RADIATION EXPOSURE TO PATIENTS AND CARDIOLOGISTS IN INTERVENTIONAL CARDIOLOGY PROCEDURES

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List of Abbreviations

ACC	American College of Cardiology
CA	Coronary Angiography
CA+PTCA	Coronary Angiography and Percutaneous Transluminal Coronary Angioplasty
DAP	Dose Area Product
FDA	Food and Drug Administration
GMC	Gleneagles Medical Centre
IAEA	International Atomic Energy Agency
IC	Interventional Cardiology
IR	Interventional Raiology
ICRP	International commission on radiology
ICRU	International Commission on Radiation Units and Measurement
ISP	International Specialty Products
OD	Optical Density
PTCA	Percutaneous Transluminal Coronary Angioplasty
MESD	Maximum Entrance Skin Dose
TLD	Themoluminescent dosimeters
WHO	World Health Organization

DEDAHAN RADIASI KEPADA PESAKIT DAN KARDIOLOGIS DALAM PROSEDUR INTERVENSI KARDIOLOGI

ABSTRAK

Prosedur intervensi kardiologi diketahui memberi radiasi dos yang tinggi kepada pesakit dan kardiologis kerana memerlukan masa fluroskopi yang panjang. Tujuan Kajian ini adalah untuk menentukan radiasi dos yang diterima oleh pesakit dan kardiologis semasa menjalankan prosedur intervensi kardiologi, seperti koronari angiografi (CA), koronari angioplasti (PTCA) dan CA+PTCA.

Pengukuran radiasi dos pesakit dan kardiologis telah dijalankan di bahagian kardilogi, Pusat Perubatan Gleneagles (GMC, Pulau Pinang, Malaysia) dengan menggunakan Filem Kodak EDR2 dan filem Gafchromic XR-RV2. Pergantungan pada tanaga, pergantungan pada dos, kadar dos dan lengkungan kalibrasi dos bagi kedua-dua filem juga telah diuji.

Semasa mengukur dos kulit maxima pesakit (MESD), filem Kodak EDR2 dan filem Gafchromic XR-RV2 diletakkan di atas meja dan di bawah badan pesakit dengan kedudukan X-ray tiub yang terletak di bawah meja. Nilai dos 35.38 – 2442.7 mGy untuk MESD dan 10.9 – 344.4 Gy cm^2 untuk pendaraban dos dengan luas (DAP) telah didapati. Korelasi yang baik telah didapati (R2 = 0.8212) dan (R2 = 0.7344) diantara MESD dan DAP dalam prosedur CA dan CA+PTCA masing-masing, tetapi DAP didapati kurang baik untuk menjadikan penunjuk MESD pada prosedur PTCA. Nilai dos kulit maxima pesakit di dalam peyelidikan ini 2443 mGy adalah di bawah nilai permulaan dos 3000 mGy untuk kecederaan kulit yang dicadangkan oleh Pentadbiran Makanan dan Ubat-ubatan (Amerika Syarikat).

Dos efektif untuk kardiologis telah diukur dengan menggunakan dosimeter pendar kilau haba (TLD) yang terletak di pemegang TLD dan lekat di atas kelenjar tiroid kolar baju kardiologis sepanjang dua bulan berturutan. TLD mengukur dos 10 mm dibawah kulit [$H_p(10)$]. Jangkaan untuk $H_p(10)$, min efektif dos per DAP nilai index (E/DAP), min efektif dos per prosedur (E/procedure) dan maxima efektif dos tahunan telah didapati.

Nilai jangkaan dos tahunan diantara keempat-empat kardiologis ialah 0.11 – 0.44 mSv dan adalah dibawah had yang dicadang oleh International Commission on Radiological Protection (ICRP).

RADIATION EXPOSURE TO PATIENTS AND CARDIOLOGISTS IN INTERVENTIONAL CARDIOLOGY PROCEDURES

ABSTRACT

Interventional cardiology (IC) procedures are known to give high radiation doses to patients and cardiologists as they involve long fluoroscopy time. The objective of the study was to determine the dose received by patients and cardiologists during interventional cardiology procedures, such as coronary angiography (CA), percutaneous transluminal coronary angioplasty (PTCA) and CA+PTCA.

Patients and cardiologists dose measurements were carried out at the cardiology department at the Gleneagles Medical Centre (GMC, Penang, Malaysia) by using Kodak EDR2 films and Gafchromic XR-RV2 films. The energy dependence, dose dependence, dose rate and dose calibration curve of both the films were also studied.

The films were placed on the table underneath the patient for an under table tube position when measuring patients' maximum entrance skin doses (MESD). Values of 35.38 – 2442.7 mGy for MESD and 10.9 – 344.4 Gy cm^2 for dose area product (DAP) were found. A good correlation was found (R^2 = 0.8212) and (R^2 = 0.7344) between the MESD and DAP values for the CA and CA+PTCA procedures respectively, but DAP was found to be poor indicator of MESD for PTCA procedure. The highest MESD value of 2443 mGy in this study was below the typical threshold dose value of 3000mGy for skin injury recommended by the Food and Drug Administration (FDA, United States).

Effective dose for four cardiologists were measured using Thermoluminescent dosimeters (TLDs) placed inside the TLD holder and then placed at the cardiologist over the thyroid collar for 2 consecutive months. The TLD measured the dose at 10mm below the skin [$H_p(10)$]. The estimation of $H_p(10)$, mean effective dose per DAP index value (E/DAP), mean effective dose value per procedure (E/procedure) and annual maximum effective dose were obtained.

The estimated annual dose among four cardiologists of 0.11 – 0.44 mSv is well below the dose limits proposed by the International Commission on Radiological Protection (ICRP 60).

CHAPTER 1

INTRODUCTION

1.1 Interventional Cardiology

Nowadays, the number of angiographic studies has increased dramatically. Interventional cardiology procedures are known to give high radiation doses to patients and cardiologists as the procedures involve long fluoroscopy times. The extensive use of X-rays in this technique results in an increase risk of deterministic and stochastic effects. Deterministic effect occurs when the dose threshold is exceeded whereas in stochastic effect there is no threshold dose. Stochastic risk is commonly based on the effective dose that relates the risk from a non-uniform exposure in the body to the risk from an equivalent whole body exposure. In contrast, deterministic risk is closely related to entrance skin dose. Increase in the dose above the threshold dose will lead to greater damage (Wanger *et al.*, 1994). Therefore the maximum entrance skin dose (MESD) may be used to assess proximity to threshold levels.

Physicians performing interventional cardiology (IC) and interventional radiology (IR) procedures should be aware of the potential for serious radiation induced skin injury caused by long periods of fluoroscopy which occur with some of these procedures. Reports of patient skin injuries in interventional radiology (IR) and in interventional cardiology (IC) are fully documented in the scientific literature (Martin, 1995; Vano *et al.*, 1998; Wanger *et al.*, 1998, 1999, 2000; Koenig *et al*, 2001). So, it is necessary to optimize the imaging equipment used during angiography with any dose saving techniques. It is important to measure the radiation doses received by the personnel involved in the cardiology procedure (Vano, 2003).

Due to growing concern about high radiation dose in complex procedures, the Food and Drug Administration (FDA, 1994), the World Health Organization (WHO, 1997), the International Commission on Radiology (ICRP, 2000) and the International Atomic Energy Agency (IAEA, 1996) have published documents on how to avoid deterministic effect of skin injuries in cardiology procedures.

Interventional cardiology (IC) refers to diagnostic and non-surgical procedures of the heart. Normally IC involves four procedures: coronary angiography (CA), percutaneous transluminal cornonary angioplasty (PTCA), CA and PTCA, and ablation. CA, PTCA, CA and PTCA procedures were selected for this study.

During interventional CA procedure, a patient is injected with a contrast media through a catheter and the blood vessels in the anatomical region of interest are then highlighted on a sequence of radio graphical images to detect the narrowing of coronary arteries (Radiology info, 2008). As such, it may be performed if the patient is suffering from symptoms of unstable angina, chest pain or unexplained heart failure.

In interventional percutaneous transluminal coronary angioplasty procedure (PTCA), cardiologists use catheters to get inside blood vessels for diagnostic tests as well as to restore damaged vessels. The small incisions which are performed on patients allow a shorter recovery time compared to surgical procedures. During angioplasty procedure, imaging techniques are used to guide a balloon-tipped catheter, a long, thin plastic tube, into an artery and advance it to where the vessel is narrow or blocked. The balloon is then inflated to open the vessel, deflated and removed. In some cases, a small wire mesh tube called a stent is permanently placed in the newly opened artery or vein to help it remain open (Radiology info, 2008).

CA and PTCA procedures refer to damaged vessels of the patient will be treating immediately after the diagnose test of patient vessels performed to improve blood flow in the vessels or arteries. The PTCA procedure proceeds immediately after the CA procedure is also call *ac hoc* PTCA. Interventional cardiology procedures have a tremendous advantage over invasive surgical procedures and are increasingly common during the past few years. Figure 1.1 shows how does a contrast material is injected through a catheter into one of the arteries. The contrast material is viewable using x-ray equipment and the catheter used in angiography is a long plastic tube.

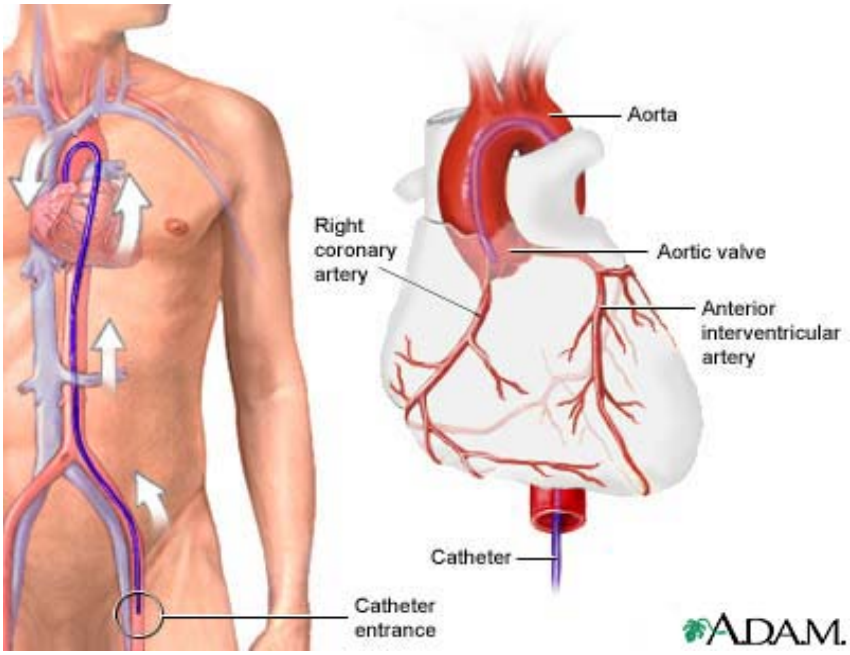

Figure 1.1: Contrast material is injected through a catheter into one of the arteries.

Source: http://nmh.adam.com/content.aspx?productId=108&pid=42&gid=000179

1.2 Research objectives

1. To calibrate the EDR2 and Gafchromic XR-RV2 films using the Toshiba X-ray Radiography System and the Interventional Unit in terms of energy dependence, dose dependence and dose rate. The dose calibration curves were also obtained for both the films.

2. To measure cardiologists' and patients' radiation doses during coronary interventional procedures and to compare the patients' absorbed doses from dose-area product (DAP) and film entrance skin dose.

3. To deduce the dose levels and the references dose levels and compare these values with the limited current values that may be available in Malaysia.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 Literature review

2.1.1 Introduction

Radiation exposure in interventional cardiology procedures are influenced by many factors which normally relate to the cardiologists and the performance of the equipment used. The cardiologists' skill and experience, screening time, dose rate of the image intensifier, image quality, the patient size, the number of radiographs taken, the methodology, the type of interventional approach (e.g. femoral or radial technique) (Clark *et al*., 2000; Padovani *et al.*, 2001; Kuon *et al*., 2003; Larrazet *et al*., 2003) and the complexity of the procedure would affect the radiation dose (Balter *et al*., 2008).

To determine and measure radiation exposure to a patient and a cardiologist, some dosimetric techniques have been investigated by previous authors (Betsou *et al*., 1998; Geise *et al*., 1999; Fletcer *et al*., 2002; Balter, 2006; Doğan *et al*., 2008). Research on patient dose evaluations in interventional cardiology mainly focuses on the measurement or the estimation of two basic parameters. They are dose area product (DAP) and the maximum entrance skin dose (MESD) over the most irradiated patient area. Dose measurement can be obtained either directly or indirectly. Indirect dose measurement is a measure of dose at a defined location either using a physical dose measurement at a convenient point (IEC, 2000) or by performing calculations based on equipment operating parameters and system geometry. In this investigation, direct measurement techniques were applied. There

are several dosimeters for direct measurements. All of these methods have problems associated with them and can be summarized as follows:

Themoluminescent dosimeters (TLD) can be used as a direct measurement of skin dose. However, the location of maximum skin exposure is very hard to predict. Hence many TLD chips are required to be placed over the expected location. Therefore, TLDs are difficult to use in routine applications for skin dose measurement. However, TLDs are suitable as personal dosimeters to evaluate cardiologist dose (Doğan *et al*., 2008).

Silicon diode dosimeters have characteristics that make them very attractive as dosimeters (Attix, 1991). They have several unique properties that are not available with other types of detectors. They have higher sensitivity, instantaneous response, and their small size and ruggedness offer special advantages over ionization chambers. Silicon diodes can be used directly, but they have to be calibrated against with ionization chamber measurements. Their major limitation includes energy dependence in photon beams, directional dependence, thermal effects and radiation-induced damage. In the use of diodes for real time estimation of maximum entrance skin dose it has to be positioned at maximum irradiated dose which is not easy. They have the disadvantage that may overlay the human anatomy.

Slow radiographic film also can be used for directly mapping skin doses to determine the probability of a possible injury (Vano *et al*., 1997; Guibelalde *et al*., 2003), but it cannot be used in areas where radiation is too high as the film then begins to saturate. It is also sensitive to room light and requires wet chemical processing. It cannot give online information. Although a new type of slow radiographic film such as Gafchcromic XR-RV2 can overcome the problem faced by silver halide film, but the cost of XR-RV2 is too high (Canne *et al*., 2006).

Dose area product (DAP) is the most convenient method for the indirect measurement of patient dose especially for dynamic procedures such as interventional procedures where the X-ray irradiation area to the patient and projection direction of the X-ray beam are continuously varying. DAP is very convenient for estimating stochastic risk for patient (Le, 1992; McParland, 1998). But, DAP cannot be used to evaluate deterministic risk because DAP cannot provide information about the most irradiated area in the patient skin. The measurement is an estimated dose over wide variability of the irradiated area.

2.1.2 Patient dose measurement

There are many different physical quantities that can be used to express the amount of radiation delivered to a patient body. Radiation quantities used in this investigation for measurement patient dose were dose area product (DAP), also called as a kerma area product (KAP) and maximum entrance skin dose (MESD).

KERMA is the acronym for Kinetic Energy Released in the Medium or sometimes Kinetic Energy Released per unit Mass. Air kerma is the amount of concentration of radiation energy (in joule, J) actually deposited or absorbed in a unit (kg) mass of air. In order words, air kerma is recognized as absorbed dose in air. Ionization chamber can be calibrated to measure air kerma as well as exposure. The unit of kerma is the joule per kilogram, J/kg, and its special name is gray (Gy). Kerma can be quoted for any special material at a point in free space or in any absorbing medium (Multimedia electronic resource, 2001)

Dose area product (DAP) or kerma area product (KAP), is a multiplication of the dose and the area exposed, often expressed in Gy cm^2. DAP is independent of the

source-skin-distance. Modern x-ray systems fitted with a DAP meter are able to record accumulated DAP during an examination (Leeds X-ray Imaging Research, 2008)

The entrance skin dose (ESD) is the absorbed dose in the skin at a given location or at the surface of entry of radiation for patient undergoing interventional procedure; it includes the backscatter radiation from the patient. ESD can be measured directly with a dosimeter such as using a slow film. Maximum entrance skin dose (MESD) refers to maximum absorbed dose received by a portion of the exposed patient's skin (Multimedia electronic resource, 2001).

Patient dosimetry in interventional procedures is extremely complex due to irradiation of different anatomical areas with X-ray beams changing to various projections, diverse field sizes, radiation qualities, focus to film distances and focus to image intensifier distances. For all these reasons, patient entrance dose is difficult to derive and has a high uncertainty (Poletti, 1997). Therefore, a lot of research has been done by previous authors to develop and investigate a suitable method to evaluate radiation dose (Vano *et al*., 1997; Betsou *et al*., 1998; Balter, 2006; Doğan *et al*., 2008).

Vano *et al* (1995) studied DAP values in several interventional radiology procedures including CA and PTCA to evaluate patients' stochastic risks. They obtained a mean value of 87.50 Gy cm^2 for PTCA procedures and 66.51 Gy cm^2 for CA procedures. DAP is an easily available estimate but information about radiological risk cannot be deduced directly from DAP value, as the latter depends on the body area irradiated.

Vano *et al.* (2001) also reported no general correlation was observed between the dose area product (DAP) and the maximum skin dose. Cumulative skin dose estimates throughout the procedure should be discarded as a realistic method for assessing deterministic risk in cardiology procedures. Maximum skin dose from 107 – 711 mGy and dose area product of 27.3 to 370.6 Gy cm^2 were found in their study.

Betsou *et al* (1998) reported mean DAP values of 30.40 Gy cm^2 and 37.60 Gy cm^2 for CA and PTCA respectively while Van de Putee *et al* (2000) reported 60.60 Gy cm^2 and 115.30 Gy cm^2 for CA and PTCA respectively. According to Van de Putee *et al*, the mean DAP gives only approximately indication of the skin dose and they suggested direct measurement is the best way to obtain information about the skin dose. Tsapaki *et al* (2003) reported, mean DAP values of 47.30 Gy cm^2 and 68 Gy cm^2 for CA and PTCA respectively.

Efstathopoulos *et al* (2004) found that 66% of the total DAP is caused by cineangiography which occupies only 13% of the total exposure time. Thus, small changes in digital cineangiography time may result in a considerable reduction of patient radiation dose. However a poor correlation was found between DAP values and total exposure time (fluoroscopy time and cineangiography time).

Morrish *et al* obtained DAP values from 28.0–39.3 Gy cm^2 for CA and from 61.3–92.8 Gy cm^2 for PTCA. They found that a strong relationship between patient weight and tube potential; the DAP had also a good correlation with the tube potential.

To measure the patient entrance skin dose, Guibelalde *et al*. (2003) used Kodak EDR2 film in interventional cardiology to map the patient skin doses and to estimate maximum skin dose up to 1400 mGy. Film dependence on kVp is negligible

and the processor condition has to be standardized to obtain skin dose estimation. The linear range for accurate dose measurement is from 50 mGy to 500 mGy.

Morrell *et al*. (2006) reported all skin doses were well below 1 Gy in coronary angiography but 23% of patients received skin doses of 1 Gy or more during PTCA procedures. DAP was not an adequate indicator of patient skin dose and Kodak EDR2 film saturates at 1 Gy. Canne *et al*. (2006) successfully used Gafchromic XR Type R films to evaluate maximum skin dose values within a range of 200 – 1700 mGy. The uncertainty on maximum skin dose values was estimated to be within 10 – 15 %.

2.1.3 Cardiologists effective dose measurement

The impact of radiation to the cardiologist does not occur in such a predictable manner as skin damage. So called stochastic effects are caused by incorrectly repaired radiation damage to cells, and the effects such as cancer, can develop years after exposure. The dose absorbed by a cardiologist can be converted to a measure of the biological damage caused by applying a radiation weighting factor (W_R), depending upon the nature of the radiation, for fluoroscopy X-ray, the radiation weighting factor is 1. This is referred to as the equivalent dose.

Effective dose takes into account the specific organs and area of the body that are exposed. Different areas and organs have different tissue weighting factor (W_T), the absorbed dose to each organ is summed with tissue weighting factors to provide an effective dose. If more than one area has been exposed, then the total body effective dose is just the sum of the effective doses of each exposed area (Leeds X-ray Imaging Research, 2008). Estimating effective dose for cardiologist in interventional procedure involves complex calculations because many variables such

as distance, beam orientation, use of protective screens and apron and complexities in procedures affect the cardiologist dose exposure (Williams, 1997).

Thermoluminescent dosimetry is the most suitable for measurements carried out on personal dosimeters. Several methods to measure the effective dose have been developed by using either one or two dosimeters (Vano *et al*., 1998; Delichas *et al*., 2003; Morrish *et al*., 2008; Gerritjan *et al*., 2008).

Niklason *et al*. (1994) proposed a method to estimate effective dose from the radiation dose by using two dosimeters. The method was independent of the lead apron's thickness but takes into account the thyroid shield. Correction factors were applied to an over-apron collar dose and an under-apron dose to estimate the effective dose. Correction factors were suggested for two cases, both with and without a thyroid shield. Effective dose may be estimated by the under-apron dose plus 6% of the over-collar dose if a thyroid shield is not worn or plus 2% of the over-collar dose if a thyroid shield is worn. He has reported that the annual radiation dose above the lead apron for 28 radiologists averaged 48 mSv and under the lead apron dose average 0.88 mSv.

Niklason method was supported by Padovani *et al*. (2001) and Mateya *et al*. (1997). Padovani *et al*. compared two simple algorithms (the Rosenstein-Webster and Niklason algorithms) with the other experimental data. Both the algorithms combined the readings of two dosimeters, one worn under the protective apron and the other on the neck outside the apron, to estimate effective dose for a range of imaging conditions typically found in medical fluoroscopy. Padovani *et al*. concluded that the Niklason algorithm's estimates were in better agreement with the experimental assessments of effective dose. Padovani derived the algorithm from Niklason, to estimate the effective dose by using a single dosimeter.

Mateya *et al*. reported that the effective dose estimation without the lead apron was within 0.2 to 20% of the expected values. However, the effective dose based on personal monitors worn at the waist (underneath the apron) was underestimated while monitors placed at the neck (above the apron) was significantly overestimated. Meteya *et al*. suggested that accurate estimation of effective dose from personal monitors under conditions of partial body exposures remained problematic and was likely to require the use of multiple monitors.

Vano *et al*. (2006) reported occupational radiation dose of interventional cardiologists during a 15-year follow-up. The individual dose values in the range of 100 – 300 mSv per month in 1989 was significantly reduced to 1.2 mSv per year in 2004. Vano et al suggested the most effective method of reducing radiation risk was by training personnel in radiation protection and the proper use of radiation protection facilities, specially ceiling-suspended protective screens.

2.2 Theory

2.2.1 Film Dosimetry

Photographic film is the oldest radiation-monitoring device worldwide mainly because of its simplicity and ease of use. When ionizing radiation of sufficient energy falls on a photographic film, some of the silver halide grains in the photographic emulsion interact with the incident radiation. After development, the silver halide grains reduce to metallic silver, which causes the blackening of the film.

The degree of blackening of the film is measured by determining the optical density，OD of the film with a densitometer. This instrument consists of a light source, a tiny aperture through which the light is directed and a light detector to

measure the light intensity transmitted through the film. The optical density, OD, is defined as:

$$OD = \text{Log}_{10}\left(\frac{I_0}{I_t}\right) \quad (2.1)$$

where I_0 is the amount of light collected without film and I_t is the amount of light transmitted through the film (Khan, 2003). The optical density of the exposed film is quantitatively related to the magnitude of the exposure. A densitometer gives a direct reading of optical density if it has been calibrated by a standard strip of film of known optical density.

Radiographic film Kodak EDR2 and Gafchromic XR-RV2 are used to map skin dose and to measure patient dose during the interventional procedures. PTCA procedures have higher entrance skin doses than CA procedures, as the maximum skin dose of PTCA procedures can reach more than 2Gy. Kodak EDR2 which has a dose range 50mGy to 1400mGy cannot be used in PTCA measurements. Therefore, Kodak EDR2 is used for coronary angiogram (CA) procedures while Gafchromic XR-RV2 is used for PTCA procedures.

2.2.2 Thermoluminescent Dosimeter

2.2.2.1 Introduction

Among the wide choice of solid state detectors that can be used for applications in radiotherapy, diagnostic radiology and radiation protection of the patient and physicians, thermoluminescent dosimeters (TLD) and diodes are currently the most used. Thermoluminescent (TL) materials are readily available commercially and do not require to be linked with a cable to the reading equipment for reading. They also have the advantage of providing very sensitive dosimeters

with small volumes and which when correctly chosen, are equivalent to the different human tissues (Attix, 1991). In this study, TLD, LiF:Ti,Mg (TLD 100) were used to measure the cardiologists' effective dose and ion-chamber was used for the proposed calibration .

2.2.2.2 TL materials and TL Process

Thermoluminescent materials are non conducting crystalline solids (semiconductors or insulators). Many materials have the property of thermoluminescence but only a few possess all the other characteristics desirable in dosimeters. When such materials are exposed to ionizing radiation, much of the radiation energy is trapped in the crystal lattice rather than released immediately. Heating the materials can cause this trapped energy to be released as light. The light emission phenomenon is called thermoluminescence (TL). Materials with this property are referred to as TL materials. The amount of the emitted light is a measure of the absorbed energy, TL materials can function as integrating dosimeters (Attix, 1991; Claudio *et al*., 1998).

Thermoluminescence is a two stage process:

1. The radiation energy is absorbed and trapped in the TL material.
2. The trapped energy is released in the form of light when the TL material is heated.

2.2.3 Fluoroscopy

Fluoroscopy is an imaging technique commonly used by physicians to obtain real-time images of the internal structures of a patient through the use of a fluoroscope. Like normal X-rays, it delivers a dose of ionizing radiation to the patient and so must only be used when the benefits to the patient outweigh the risk of developing cancer due to the radiation. Modern fluoroscopes couple the screen to an X-ray image intensifier and CCD video camera allowing the images to be played and recorded on a monitor (University Virginia Health System, 2008).

Fluoroscopy is used in many types of examination and procedures, such as barium X-rays, cardiac catheterization and placement of intravenous (IV) catheters (hollow tubes inserted into veins or arteries). In cardiac catheterization, fluoroscopy enables the physician to see the flow of blood through the coronary arteries in order to evaluate the presence of arterial blockages (University Virginia Health System, 2008).

Fluoroscopy and radiography share some of the same imaging chain components, but differences exist. The primary difference is that the radiation exposure rate is much lower for fluoroscopy compare with radiography. Fluoroscopy of an average-sized adult abdomen typically is normal performed at approximately 45 mGy/min. For an abdominal radiograph, the entrance skin exposure to the patient is approximately 3 mGy with an exposure time of 200 msec for an exposure rate of 900 mGy/min, which is 20 times higher than the rate for fluoroscopy. However, the total exposure for a radiograph is much lower than a typical fluoroscopic examination because the fluoroscopic exposure time is extended. To avoid radiation injury to the patient, low fluoroscopic exposure rates are required.

CHAPTER 3

GENERAL INSTRUMENTATION

3.1 Equipments and materials

General instruments and materials used in this study are shown in table 3.1. Table 3.1 describes and summarizes the location and the main function of the equipments and materials used for this study. This study had been done in the cardiology department, at the Gleneagles Medical Centre (GMC) for patients and cardiologists doses measurement and the medical physics laboratory, Universiti Sains Malaysia (USM) for calibration purpose.

Table 3.1: Location and main purpose of the equipments and materials used in this study

Instruments and materials	**Location**	**Purpose**
Kodak EDR2 film	GMC & USM	To act as a dosimeter To measure patients' entrance skin dose in CA procedures
Gafchromic® XR-RV2 film	GMC & USM	To act as a dosimeter To measure patients entrance skin doses in PTCA and CA+PTCA procedures
Medical film processor model SRX-101A	USM	To develop EDR2 film
Perspex Phantom	GMC & USM	To simulate patients' chest
TLD LiF:Mg,Ti	GMC & USM	To measure cardiologists effective doses
Harshaw TLD reader model 3500	USM	To heat and read TLDs
Labotherm Program Controller S27 Furnace	USM	To anneal TLDs

PTW flat diagnostic ion chamber type 77337	USM	A calibrated dosimeter To calibrate EDR2, XR-RV2 films and TLDs
PTW UNIDOS Freiburg electrometer	USM	A calibrated dosimeter To measure and display the dose measured by the ion chamber
Unfors Mult-O-Meter 517L	USM	To calibrate PTW flat diagnostic ion chamber
Philips Integris HM 3000 Interventional Unit	GMC	X-ray machine for interventional procedures To irradiate EDR2 and XR-RV2 films during interventional procedures
Toshiba KXO-15R X-Ray Radiography system	USM	X-ray machine used to calibrate films and TLDs

3.2 Film Dosimetry

3.2.1 EDR2 (Extended Dose Range) film

Kodak EDR2 film (Eastman Kodak, Rochester, New York) is a low sensitive film and is available in 25.4 cm × 30.5 cm sheets. It belongs to the line of Kodak Ready-Pack products. Kodak EDR2 films are pre-wrapped in light proof paper and are ready to use with an exposure range from 25 cGy to 400 cGy. The film is a convenient medium for calibration and monitoring exposure, relatively insensitive to X-ray energies and the response extends to high exposures.

Exact dose responses of EDR2 are a function of facility dependent factors such as processing conditions (processing time, processing temperature, processing equipment, processing chemistry), the density sampling (digitizer equipment and calibration) and exposure monitoring equipment.

Normally, long and complex interventional procedures require wider dose measurement ranges. EDR2 film with a limited dose range is good to estimate skin dose distributions in coronary angiography (CA), where the maximum skin dose is normally below 1Gy. Guibelalde *et al*. (2003) successfully used it to measure maximum skin dose up to 1400 mGy undergoing CA and PTCA procedures.

3.2.2 Gafchromic® XR-RV2

Recently, ISP (International Specialty Products, Wayne, NJ) have introduced a new reflective Gafchromic® film XR-RV2 (Gafchromic Radiochromic Dosimetry, 2008) to replace Gafchromic® XR-R. XR-RV2 film has a higher sensitive dose range than XR-R film. Gafchromic® XR-RV2 shown in figure 3.1, has been developed to specifically measure absorbed dose at both low and high energy photons where the energies are between 30 keV and 30MeV.

Gafchromic® XR-RV2 is the most suitable dosimeter to map patient skin dose in complex interventional procedures. It is used to measure a dynamic dose range from 1cGy to 50Gy. Some features of XR-RV2 are dose-rate independent; dose fractionation independence and orientation independence. It is self developing and needs no post-exposure processing, tissue equivalent and can be handled in room light (Sharifeh *et al*., 2005) (Gafchromic Radiochromic Dosimetry, 2008).

Gafchromic® XR-RV2 has several advantages compared with the silver halide films; the films are not sensitive to visible light and need no wet chemical processing. Gafchromic films can give immediate visualization information of patient exposure which enables cardiologists to treat latent skin injuries and to avoid future exposure in that region.

The active layer of Gafchromic® XR-RV2 is approximately 17 μm. It is sandwiched between two sheets of polyester; one transparent film substrate with thickness 97 μm and one opaque, white film substrate with thickness 97 μm.

The transparent polyester substrate used in the film contains a yellow dye. The yellow dye enhances the visual contrast of the chromatic changes when the film is exposed to radiation. The yellow dye also protects the active layer against exposure by UV and blue light and thereby enable the film to be even more tolerant of being handled in the light. The opacity of the white substrate in XR-RV2 is provided by a baryta filling. It employs the same active component as XR-R film but includes a proprietary high Z material thus making it more sensitive than XR-R film (Gafchromic Radiochromic Dosimetry, 2008). This thickness of layer may vary from batch-to-batch and hence a new calibration should be done when a different lot number or batch is used.

GAFCHROMIC® XR-RV2 radiochromic dosimetry films may be measured with reflective type densitometers, film scanners or spectrophotometers. The analysis of flatbed scanner method was reported in literature (Thomas *et al*., 2003; Delle *et al*., 2006). When the active component in the films is exposed to radiation, it reacts to form a blue colored polymer with an absorption maximum at about 635nm (Gafchromic Radiochromic Dosimetry, 2008; Cheung *et al*., 2005). Therefore, the response of GAFCHROMIC® XR-RV2 dosimetry media is enhanced by measurement with a red light.

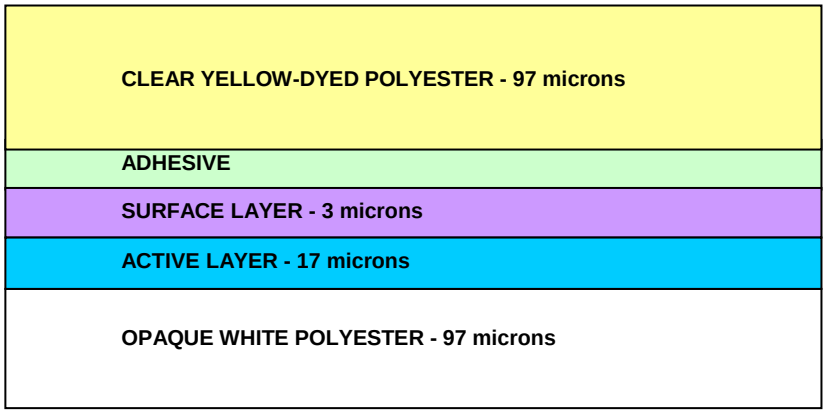

Figure 3.1: Configuration of GAFCHROMIC® XR-RV2 dosimetry film

Source: http://online1.ispcorp.com/_layouts/Gafchromic/index.html

3.3 Film Development

Automatic medical film processor manufactured by Konica Minolta, model SRX-101A shows in figure 3.2 was used to develop EDR2 films. The Konica Minolta SRX 101A processor produces high quality radiographs with easy operation; the developer and fixer used are in accordance with developing EDR2 films.

The processor was allowed to warm up about 30 minutes before developing the film. In order to assure the highest quality images, it is necessary to keep the rack rollers and guides clean. One to two cleaning films were inserted every time before the EDR2 films were processed.

Figure 3.2: Automatic medical film processor model SRX-101A

3.4 Perspex Phantom

Normally, water is the most preferred material because it approximates the radiation absorption and scattering properties of muscle and other soft tissues. Water is also universally available with reproducible radiation properties.

Although water is the preferred phantom material, there are situations where using a solid plastic phantom may be more convenient. It may provide better positional accuracy, particularly for low-energy electron beams and for low-energy kilo voltage x-ray beams; it is easy to set-up and the chamber can be placed at different depths reproducibly. An ideal solid water phantom should be water-equivalent, but in reality there is no material that meets this requirement. Therefore the practical phantoms are, at best, approximations to water.

The materials for water phantom that have been widely used are acrylic (PMMA, known as Perspex or Lucite) and polystyrene. In this study, PMMA Perspex solid phantom with the dimension 30cm × 30cm was used. The phantom thickness is 1 cm, total 10 slabs which is 10cm thick of Perspex were used to provide sufficient backscatter during calibration.

3.5 TLD 3500 reader

The instrument used to heat a TLD phosphor and to measure the resulting thermoluminescence light emitted is called a TLD reader. The TLD phosphor to be measured is placed in the heater pan at room temperature and heated while the emission is measured with a photomultiplier.

TLD readers can be simple or complex. With some, each TLD must be handled and read individually. Other systems can automatically read hundreds of badges and transfer data into the appropriate files of a computer.

Harshaw TLD reader, model 3500 shown in Figure 3.3, was used in this study. The system consisted of two major components, TLD Reader and the Windows Radiation Evaluation and Management System (WinREMS) software resident on a personal computer, which was connected to the Reader via a serial communication port. The software controls the operation of the Reader which has a user interface, storage and the application software.

The basic external component of the instrument included a sample drawer for a single element TLD dosimeter and a drawer for neutral density filters. The rear panel housed a voltage-selectable power input module with fuse access, an instrument reset button, a fitting for nitrogen gas tubing, a communication port and a recessed pressure sensor adjusting screw.

The instrument used contact heating with a closed loop feedback system that produced linearly ramped temperature accurate to within ±1˚C to 400 ˚C. The time Temperature Profile (TTP) is user defined in three segments: Preheat, Acquire, and Anneal, each with independent times and temperature.

For low dose measurement, the instrument provided nitrogen to flow around the planchet. This eliminated the effects of non-radiation-induced TL. Nitrogen is also routed through the Photomultiplier Tube (PMT) chamber to eliminate moisture caused by condensation.

Figure 3.3: Harshaw TLD reader model 3500

3.6 Labotherm Program Controller S27 Furnace

In this study, Labotherm Program Controller S27 Furnace was used as a furnace to anneal the TLDs. The Program controller S27 is an electronic temperature program controller that consisted of 8 memories location for one program each, with maximum of 4 ramps and 4 holding times. The additional features of the machine enabled the user to program the acoustic signal, sequences of higher and lower temperature and to be performed with specified start-up time.

3.7 PTW System

3.7.1 PTW flat diagnostic ion chamber

A 1 cc flat chamber type 77337 (PTW Freiburg), Figure 3.4, was used throughout the project as a tertiary standard dosemeter. This ionization chamber was used with diagnostic dosemeters for radiography and fluoroscopy measurement during installation and maintenance of diagnostic X-ray installation.

The ionization chamber was used together with the Freiburg diagnostic electrometer (PTW Freiburg) and it had a calibration traceable to the national standard of the German national laboratory, PTB, Braunschweig. Refer to Appendix B for technical specification and calibration certificate.

The window material for the ionization chamber was graphite coated and the window thickness is 50 μm. The active volume of the chamber is 1.0 cm^3 and the area density is 7.1 mg/cm^2. The maximum voltage is 100 V. Finally, the response of the chamber is approximately 4×10^{-8} C / Gy.

Figure 3.4: PTW flat diagnostic ion chamber type 77337

3.7.2 PTW UNIDOS Freiburg electrometer

The PTW UNIDOS Freiburg electrometer (PTW, Freiburg) shown in Figure 3.5, was used together with the PTW diagnostic ion chamber. The UNIDOS provided several measurements including measurement of current and charge, radiological quantities, photon equivalent dose, air kerma and absorbed dose to water.

The warm-up period for the UNIDOS was 15 minutes and the chamber voltage was from 0 to ± 400 V. The UNIODS provided the two measuring modes, “dose” mode for measuring X-ray diagnostics and “dose rate” mode for measuring radiotherapy. For X-ray diagnostics mode, the UNIDOS displayed in Gy unit. Using manually entered correction factor for pressure and temperature, commonly used dosimetric quantities could be calculated and displayed.