended to determine the patient and cardiologist doses during the implementation of permanent cardiac pacemakers under fluoroscopic control. For 55 procedures concerning three different types of pacemakers (DDD, VDD, and VVI), the DAP meter readings and FT were recorded. The median values of DAP and FT for all the procedures monitored were 11.4 Gy.cm^2 and 6.6 minute, respectively. For the 22 DDD, 21 VDD, and 12 VVI pacemakers implanted, the respective DAP median values were 14.7, 9.9, and 7.3 Gy.cm^2 and the respective median FT were 8.4, 5, and 2.9 minutes. The median doses to the hands, chest, eyes, and legs of the cardiologist conducting the manipulations were estimated to 0.21, 0.06, 0.03, and 0.11 mGy, respectively, per procedure. Compared to the existing literature, the median DAP value of this study is almost identical to the 11.2 Gy.cm^2 reported from a sample of 627 patients in 17 different X-ray rooms, whereas the fluoroscopy times are within the range of values reported by other authors. Concerning the cardiologist exposure, the estimated values indicate that the implantation of pacemakers is a procedure that does not involve a severe risk, especially if it is taken into account that lead aprons and collars are routinely used. **Perslidenet** et al (2005). Interventional procedures in radiology are of concern because of irradiation doses to the patients and also to the staff. A total of 380 procedures were grouped into cranial, neck and thorax, intestine and abdominal, urogenital and pelvis and extremities. DAP and fluoroscopy times (mean values) were 200 Gy cm^2 for 57 min, 57 Gy cm^2 for 16 min, 270 Gy cm^2 for 35 min, 212 Gy cm^2 for 37 min, 67 Gy cm^2 for 21 min, respectively, for the named procedures. Maximum patient skin doses exceeded threshold values for erythema (2 Gy) in cranial, neck/thorax and intestine/abdominal procedures. Effective doses to the patients could be high, 200 mSv. It was found that patient doses could exceed threshold values for skin erythema (2 Gy) and temporary epilation (3 Gy). Hence, the procedures require immediate improvement.

E.Cotelo et al, 2004 reported patient doses in interventional cardiology in Uruguay to establishing guidance levels in significant differences between the two hospitals. They found CA mean total DAP ($\pm 1 \text{ SD}$) in PH is $(63.0 \pm 34.5) \text{ Gy.cm}^2$, and in UH is $(20.2 \pm 14.4) \text{ Gy.cm}^2$, PTCA total DAP ($\pm 1 \text{ SD}$) in PH is $(100.9 \pm 65.9) \text{ Gy.cm}^2$ and in UH is $(31.9 \pm 26.5) \text{ Gy.cm}^2$. No important clinical complexity differences were found. Differences in DAP values seem to be the result of some X-ray system characteristics combined with the way procedures are performed in both hospitals. The differences found in fluoroscopy times are also related to the way procedures are performed. This approach to the establishing of GL in IC furnishes a powerful tool in order to explore the possibilities of modifying or correcting those aspects of the practice conducive to patient dose reduction (optimization). **Geijer** et al 2002. They aimed to evaluate the

effects of the fluoroscopy dose rate in a clinical population undergoing PCI of the dose-reducing measures detailed previously. KAP values were first recorded for 154 patients undergoing PCI. Then, the fluoroscopy KAP rate was reduced from 44 to 16 mGy.cm²/s by increasing filtration and reducing H dose request. After this optimization, KAP was recorded for another 138 PCI procedures. After adjustment for differing proportions of combined procedures (CA+PCI), the total KAP was reduced to 67% of the original value with a 95% confidence interval from 57 to 78%, statistically significant. The mean total KAP values were 93.6 Gy.cm² before and 69.1 Gy.cm² after optimization. The KAP for digital acquisition did not change significantly. It is possible to make a large dose reduction in PCI by reducing the fluoroscopy dose rate, which is beneficial for both patients and staff. **E VANO** et al, 2001, studied Skin radiation injuries in patients following repeated coronary angioplasty procedures. The 14 patients were included in the study, each patient had undergone between 4 and 14 coronary angiographies and between 5 and 10 PTCAs, performed over a period of 2-10 years. He found the estimated mean DAP per procedure was 46 Gy.cm² for coronary angiography and 82 Gy cm² for PTCA. Mean values of maximum skin dose per procedure were 217 mGy for the diagnostic studies and 391 mGy for the PTCAs. Only a slight radiation skin injury was clinically demonstrated in one patient with a history of 10 coronary angiographies and 10 PTCAs (estimated MSD 9.5 Gy). Another patient who underwent 14 coronary angiographies and 10 PTCAs (estimated MSD 7.3 Gy) showed a slight telangiectasia and discrete pigmentation. Another patient with a cutaneous lupus erythematosus showed pigmentation in the area of the radiation field following 7 coronary angiographies and 6 PTCAs (estimated MSD 5.6 Gy), as expected bearing in mind that skin tolerance to high doses may be altered for patients with this pathology. Each of the remaining 11 patients with no skin injuries had undergone between 5 and 7 PTCAs and between 5 and 14 additional angiographies. None of the 14 patients reported acute skin injuries and no necrosis or radiodermatitis was observed. **PUTTE** et al 2000. Correlation of patient skin doses in cardiac interventional radiology with DAP. Skin dose measurements were made with TLDs placed at eight different locations on the body. Maximum skin dose values found were 412 mGy, 725 mGy, 760 mGy, and 1800 mGy for CC, CC/LV, and PTCA with and without stenting, respectively. Median DAPs for these same procedures were, respectively, 5682 cGy.cm², 10632 cGy.cm², 10880 cGy.cm², and 13161 cGy.cm². They found a poor correlation of DAP with maximum skin dose ($r=0.77$) and skin dose indicator ($r=0.78$). However, there were large

differences between the calculated skin doses using the individual DAP data per patient and measured skin doses of individual patients ($r=0.66$). Hence, calculation of individual skin doses based on the specific DAP data per patient is not reliable and therefore measuring skin doses is preferable. With the biplane system used in their study, the doses at the back and right side of the body (mean 50-80 mGy, median 30-45 mGy in CC) are much higher than the front or left (mean 2-20 mGy, median 2-6 mGy in CC). An explanation for this can be found in the position of the X-ray tubes that is under the patient-supporting tabletop for the frontal tube and at the patient's right side for the lateral tube. Outliers of the local high dose values (up to 400 mGy in CC) are located on the right side of the body under the right arm. This area of the patient skin is clearly critical as the X-ray tube can come very close to the patient's right side. **Cusma** et al 1999 they aimed to accurately assess the radiation exposure received by patients during cardiac catheterization (706 CA & 286 PCI). The median exposure for all was 41.8 mC/kg (162.1 R); the corresponding values for CA and PCI procedures were 34.9 and 95.6 mC/kg, respectively (135.3 vs. 370.5 R). There were significant differences in the FT between CA and PCI procedures: 4.7 min vs. 21.0 min. Heavier patients (<83 kg) received X-ray exposures at a significantly higher rate than did lighter patients (>83 kg) during both fluoroscopy and cine; 44.9 mC/kg/min (173.9 R/min) vs. 27.9 mC/kg/min (108.3 R/min) for cine exposure rate and 2.3 mC/kg/min (8.8 R/min) vs. 1.5 mC/kg/min (5.8 R/min) for fluoroscopy exposure rate. They concluded that the changes in practice have led to higher values for patient X-ray radiation exposures during cardiac catheterization procedures. The real-time display and recording of X-ray exposure facilitates the reduction of exposure in the catheterization laboratory. **EVANO** et al 1998. Dosimetric and radiation protection considerations based on some cases of patient skin injuries in interventional cardiology. Poor image quality could have influenced the length of the procedures. However, the focus-to-skin distance for horizontal X-ray beam was too short, resulting in a high skin dose rate. Additionally, X-ray beams are of fixed orientation, and accumulated skin dose in the patient's right side has been estimated as 11-15 Gy per procedure. They concluded that the practical radiation protection considerations to avoid further incidents of this sort are proposed, concerning X-ray system specially designed for interventional radiology, the improvement of cardiologists' training in radiation protection and routine patient dose measurements for complex interventional procedures (e.g. endocardiac radiofrequency catheter ablation). The measurement of patient dose was performed periodically. As consequence, the cardiologists were not aware of

the high dose levels associated with these procedures, nor could they take additional precautions prior to the realization of the high dose. Therefore, in these complex procedures, patient dose measurements must be performed or, at least, parameters which permit realistic retrospective estimate must be recorded. This kind of quality control should form a part of the routine protocol in these procedures. Fluoroscopy time is not sufficient parameter to estimate the patient skin dose. There are great numbers of factors which substantially modify the dose rate at patient entrance, and which should be recorded along with the duration of the fluoroscopy treatment. **Betsou** et al (1998) determined the dose received by patients during cardiac procedures; CA, PTCA, and stent implantation. Calibrated TLDs were used for the measurement of the dose received at four anatomical locations on the patient's skin, while a DAP meter also used. They found that the mean values of effective dose for CA 5.6 mSv, for PTCA 6.9 mSv, for CA and ad hoc PTCA 9.3 mSv, for PTCA followed by stent implantation and CA 9.0 mSv, and for ad hoc PTCA followed by stent implantation 13.0 mSv were estimated. Total DAP (30.4, 37.6, and 49.2 Gy.cm²) was higher than that of fluoroscopy. They had been concluded that the range of DAP values (and all dosimetric indicators) is quite large for procedures such as CA and/or PTCA and stent implantation. This is reasonable, as several projections may be used, each one more or less than the rest.

CHAPTER THREE

MATERIALS AND METHODS

Chapter Three

Materials and Methods

3. Materials and Methods

3.1 Study area and duration:

All cardiac catheterization procedures were performed in three cardiac catheterization centers; Wad Madani Heart Center (WMHC), Sudan Heart Center (SHC), and Al-Faisal Specialized Hospital (FSH), in Sudan. The data of patient demographic, technical parameters, and mean and range of patient's doses used in cath lab catheterization was collected during the period from September 2015 to October 2016. All machines had passed quality control tests performed by Sudan Atomic Energy Commission (SAEC).

In the present study, the patient dose measurements during cardiac catheterization were made by using some dosimetric quantities, namely: dose area product (DAP-Gy.cm²), total dose area product (DAP-Gy.cm²) or cumulative dose area product (CDAP-mGy.cm²), cumulative dose (CD-rad.cm²), entrance dose (ED-mGy), and cumulative air kerma (CAK-mGy), were measured during data collecting. The data collected also including patient's sex, age, height, weight, number of frames, number of films, and total fluoroscopic time (FT). Exposure factors as kVp and mA also collected as well as procedure type.

In Sudan Heart Center (SHC); a PHILIPS X-ray machine with model Integris V5000, a total filtration of the X-ray beam was 3.5 mm Cu was used, maximum kVp 125. Last image hold capability, automatic brightness control and during the procedure, tube potential setting is set manually, mAs being under automatic exposure control. The machines had already passed the routine quality control tests performed by Sudan Atomic Energy Commission. The second X-ray machine also is Philips but with model (Allura X per FD10) which installed in Wad Madani Heart Center (WMHC) and different year of production as well as maximum kVp 150 and the total filtration was 3.5 mm Al was used. The third one which was found in Al-Faisal Specialized Hospital (FSH) was GE 9800PLUS with model (GE 9800PLUS) which has maximum kVp 120 and the total filtration was 2.5 mm Al was used.

The image intensifier (II) has three fields of view of sizes 23, 18 and 12 inches. The system operates under (1, 2, 3.75, 15 and 30) pulses per second for fluoroscopy function and (15, 30, 60 and 90) frames per second in the cine function. Operators were found routinely using 15 pulses per second and 30 frames per second. Selected procedures the most common performed cardiac procedures in the hospitals were selected, namely coronary angiography (CA), coronary angiography + percutaneous intervention (CA+PCI), percutaneous intervention (PCI), and pacemaker (PM) for the examination of blood vessels or chambers of the heart, percutaneous transluminal angioplasty (PTCA); for treating the stenotic coronary arteries of the heart, Percutaneous Transvenous Mitral Commissurotomy (PTMC) which is carried out when a mitral valve becomes narrowed. The last procedure was the implantation of an artificial pacemaker by physicians to correct a slow heart.

3.2 Sample size:

A total of 346 cardiac catheterization procedures were performed in this study including [(187 diagnostic coronary angiographic (DCA) (54%), 118 percutaneous intervention (PCI) (34.1%), and 41 pacemaker (PM) (11.9%)]. Wad Madani Heart Center (WMHC): 188 patients; compromise 54.3% from the total number of patients, its distribution as: 97 DCA (51.6 %), 59 PCI (31.4%), and 32PM (17%), Sudan Heart Center (SHC): 110 patients; compromise 31.8% from the total number of patients, its distribution as: 63 DCA (57.3%), 42 PCI (38.2%), and 5 PM (4.5%), Al-Faisal Specialized Hospital (FSH): 48 patients; compromise 13.9% from the total number of patients, its distribution as: 27 DCA (56.3%), 17 PCI (35.4%), and 4P M (8.3%).

Table 3.1: Gender Clinical indications

| Clinical Indication | sex | | Total |
|---------------------|------|--------|-------|
| | Male | Female | |
| DCA | 102 | 85 | 187 |
| PCI | 84 | 34 | 118 |
| PM | 25 | 16 | 41 |
| Total | 211 | 135 | 346 |

Table 3.2 Clinical indications and Distribution of cases by hospitals

| Hospitals | Sudan Heart Center (SHC) | Al-Faisal Specialized Hospital (FSH) | Wad Madani Heart Center (WMHC) | Total |
|---------------------|--------------------------------|--|--------------------------------------|-------|
| Clinical indication | | | | |
| DCA | 63(33.7%) | 27(14.4%) | 97(51.9 %) | 187 |
| PCI | 42(35.6 %) | 17(14.4%) | 59 (50%) | 118 |
| PM | 5(12.2%) | 4(9.8%) | 32 (78%) | 41 |
| Total | 110 | 48 | 188 | 346 |

3.2 X-ray machines:

Philips (Allura XperFD10 - Netherland, installed 2011(WMHC), PHILIPS Integris V5000 (SHC), and GE 9800PLUS (FSH).

3.3 Patient data measurement:

Radiation doses received during a period of 13 months in a hospital in Khartoum, and Wad Madani, Sudan. A total number of 346 cardiology procedures were evaluated (187 diagnostic, 118 therapeutic, and 41 pacemakers). The patients were adults and pediatrics. The ethics, research committee approved the study, and a written consent was obtained from all patients prior to the procedure.

Table 3.3. X ray machines

| Hospital | X-ray machine(Model) | Filtration | kV max | mAs Max | Last image hold | Pulsed fluoroscopy | Date of installation |
|----------|---------------------------------|--------------|-----------|------------|-----------------------|-----------------------|-------------------------|
| SHC | PHILIPS Integris V5000 | 3.5 mm Cu | 125 | | YES | YES | 1998 |
| FSH | GE 9800PLUS | 2.5 mm Al | 120 | 8 | YES | YES | 2005 |
| WMHC | Philips (Allura X per FD 10) | 2.5 mm Al | 150 | 1250 | YES | YES | 2011 |

SHC: Sudan Heart Center

WMHC: Wad Madani Heart Center

FSH: Al-Faisal Specialized Hospital

3.4 Imaging protocol:

4.4.1 Procedure Issues

The physician must manage radiation in the cardiac catheterization laboratory from the outset to the completion of the procedure. This includes fluoroscopy and cine imaging. While radiation is never completely safe and should never be administered without indication/justification, procedures cannot be terminated solely on the basis of the radiation dose administered. When high dose radiation has been administered, the operator must balance risk with benefit when

deciding to proceed with additional vessel interventions or continuing to achieve a “better” angiographic result. During the case, the physician should consider the following variables:

1. Limit exposure duration with “beam-on time” occurring only when the physician is looking at the monitor.
2. Standard fluoroscopy dose mode should be chosen for each case, with the high dose mode (also known as high contrast mode, override mode, boost mode) limited as required.
3. Change the imaging beam angle, when the procedure is prolonged, so that the primary beam entrance site is altered and peak skin dose minimized.
4. Avoidance of steep angulations will decrease effective patient thickness, radiation dose rate, scatter radiation, and staff exposure.
5. Examination table height should be placed such that the primary operator is comfortable. Radiation safety devices can be moved to accommodate changes in table height.
6. X-ray source to skin distance is a concern when the patient is placed too close to the X-ray source (low table height or steep angulations) significantly increasing the patient’s skin dose.
7. Image receptor placement must be as close to the patient as possible to minimize input dose and significantly decrease scatter radiation.
8. Cine mode should be utilized only when required, realizing that the cine acquisition dose rate is significantly greater than fluoroscopy. Use lower framing rates and store X-ray fluoroscopy (for balloon inflation) when appropriate.
9. Cine frame rate should be utilized appropriately for needed temporal resolution understanding that increasing the frame rate increases dose.
10. Higher magnification (zoom) increases the image receptor’s dose requirements, potentially increasing patient dose, and should be utilized only when needed.
11. Utilize collimation to decrease scatter radiation. The use of additional copper filters will decrease primary beam exposure with some combination of reduced skin dose and improved iodine visualization.

12. Patient's non-target anatomy, such as extremities, must be kept out of the primary X-ray beam. Automatic dose rate controls are designed to increase X-ray tube output with increasing patient thickness; this may result in significant skin dose if extremities are in the field of view, similar to steep angulations or morbidly obese patients.

13. Operator appendages (hands) must be kept out of the field of view.

14. Protective shields should be utilized to the fullest extent possible.

15. Communication between staff and operator, noting monitor displays, in high dose cases is essential. The staff should notify the physician operator during the procedure when $K_{a,r}$ is in excess of 3 Gy and then every 1 Gy thereafter.

A radiation safety program for the catheterization laboratory should be a collaborative effort involving physicians, staff, medical or health physicists, quality assurance personnel, and hospital administration. Establishing safe radiation practice improves patient, staff and physician safety. The interventional cardiologist, as the person responsible for all aspects of patient care in the catheterization laboratory, must be actively involved in managing radiation dose to maximize patient safety. SCAI presents this review as a practical best practice approach to radiation dose management in the setting of a comprehensive radiation safety program within the cardiac catheterization laboratory.

3.5 Statistical analysis

All patient demographic data and dose parameters were analysed using Excel 2013. The necessary statistical measures were applied to assess the results.

CHAPTER FOUR

RESULTS

Chapter Four

Results

4.1 Results

Cardiac catheterizations have contributed greatly to the treatment of heart diseases. However, the radiation exposure to the patient is significantly higher compared with other radiological examination. Dose monitoring during catheterization procedures and re-evaluation of equipment and techniques used, if necessary, are mandatory to keep patients radiation risk as low as reasonable achievable. Patient dose measurement from cardiac catheterization procedures has been used frequently for the evaluation of patient risk from radiation exposure. Cardiac catheterization has become an essential technique to the practice of cardiology as a part of this technique is fluoroscopy. Although the benefits provided by the fluoroscopy but there is a risk for the patient and staff from exposure of the radiation come from it. There is a several studies have been done but more studies will help to protect the patient and staff from relatively high potential radiation hazard, as previously mentioned, the aim of this study was to estimate the risk for patients and to provide patients dose measurement during cardiac catheterizations.

A total of 346 procedures were monitored over three years. Procedures were performed on 211 (61%) male patients and 135 (39%) female patients. Table 4.1 presents the mean and range of demographic data for adult patients undergoing diagnostic coronary angiography (DCA) procedures, which show that 41.7% of the procedures were performed in Sudan Heart Center (SHC), and within high range of BMI. Table 4.2 presents the mean and range of demographic data for adult patients undergoing pacemaker (PM) procedures, which show that the most of the procedures were performed in Wad Madani Heart Center (WMHC) which constitutes a proportion 73.3%, and within normal range of BMI. Table 4.3 presents the mean and range of demographic data for adult patients undergoing percutaneous intervention (PCI) procedures, which show that 58.2% of the procedures were performed in Sudan Heart Center (SHC) which within high range of BMI, but Madani Heart Center (WMHC) within normal range of BMI. Body mass index had the most significant association with the radiation dose during the procedure. Despite having similar procedure times and contrast doses, patients with increased BMI received much higher radiation dose during CAG. Table 4.4 illustrates the mean and range

of technique parameters for adult patients undergoing diagnostic coronary angiography (DCA) procedure, which show that the high (kVp and fluoroscopic time) were found in Al-Faisal Specialized Hospital (FSH), while that the high (mA, and No. of frames) were found in both [(Wad Madani Heart Center (WMHC) & Sudan Heart Center (SHC)]. Table 4.5 illustrates the mean and range of technique parameters for pediatric patients undergoing diagnostic coronary angiography (DCA) procedure, which show that the high (kVp, mA and No. of films) were found in Wad Madani Heart Center (WMHC), while that the high fluoroscopic time was found in Sudan Heart Center (SHC). Tables 4.6 illustrates the mean and range of technique parameters for adult patients undergoing pacemaker (PM) procedures, which show that the high (kVp, No. of frames, and fluoroscopic time) were found in Al-Faisal Specialized Hospital (FSH), while that the high mA was found in Wad Madani Heart Center (WMHC). Tables.4.7 illustrates the mean and range of technique parameters for pediatric patients undergoing pacemaker (PM) procedures, which show that the high (kVp & fluoroscopic time) were found in Sudan Heart Center (SHC), while that the high (mA & No. of frames) were found in Wad Madani Heart Center (WMHC). Table 4.8 presents the mean and range of technique parameters for adult patients undergoing percutaneous intervention (PCI) procedures, which show that the high (kVp, No. of films, and fluoroscopic time) were found in Al-Faisal Specialized Hospital (FSH), while that the high (mA & No. of frames) were found in Wad Madani Heart Center (WMHC). Table 4.9 presents the mean and range of technique parameters for pediatric patients undergoing percutaneous intervention (PCI) procedures, which show that the high (kVp, No. of films, and fluoroscopic time) were found in Sudan Heart Center (SHC), while that the high mA were found in Wad Madani Heart Center (WMHC). Table 4.10 illustrates the mean and range patient dose for procedures as cumulative dose (CD rad.cm²) which performed at Al-Faisal hospital, and show that the doses are considered in normal range between the hospitals. Table 4.11 illustrates the mean and range adult patient dose as (ED mGy and CDAP cGy.cm²) for procedures which performed at Sudan Heart Center (SHC), and show that the doses are considered in normal range between the hospitals also. Table 4.12 illustrates the mean and range pediatric patient dose as (ED mGy and CDAP cGy.cm²) for procedures which performed at Sudan Heart Center (SHC), and show that the doses are considered the lowest range between the hospitals. Table 4.13 illustrates the mean and range adult patient dose as (CAK mGy & CDAP mGy.cm²) for procedures which performed at Wad Madani Heart Center (WMHC), and show that the doses are

considered the highest range between the hospitals in PCI and DCA procedures. Table 4.14 illustrates the mean and range pediatric patient dose as (CAK mGy & CDAP mGy.cm²) for PCI and DCA procedures which performed at Wad Madani Heart Center (WMHC), and show that the doses also considered the highest range between the hospitals.

Table 4.1 illustrates the mean and range of demographic data for adult patients undergoing diagnostic coronary angiography (DCA) procedures

| Hospital | No. of Patients | Age (Yrs.) | Height (cm) | Weight(kg) | BMI(kg/m ²) |
|----------|-----------------|------------|-----------------|--------------|-------------------------|
| FSH | 27 | 59 (31-80) | NA | NA | NA |
| SHC | 53 | 55 (22-75) | 168 (146-177) | 78 (62-128) | 27.8 (20.3-41.8) |
| WMHC | 47 | 57 (30-80) | 165.5 (150-183) | 64.9 (50-92) | 23.7 (19-31.2) |

Table 4.2 illustrates the mean and range of demographic data for adult patients undergoing pacemaker (PM) procedures

| Hospital | No. of Patients | Age (Yrs.) | Height(cm) | Weight(kg) | BMI(kg/m ²) |
|----------|-----------------|--------------|-----------------|--------------|-------------------------|
| FSH | 04 | 59 (31-80) | NA | NA | NA |
| SHC | 04 | 73 (60-80) | 162 +(158-168) | 58 (55-65) | 22 (21.5-23) |
| WMHC | 22 | 66.6 (39-85) | 164.8 (150-175) | 61.7 (50-70) | 22.7 (20.2-28.9) |

Table 4.3 illustrates the mean and range of demographic data for adult patients undergoing percutaneous intervention (PCI) procedures

| Hospital | No. of Patients | Age (Yrs.) | Height (cm) | Weight(kg) | BMI(kg/m ²) |
|----------|-----------------|--------------|-----------------|---------------|-------------------------|
| FSH | 17 | 60 (37-76) | Not available | Not available | Not available |
| SHC | 39 | 56 (21-75) | 167 (1150-179) | 78.5 (46-139) | 27.6 (20.4-45.4) |
| WMHC | 11 | 65.4 (50-77) | 165.5 (150-175) | 64.6 (50-75) | 23.7 (19.8-29.7) |

Table 4.4 illustrates the mean and range of technique parameters for adult patients undergoing diagnostic coronary angiography (DCA) procedure.

| Hospital | kVp | mA | No of Films | Fluoro Time(s) | No of Frames |
|----------|-------------------|---------------------|-------------|--------------------|-----------------|
| FSH | 108 (69-120) | 96 (61.6-136.7) | 10 (1-30) | 646 s(94.3-3421.7) | 386 (44-775) |
| SHC | 86.4 (71-110.3) | 382.2 (167.9-565) | 8 (2-13) | 3.47min(0.4-21.7) | 501 (73-1053) |
| WMHC | 81.7 (68.75-94.9) | 750.8 (528.5-858.3) | 10.2 (3-33) | 5.1 min(0.57-3) | 621.4 (64-1764) |

Table 4.5 illustrates the mean and range of technique parameters for pediatric patients undergoing diagnostic coronary angiography (DCA) procedure.

| Hospital | kVp | mA | No of Films | Fluoro Time(min) | No of Frames |
|----------|---------------|-------------------|-------------|------------------|----------------|
| SHC | 70.9(64-75.6) | 166.6 (160-197.5) | 5.8 (2-11) | 20.4 (4.1-54.8) | 269.3 (67-486) |
| WMHC | 74.9 (62-125) | 668.7 (343-898) | 12.3(3-21) | 5.4 (1.4-23.6) | Not available |

Tables.4.6 illustrates the mean and range of technique parameters for adult patients undergoing pacemaker (PM) procedures.

| Hospital | kVp | mA | No of Films | Fluoro Time | No. of Frames |
|----------|------------------|-------------------|-------------|--|---------------|
| FSH | 81.4 (69-116.5) | 74 (61.6-102.6) | 3 (1-5) | 1257.2s (34.1-2714.4) 20.95min | 194 (24-345) |
| SHC | 75.4 (74.3-76.1) | 188.6 (160-217) | 1.25 (1-2) | 10.6 min(5.7-18.4) | 77 (5-259) |
| WMHC | 70.8 (67-76) | 598.3 (218.8-860) | 3.2 (1-20) | 4.52 min(0.2-15.06) | 70.2 (5-509) |

Tables.4.7 illustrates the mean and range of technique parameters for pediatric patients undergoing pacemaker (PM) procedures.

| Hospital | kVp | mA | No of Films | Fluoro Time | No. of Frames |
|----------|--------------|-----------------|-------------|-------------------|---------------|
| SHC | 70.5 | 160 | 3 | 5.8 min | 16 |
| WMHC | 69.8 (65-75) | 612.3 (462-687) | 3 (1-6) | 3.85 min(2.5-8.1) | 70.2 (5-509) |

Table 4.8 illustrates the mean and range of technique parameters for adult patients undergoing percutaneous intervention (PCI) procedures.

| Hospital | kVp | mA | No of Films | Fluoro Time | No of Frames |
|----------|--------------------|---------------------|-------------|--------------------------------------|------------------|
| FSH | 116 (110-120) | 120 (83-318) | 16 (1-35) | 1243.5 (101-3331.8) 20.73 min | 738.1 (110-1838) |
| SHC | 85.7 (70.47-105.8) | 350 (160-554.3) | 7.8 (4-22) | 4.48 (0.9-22.4) | 525.5 (257-1234) |
| WMHC | 80.9 (67-106.5) | 730.9 (448.6-851.7) | 15.8 (1-47) | 7.47 (1.25-20.13) | 771 (26-2434) |

Table 4.9 illustrates the mean and range of technique parameters for pediatric patients undergoing percutaneous intervention (PCI) procedures.

| Hospital | kVp | mA | No of Films | Fluoro Time | No of Frames |
|----------|------------------|-----------------|-------------|------------------|----------------|
| SHC | 74.3 (70.5-74.4) | 173.2 (160-184) | 5.3(3-7) | 11.3 (7.2-13.6) | 346.3(227-421) |
| WMHC | 63.2 (53-70) | 340.9 (134-845) | 3.8 (1-6) | 5.4 (1.75-21.65) | Not available |

Table 4.10 illustrates the mean and range adult patient dose as (CD rad.cm²) for procedures which performed at Al-Faisal specialized hospital (FSH)

| Procedure | CD rad.cm ² |
|-----------|---|
| DCA | 3261 (730-14700) = 32.61 Gy.cm ² |
| PM | 3154.2 (716.4-7536.2) = 31.54 Gy.cm ² |
| PCI | 6173.6 (734.8-14248.9) = 61.74 Gy.cm ² |

Table 4.11 illustrates the mean and range adult patient dose as (ED mGy and CDAP cGy.cm²) for procedures which performed at Sudan Heart Center (SHC)

| Procedure | ED mGy | CDAP cGy.cm ² |
|-----------|----------------------|---|
| DCA | 994.1(59.3-20296.6) | 3299.5 (139.9-10548.7) = 32.99 Gy.cm ² |
| PM | 109.3 (32.66-213.3) | 3213.1 (1592-4738) = 32.13 Gy.cm ² |
| PCI | 413.4 (20.69-3369.8) | 4397.9 (606.9-32927.6) = 43.98 Gy.cm ² |

Table 4.12 illustrates the mean and range pediatric patient dose as (ED mGy and CDAP cGy.cm²) for procedures which performed at Sudan Heart Center (SHC)

| Procedure | ED mGy | CDAP cGy.cm ² |
|-----------|----------------------|--|
| DCA | 116.17(12.83-806.26) | 417.37(67.13-780.8) = 4.17Gy.cm ² |
| PM | 104.98 | 12.25 = 0.123 Gy.cm ² |
| PCI | 34.08 (32.8-35.9) | 465.61(380.65-501.13) = 4.66Gy.cm ² |

Table 4.13 illustrates the mean and range adult patient dose as (CAK mGy & CDAP mGy.cm²) for procedures which performed at Wad Madani Heart Center (WMHC)

| Procedure | CAK (mGy) | CDAP(mGy.cm ² |
|-----------|------------------------|--|
| DCA | 694.6 (73.05-2653.54) | 49449(6615-140910) = 49.45 Gy.cm ² |
| PM | 210.9 (24.07-942.81) | 22382.3 (2857-105079) = 22.38 Gy.cm ² |
| PCI | 1149.4 (117.45-4222.6) | 67383.3 (13498-221490) = 67.38Gy.cm ² |

Table 4.14 illustrates the mean and range pediatric patient dose as (CAK mGy & CDAP mGy.cm²) for procedures which performed at Wad Madani Heart Center (WMHC).

| Procedure | CAK (mGy) | CDAP(mGy.cm ²) |
|-----------|----------------------|---|
| PCI | 262.75 (2.98-8838.3) | 6588.32 (23.78-80800) = 6.59 Gy.cm ² |

CHAPTER FIVE

DISCUSSION, CONCLUSION & RECOMMENDATIONS

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5.1 Discussion

The use of radiation in medicine may be one of the most difficult areas for ensuring a balance between risks and benefits. Medical professionals are responsible for evaluating the risks and benefits to determine if an X-ray procedure is warranted. Some of contributing factors in the observed variations of patients' exposure can be attributed to the use of suboptimal imaging equipment, and poor choice of technical factors due to the lack of experience. The results of this dose survey provide valuable data for awareness from situation of patient dose in Wad Madani Heart Center (WMHC), Sudan Heart Center (SHC), and Al-Faisal Specialized hospital (FSH) in Khartoum; it is the first step in reduction of patient dose program. Although many patients derive great diagnostic and therapeutic benefits from intervention catheterization (IC) procedures, the use of ionizing X-ray constitutes an associated hazard which must be justified by the procedure's benefits. Cardiac catheterizations are the highest patient radiation dose among the radiological X-ray procedures. Some of the factors that affect the patient's radiation dose depend on the X-ray system, but many others depend on how the operator uses the x-ray system. During the procedure, the cardiologist should be kept aware of the fluoroscopy time, the number of cine series and cine frames, and the total patient dose. As patient radiation dose increases, the operator should consider the radiation dose already delivered to the patient and the additional radiation necessary to complete the procedure. [ICRP ref 4818-2733-7736 2 May 20, 2011] Body mass index had the most significant association with the radiation dose during the procedure. Despite having similar procedure times and contrast doses, patients with increased BMI received much higher radiation dose during CAG. Obese patients require more than double the radiation dose in comparison to those with normal BMI.

The results obtained were compatible with studies conducted by Sulieman A.A. 47.1Gy.cm² (2011), Sanchez 51.3Gy.cm² (2011), Olivera 50Gy.cm² (2010), and Bor 49.1Gy.cm² (2009). Also were lower than some studies conducted by Harbron 139Gy.cm² (2016), Aly 72.14Gy.cm² (2015), Lefterova 172Gy.cm² (2014& 2010), Eitidal 167Gy.cm² (2013), Journy 65Gy.cm² (2012), Ying and Kandaiya 344.4Gy.cm² (2010), Neil 300Gy.cm² (2010), Domienik 317Gy.cm² (2008), and Georges 63Gy.cm² (2007). Whereas they were higher than some studies

conducted by Varghese 37.6Gy.cm² (2016), Abdelaal 30±14Gy.cm² (2014), Taghi 20.96Gy.cm² (2013), Ahmed NA 20Gy.cm² (2012), Brnić 32Gy.cm² (2010), Dragusin 11.6Gy.cm² (2010), and Morrish 39.3Gy.cm² (2008); all these in diagnostic coronary angiography (DCA) for adult patients.

On the other hand the results of the PCI examinations were found to be compatible with studies conducted by Taghi 70.9 Gy.cm² (2013), Journy 69 Gy.cm² (2012), Brnić 72Gy.cm² (2010), Bor 66.8Gy.cm² (2009), and Livingstone 66.16Gy.cm² (2007). Since it is lower than some studies conducted by Aly 143Gy.cm² (2015), Lefterova 326Gy.cm² (2014), Sanchez 82.2Gy.cm² (2011), Olivera 113Gy.cm² (2010), and Georges 178Gy.cm² (2007). Whereas these results were higher than some studies conducted by Heilmaier 37Gy.cm² (2016), Shah 4.818Gy.cm² (2014), Ahmed NA 56.537Gy.cm² (2012), Bernier 48.4Gy.cm² (2012), and Dragusin 32.7Gy.cm² (2010).

But regarding the pacemaker examinations, the results were found to be higher than the studies conducted by Ahmed NA 15.3Gy.cm² (2012), Tsalafoutas et al 14.7Gy.cm² (2005), whereas they were lower than studies conducted by Abdoelrahman 35.12Gy.cm² (2015), and Eitidal 56Gy.cm² (2013).

Scatter radiation levels in the vicinity of the patient may be quite high under normal working conditions of protection tools and good operational measures are not used, and if several complex procedures are undertaken per day, radiation lesions of the eyes may result after several years of work, particularly when the equipment used is not designed for interventional practices. [Vano 2003]

Considerable variations were observed among patient populations in terms of radiation dose, and fluoroscopic time. These variations are due to the different indications, patient characteristics and pathological findings. Also, a remarkable difference between the therapeutic and the diagnostic doses was observed. [Jobbágy; 2012] This can be attributed to the prolonged exposure times in therapeutic procedures. In order to optimize the procedures in this catheterization laboratory it is important to understand the relation between the different factors and dose indicators in each case, and which factors have significant influence on patient dose. Potential optimization of the practice in these cases may be achieved by reducing the irradiation area to the clinical interest only. Procedures could be performed in shorter time but with an increased number of frames and

vice versa. It is suggested that the difference in the number of cineangiographic frames used is the explanation for that [Betsou et al 1998] have shown that radiation dose from cineangiographic mode frames contribute 60 % of the total dose in diagnostic procedures.

A successful radiological protection program should protect the staff and patient from avoidable radiation risks and reduce the probability of unavoidable risks. Therefore, the use of protective devices has been shown to be effective (Chambers et al., 2011; Ciraj-Bjelac et al., 2010). Miller et al 2010 and Shortt et al recommended the use of transparent ceiling-mounted shielding and below-table-mounted shielding should be used routinely (Miller et al., 2010; Shortt et al 2007). In addition to that, King et al., 2002, reported that the use of disposable radiation-absorbing patient sterile drapes may also help to reduce staff dose

As can be seen there was no correlation for CA and PCI, but good correlation for PCI and pacemaker, which means that BMI is not an indicator for dose in CA and PCI procedures. It is possible that differences in diseased vessels' location and type and complexity of disease from patient to patient have more influence on (KAP & DAP) than BMI. However, overweight will most likely lead to a higher dose when a complex procedure is performed. The increase of KAP with BMI in pacemaker and PCI might be attributed to the absence of oblique projections in the pacemaker and the use of mainly the right anterior oblique projection in PCI, as changing in beam angulations will considerably change exposure factors owing to the increased or decreased volume exposed.

In literature, many techniques were suggested to reduce the patient exposure in cardiac catheterization procedures. These factors are

1. Staff location within the room (distance from the radiation source)
2. Exposure time
3. Shielding : the use of radiation barriers and lead aprons and other protective devices
4. Fluoroscopy mode, intensity is lower by a factor of few tens as compared to the radiography or cine mode;

5. exposure parameters - typically they are automatically controlled by equipment and are higher for patients with high body mass;
6. Cardiologists may work in the catheterization laboratory only few days a week (against five or six days a week for the staff at the console).

Considering all these factors, the exposure to interventionalists can be many times higher than a staff who works only at the console located just outside the X ray room.

5.2 Conclusion

To sum up, our result has shown that the dose values were found to be comparable with a recent literature published worldwide. Patient dose reduction is very important in view of radiation protection as well as radiation safety. Furthermore, the practitioners should optimize the radiation dose for further dose reduction without compromising the diagnostic and therapeutic findings. The monitoring of radiation workers is not established properly. Obviously, the high radiation dose received by the patient and staff is due to the lack of experience and protective tools. Interventional procedures remain operator dependent; therefore, continuous training is crucial.

Considerable variations were observed among patient populations in terms of radiation dose, and fluoroscopic time. These variations are due to the different indications, patient characteristics and pathological findings. Also, a remarkable difference between the therapeutic and the diagnostic doses was observed. This can be attributed to the prolonged exposure times in therapeutic procedures. Additional studies need to be conducted in order to establish reference dose levels for patients, for each clinical indication individually, and effective dose estimation for staff.

Additional studies need to be conducted in order to establish reference dose levels for patients, each clinical indication individually, and effective dose estimation for staff.

5.3 Recommendations

The followings measures are important in patient and staff dose reduction:

- ❖ The operator should be aware of the increased dose of radiation required when performing CAG in patients with a high BMI, and especially in LAO cranial and caudal views.
- ❖ Avoiding prolonged fluoroscopic procedures, and multiple radiation exposure.
- ❖ Avoiding repetitions of PCI as much as possible.
- ❖ Pacemaker procedures or any interventional procedure should be done only by interventionalist.
- ❖ Therefore, cardiologists may exceed the threshold for lens opacities if protective tools are not used.
- ❖ Minimize the use of fluoroscopy and use low fluoroscopy modes (for example, pulsed fluoroscopy) when possible.
- ❖ A radiation dose monitoring for patients received a dose above 1.0 Gy was expected for erythema detection.
- ❖ Establish a well defined radiation protection program including a monitoring plan for workers and work places.
- ❖ Organize regular training activities to improve the performance which will contribute in exposure time reduction, optimize patient doses and consequently staff exposure.
- ❖ using radiation protection principles and tools it is possible for staff in most situations to carry out the full work load typical in a busy facility still keeping the annual radiation dose in the normal range.

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APPENDICES

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

Sudan Atomic Energy Commission
Radiation Safety Institute



هيئة الطاقة الذرية السودانية
معهد السلامة الإشعاعية

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التاريخ : 16/2/2017

السيد/ مدير مستشفى مدنى للقلب

السلام عليكم و رحمة الله و بركاته

الموضوع / اجهزه الاشعه السينيه بالمستشفى

في إطار خطة هيئة الطاقة الذرية السودانية للوقاية من الإشعاع ، قام فريق من معهد السلامة الإشعاعية بالهيئة بزيارة إلى المركز وذلك بتاريخ 14/2/2017 بغرض الكشف عن جودة اجهزة الأشعة السينيه التقليديه والمتفلوره بالمستشفى وذلك لحماية العاملين و المرضى و الجمهور من مخاطر الأشعة المؤينة .

١- جهاز الاشعة المتفلوره (PHILIPS C-arm) :-

Tube SN: 98685M119441

بحاله جيده.

٢- جهاز الاشعه السينيه التقليديه الثابت (TOSHIBA):-

Tube SN: 09C192

بحاله جيده.

3 - جهاز الاشعه السينيه التقليديه المتحرك (TOSHIBA):-

Tube SN: 99B0962614

بحاله جيده.

٤-مواصفات الغرف من الاشعاع:-

مقبولة

اجراءات الوقاية بالنسبه للعاملين والمرضى

المعدات المستخدمة لوقاية العاملين متوفره ولكن نلفت عنايتكم ان التصوير بالاشعة التداخلية قد يعرض المرضى والعاملين لجرعات عاليه اذا لم يتم اتباع الاجراءات الوقائيه بصوره جيده ،لذلك ينصح بالاتي:-

- الاهتمام بارتداء الواقي الرصاصي وتعليقه عند عدم استخدامه(لايطوي لسهولة تكسر الرصاص وبالتالي لا يكون فاعلا)
- ارتداء مقاييس للجرعة الفردية علي ان يرتدي الطبيب مقياسيين واحد تحت الواقي الرصاصي والاخر فوق الواقي عند مستوي الصدر
- الوقوف علي اتجاه مقوي الصورة في حالة الوضع الجانبي للجهاز وليس علي اتجاه انبوب الأشعه وذلك نسبة لان الجرعه الاشعاعية في حاله الثانيه تكون اكبر بكثير من الوقوف علي اتجاه مقوي الصورة .
- تركيب ستاره من الرصاص علي الطاولة الي اسفل لتقليل الأشعه المنتشته من اسفل.

- عند استخدام ال (cine mode) يجب الوقوف ابعد مايمكن عن المريض يفضل عند غرفه المراقبه او خلف حاجز متحرك من الرصاص.

كما و ينصح بالاستخدام المرشد للاشعه واختيار النمط الاقل (Fluoroscopy and/Cine mode) مع المحافظة علي جودة الصورة واخذ اقل عدد ممكن من الصور.

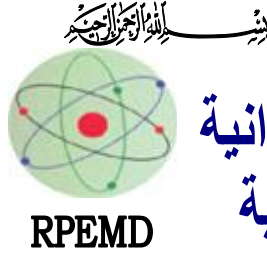
والله الموفق،،،،،

أ. إيناس حامد عثمان

رئيس قسم ضبط الجودة لاجهزة الأشعة التشخيصيه

- صورة إلى :

- ملف القسم



التاريخ ٢٠١٧/٠٤/١٢

السيد/مدير مركز السودان للقلب

السلام عليكم ورحمة الله وبركاته

الموضوع/ نتائج ضبط جودة جهاز الأشعة المتفلورة بالمركز

في إطار خطة قسم الوقاية من الإشعاع بهيئة الطاقة الذرية السودانية و بالتعاون مع وزارة الصحة ولاية الخرطوم قام فريق من قسم الوقاية بالهيئة بزيارة إلى قسم الأشعة بمركز السودان للقلب وذلك بتاريخ ٢٠١٧/٠٤/١٠ بغرض ضبط جودة جهاز الأشعة المتفلورة (C-arm PHILIPS) وذلك حماية للعاملين ، للمرضي و للجمهور من مخاطر الإشعاع وقد كانت النتائج كالآتي:

١. إجراءات الوقاية بالنسبة للعاملين

- يتم اتباع إجراءات الوقاية من الاشعاع بصورة جيدة فيما يخص:-

ارتداء الواقي الرصاصي

- ينصح بالآتي:-

- ارتداء مقاييس للجرعة الفردية علي ان يرتدي الطبيب مقياسيين واحد تحت الواقي الرصاصي والاخر فوق الواقي عند مستوي الصدر

- الوقوف علي اتجاه مقوي الصورة في حالة الوضع الجانبي للجهاز وليس علي اتجاه انبوب الأشعه وذلك نسبه لان الجرعه الاشعاعية في حاله الثانيه تكون اكبر بكثير من الوقوف علي اتجاه مقوي الصورة .
- تركيب ستاره من الرصاص علي الطاولة الي اسفل لتقليل الأشعه المتشتته من اسفل.
- تركيب لوحه من الزجاج المرصص لتكون بين الطبيب والمريض (ceiling suspended lead glass).
- عند استخدام ال (cine mode) يجب الوقوف ابعد مايمكن عن المريض يفضل عند غرفه المراقبه او خلف حاجز متحرك من الرصاص.

اجتاز جميع الاختبارات.

أ. إيناس حامد عثمان

- صورة إلى :

-ملف ضبط الجودة

هيئة الطاقة الذرية السودانية معهد السلامة الإشعاعية

التاريخ: ٢٠١٧/٠٤/١٢

تقرير عن ضبط الجودة لجهاز الأشعة السينية المتفلوره (PHILIPS) بمركز السودان
للقاب

قام الفريق المكون من:

٢- عبدالرحمن ابراهيم نايل

١- علي محمد عبد الرازق

بزيارة الى المستشفى في يوم ٢٠١٧/٠٤/١٠ بغرض ضبط جودة جهاز الأشعة وقد كانت نتائج الاختبارات التي اجريت كالآتي :

| | | |
|---|--|-------|
| ١ | KVp Accuracy: | مقبول |
| 2 | HVL | مقبول |
| 3 | Dose rate at the entrance of the patient under AEC | مقبول |
| 4 | Automatic exposure control AEC | مقبول |
| 5 | Field limitation | مقبول |

| | | |
|----|---|----------------|
| 6 | Source to skin distant | مقبول |
| 7 | Threshold contrast detail detectability | مقبول |
| 8 | Resolution | مقبول |
| 9 | II input dose rate | لم يتم اجراءه* |
| ١٠ | protection | مقبول |

*تعذر اجراء الاختبار لعدم معرفه معامل الامتصاص لشبكه التبعثر للاشعة.

عبدالرحمن ابراهيم

علي محمد عبد الرازق