The Identification and Evaluation of Likely High-Dose Electrophysiology (EP) Procedures at a Large Teaching Hospital

James Bradford Taylor

A thesis submitted to the faculty of the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Masters of Science in the Department of Environmental Sciences and Engineering

Chapel Hill
2006

Approved by

Advisor: Donald L. Fox
Committee Member: Marija Ivanovic
Committee Member: James E. Watson

ABSTRACT

JAMES BRADFORD TAYLOR: The Identification and Evaluation of Likely High-Dose Electrophysiology (EP) Procedures at a Large Teaching Hospital
(Under the direction of Donald L. Fox)

Fluoroscopy-guided procedures utilizing x-rays may expose patients to radiation doses above the threshold for observable radiation-induced effects. Total fluoroscopy time is often available and serves as an indicator of skin dose. We conducted a retrospective review of fluoroscopy times for 225 procedures and identified ablations and biventricular (BIV) device implants as likely high-dose procedures, with mean fluoroscopy times of 62$\pm$48 minutes and 51$\pm$28 minutes, respectively. To determine which variables best describe dose, we measured skin dose for thirty subjects using radiochromic dosimetry film and found mean doses of 133$\pm$94 rad and 164$\pm$176 rad for ablation and BIV procedures, respectively. We correlated dose to fluoroscopy time, weight, body mass index (BMI), the weight and time product, and the BMI and time product, and found the latter two correlate best with r^{-2} values of 0.41 and 0.36, respectively. Overweight patients appear to be at the greatest risk of receiving high skin doses.

ACKNOWLEDGEMENTS

I want to first thank Dr. Fox for his consistent guidance and valuable input throughout this entire project. It would not have been possible to complete this work without his sincere interest and guidance. I also want to thank Drs. Ivanovic and Watson for their active participation over the years. Not only have they been valuable throughout this project, they have also helped to develop me professionally and personally as well.

Thanks also to David for you confidence and support, and to Ryan for helping me find the motivation necessary to complete this project.

A sincere appreciation is extended to Drs. Sanders and Selzman, and the staff of the EP Lab for their support. In particular, thanks to Jim Jack for making things fun and to Dianne for helping with scheduling details. Final recognition goes to the UNC Department of Environment, Health and Safety for providing the many resources necessary to complete this work.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Rationale

Fluoroscopic procedures, such as barium swallows, which utilize x-rays are primarily diagnostic in nature and involve minimal risk to the patients. However, an increasingly larger percentage of procedures, such as angioplasty and vascular stent placement, offer a therapeutic benefit to the patient. Such fluoroscopy-guided interventional procedures often provide a less invasive alternative to higher-risk surgical procedures. Although infrequent, severe skin injury can be a resulting side effect from these procedures because they may prove to be technically difficult, and can involve total fluoroscopy times in excess of one hour or more (Mahesh 2001).

The Food and Drug Administration (FDA) has reported that occasionally, severe radiation-induced burns have occurred in patients undergoing such non-invasive fluoroscopic-guided procedures, and has made recommendations for the avoidance of such x-ray-induced skin injuries. In response to the increase in likelihood of radiation-induced injuries from such procedures, a September 1994 public health advisory titled *Avoidance of Serious X-Ray Induced Skin Injuries to Patients During Fluoroscopy-Guided Procedures*, was issued by the Center for Devices and Radiological Health (CDRH) of the FDA which recommended recording pertinent information in the patient's record allowing for the estimation of absorbed dose to the skin (FDA 1994). One year later, in a follow-up advisory titled *Recording Information in the Patients Record that Identify the Potential of Serious X-Ray*

Induced Skin Injuries Following Fluoroscopy Guided Procedures, the agency provided clarification to earlier recommendations and stated that "the purpose of the recommendation (1994 advisory) is to encourage identification of those areas of the skin which are irradiated at levels of absorbed dose that approach or exceed a threshold for injury" (FDA 1995). The only step most institutions have taken to comply with these advisories is to document total fluoroscopy times.

More recently in December 2005, the Joint Commission on Accreditation of Healthcare Organizations (JCAHO 2006) updated their list of reviewable sentinel events to include high patient skin dose from extended fluoroscopy procedures. A sentinel event is an adverse occurrence that involves death or serious injury, or the risk thereof (JCAHO 2006). The update has caused institutions across the country to develop methods and procedures to demonstrate compliance with these new requirements; which may include the estimation or measurement of skin dose during lengthy fluoroscopy procedures.

Study Purpose

The primary objective of this project was to evaluate the radiation dose to adult patients undergoing fluoroscopy-guided x-ray procedures in an Electrophysiology (EP) facility at a large teaching institution. Key to this project was the collection and evaluation of data on fluoroscopic times, which serve as an indicator of the absorbed dose to the patient. These data helped determine which procedure categories are most likely to produce visible effects of radiation exposure to the skin. Those procedures associated with likely high-doses were further evaluated and direct measurements of the actual skin doses were made using a radiochromic film that is specifically designed to measure skin dose during fluoroscopically-

guided procedures. Supplemental purposes of this project included providing physicians with information needed to make informed decisions concerning the management of high-dose procedures (such as which patients may need follow-up evaluation for skin injury), evaluating the need for future assessment of skin doses (such as monitoring for certain high-risk patients), determining the need for any dose-reduction measures necessary (such as which modes of equipment operation deliver the lowest doses), and assisting in compliance with FDA Public Health Advisories and JCAHO sentinel event requirements described above (such as monitoring high-dose procedures).

Specific goals of this project include:

1. Collecting and evaluating retrospective data on fluoroscopy times for patients undergoing various categories of procedures involving x-ray at a large teaching hospital.
2. Determining which categories of procedures are likely to produce observable effects to the skin.
3. Measuring the peak skin dose for thirty-three patients undergoing high-dose procedures using a radiochromic film, and evaluating the associated radiation risks.
4. Evaluating the relationship between peak skin dose, fluoroscopy time, subject weight, and subject body mass index (BMI).
5. Determining which of the above variables may be good predictors of dose for EP procedures.
6. Devising a protocol which provides physicians with an indication as to when skin dose may approach a threshold for injury that may indicate when a patient is at risk for developing a radiation-induced injury.

The remainder of this paper will explain not only how we set out to achieve these goals, but will also provide the reader with background information useful for understanding how fluoroscopic x-ray equipment is used for clinical imaging, as well as for understanding the science of electrophysiology and the types of abnormalities of the hearts electrical system that are effectively treated with the aid of fluoroscopy. A review of the available literature is presented to give the reader a current perspective on fluoroscopy times and radiation doses for procedures performed at other EP facilities. This paper also discusses the experimental design and protocols utilized for the retrospective evaluation of fluoroscopy times and for measuring skin dose during two selected procedures with possible extended fluoroscopy times. Results of this project are revealed to the reader, and suggestions on the future direction for the proper management of high-dose EP procedures are offered.

BACKGROUND

Radiation Terms

There are many terms used to describe radiation. The Roentgen (R) is a unit of radiation exposure, and is a measure of the concentration of free electrons that are produced in air from x and gamma rays (Wagner 1996). One Roentgen is equal to 2.58×10^{-4} Coulombs (C) kg^{-1} in the International System of Units (Cember 1983). The intensity of an x-ray beam is dependent upon kilovoltage peak (kVp), tube current (mA), the target material in the x-ray tube housing, plus any filtration inherent or added to the beam prior to its exposure to the patient (Curry 1990). X-ray beam strength is often described as the exposure rate, which is equal to the exposure divided by the time unit (Cember 1983).

The two most common interactions between x-rays of the diagnostic energy range and atoms in a patient are the photoelectric effect and Compton scattering. During the photoelectric effect, the incident x-ray disappears and the energy is transferred to bound electrons which are ejected and have an energy that is equal to the energy of the x-ray minus the binding of the electron. Compton scattering occurs when an x-ray interacts with free electrons. Only part of the energy is transferred to the electron, and the energy of the incident x-ray is distributed between the electron as kinetic energy and the remaining scattered x-ray. Electrons ejected by these interactions loose their kinetic energy by colliding with other orbital electrons and creating charged particles through a process called ionization (Curry 1990). If a sufficient number of ionization events occur, they can be destructive to

living tissue. The quantity of kinetic energy that is absorbed along the path of this ejected electron per unit mass is referred to as the absorbed dose. The rad is the term used to describe absorbed dose and is equal to the energy deposition of 100 ergs per gram of absorber material. The SI unit of absorbed dose is the Gray (Gy), and 100 rad = 1 Gy (Seeram 1997). The rad is an indicator of the potential of biological effects from exposure to radiation and is the term used throughout this report to describe absorbed dose and the likely effects on the skin (Wagner 1996).

The relationship between exposure (R) and absorbed dose (rad) depends primarily upon the number of electrons present per gram of absorbing material. One Roentgen of exposure corresponds to an energy absorption of 87.8 ergs per gram in air, and to 95 ergs per gram in tissue. Since the absorbed dose in tissue from 1 Roentgen of exposure in air corresponds so closely to the adsorbed dose of 1 rad (100 ergs per gram), the two may be considered approximately equivalent (Cember 1983). As other authors have suggested (Seeram 1997, Bushberg 2002), it is assumed throughout this paper that 1 Roentgen of measured exposure in air equals 1 rad of absorbed dose in tissue.

Biological Effects of Radiation Exposure

Biological effects of radiation can be broadly classified as stochastic or nonstochastic. Stochastic effects are those in which the probability of the effect increases with dose. Examples include radiation-induced cancer and genetic effects. There is believed to be no minimum threshold dose because injury to a few cells could theoretically result in the occurrence of the effect (Koenig 2001).

Nonstochastic, or deterministic, effects of radiation exposure require a minimum number of cells be adversely involved before the effect can be seen, and such effects are associated with a minimum threshold below which the effect can not be detected. There is a positive relationship between increased dose and increased observed damage. Cataract induction, erythema, epilation, and death are examples of deterministic effects (Koenig 2001). The threshold dose is not an absolute number and varies between individuals. When dose to the skin is sufficiently high, repair mechanisms are overwhelmed and the result is cell death and tissue breakdown (Wagner 1996). Wagner et al. have reviewed information on the likely deterministic effects of radiation exposures from fluoroscopically-guided procedures, and a summary of their research is seen below in Table 1.

Table 1: Single delivery (nonfractionated) threshold doses for likely deterministic effects of radiation dose (rad) to the skin (Wagner 1996).

Effect	Single-dose Threshold (rad)	Onset	Peak
Early Transient Erythema	200	hours	~24 hours
Main Erythema	600	~10 days	~2 weeks
Temporary Epilation	300	~3 weeks	NA
Permanent Epilation	700	~3 weeks	NA
Dry Desquamation	1000	~4 weeks	~5 weeks
Moist Desquamation	1500	~4 weeks	~5 weeks
Secondary Ulceration	2000	>6 weeks	--
Late Erythema	1500	~6-10 weeks	--
Dermal Necrosis (1st phase)	1800	>10 weeks	--
Dermal Atrophy (1st phase)	1000	>14 weeks	--
Dermal Atrophy (2nd phase)	1000	>1 year	--
Telangiectasia	1200	>1 year	--
Dermal Necrosis (late phase)	>1500?	>1 year	--

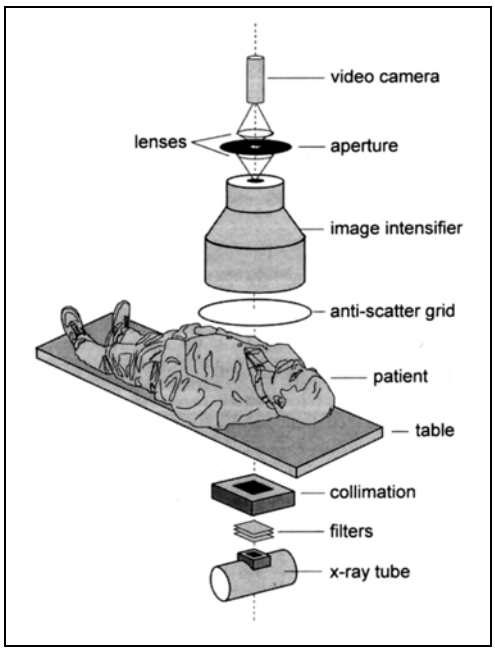
It is important to note that the intensity of radiation causing such effects is not felt in any way by the patient during the procedure (Wagner 1996).

As mentioned earlier, the JCAHO has included high doses from fluoroscopy as a category of sentinel event. Specifically, doses that patients receive are classified as a sentinel event when the cumulative dose to a single site exceeds 1500 rad (JCAHO 2006).

The Physics of Fluoroscopic Imaging

Fluoroscopy is an imaging technique utilizing radiation to allow for the real-time viewing of patient anatomy and physiological function. Most modern fluoroscopy equipment utilizes a CsI-based image intensifier (II) which is coupled to a closed-circuit image-viewing system (Bushberg 2002). The components of an II-based fluoroscopy system are shown below in Figure 1.

Figure 1: Components of an image intensifier-based fluoroscopy system.



Source: Bushberg 2002 ©Lippincott Williams & Wilkins. Used with permission.

X-rays first enter the II system by passing through a vacuum window and its supporting structure. They then interact with the input phosphor to produce light. This light strikes the photocathode, and liberates electrons into the electronic lens system, which serves to accelerate and focus the electrons onto the output phosphor of the system. Intermediate electrodes also serve to shape and focus the electrons, which interact with the output phosphor to produce a green light. The green light is achieved using a zinc cadmium sulfide phosphor that has been doped with silver, and is well matched to the spectral sensitivity of many video camera systems used to record the output phosphor image (Bushberg 2002).

An image-intensified fluoroscopy system is several thousand times more sensitive to radiation than a film-screen radiographic imaging system. Typically in clinical practice, an II requires an incident exposure of 1-5 μR per image or frame. Most analog video systems have only a 30 image per second operation but work using an interlacing fashion; a process which divides each frame into two fields and then refreshes each field at a rate of 60 times per second. This virtually eliminates the perception of flicker by the observer which would normally be seen at the 30 image per second rate. (Bushberg 2002).

A number of enhanced features have been added to fluoroscopy systems over the years, one of which is variable frame rate pulsed fluoroscopy. Unlike continuous fluoroscopy in which the x-ray beam is continuously on and typically operates between 0.5 and 5 mA, pulsed fluoroscopy produces x-rays in short pulses (Bushberg 2002). Pulsed systems operate at and below 30 pulses second^{-1}, and the pulsed beam is typically of a higher mA than when operated in continuous mode. Since the exposure time is shorter, there is less image blur from patient motion and thus image quality is improved with close to or near the same dose

rates as continuous fluoroscopy (Bushberg 2002). This is a distinct advantage in procedures involving high object motion such as pulsating vessels or organs such as the heart.

The primary variable settings controlling the production and intensity of the x-ray beam are kVp and mA. The kVp determines the energy of the electrons that are accelerated towards the tube target material, which in turn determines the energy spectrum of the x-rays produced. Increases in kVp result not only in higher energy x-rays but also an increase in the quantity as well. Beam intensity is proportional to kVp^2 (Curry 1990).

The number of electrons striking the target depends directly upon the tube current (mA). The higher the mA, the more electrons there are to strike the target and as a result more x-rays are produced (Curry 1990).

The exposure rates of modern fluoroscopy systems are controlled automatically with a system called the Automatic Brightness Control (ABC). Its purpose is to maintain the brightness of the image displayed on the monitor when thicker and thinner regions of the patient are imaged. It performs this task by controlling the x-ray exposure rate that is incident on the input surface of the image intensifier by a sensing process that takes place in either the photodiode or video signal (Bushberg 2002).

The ABC regulates the kVp and mA in continuous mode, as well as controlling pulse width (duration) in pulsed fluoroscopy. How these variables change as a function of patient thickness plays an important role in not only image quality but also patient dose. The kVp and mA generally increase together, but the curves utilized by the equipment manufacturers controlling this process can be designed, depending upon the situation, to aggressively preserve subject contrast or to give the lowest dose examination possible.

Typical Exposure Rates and Variability during Fluoroscopy

The CDRH of the FDA regulates the performance of fluoroscopic equipment in the United States. Radiological Health is addressed under Title 21, Chapter I, Subpart J of the Code of Federal Regulations. Part 1020 of Title 21 covers the performance standards for ionizing radiation emitting products, and Section 1020.32 specifically addresses fluoroscopic equipment. The following regulations apply to entrance exposure rate limits and the means for measuring compliance.

Section 1020.32 dictates that the exposure rate of fluoroscopic x-ray equipment is measured at 30 cm from the input surface of the image intensifier (21 CRF). Giles (2002) has reported that exposure rates may vary between 0.5 R minute^{-1} and 10 R minute^{-1} (1.29 x 10^{-4} C kg^{-1} minute^{-1} and 2.58 x 10^{-3} C kg^{-1} minute^{-1} respectively). Such variability is due to the mode of equipment operation, movement of the x-ray source during the procedure, and age, size, body composition, and specific pathology of the patient (Mahesh 2001). Many modern fluoroscopic x-ray systems, including the equipment used during this study, also have an optional high-dose rate mode of operation which allows for exposures as high as 20 R minute^{-1} (Giles 2002).

Body Mass Index and its Effect

Paisey (2004) and others have looked at patient body mass index (BMI) as it relates to the radiation dose received during fluoroscopy. Body mass index is a number that shows body weight that has simply been adjusted for height. As patient size and BMI increases, the ABS of the fluoroscopy equipment will automatically increase the radiation output to allow for adequate image creation.

This project evaluated the role that BMI plays in relation to the entrance skin dose received. BMI was calculated for each subject that was monitored using their weight in pounds and their height in inches. The Centers for Disease Control and Prevention (CDC) English calculation for adults BMI was utilized and is given below (Centers for Disease Control and Prevention 2005):

$$BMI = \left(\frac{\text{Weight in Pounds}}{(\text{Height in inches}) \times (\text{Height in inches})} \right) \times 703$$

The CDC classifies weight status according to BMI, with underweight individuals having a BMI below 18.5. A BMI of 18.5-24.9 is normal, 25-29.9 is overweight, and 30 and above is defined as obese (Centers for Disease Control and Prevention 2005). Although the units for BMI are pounds per square inch, they are often omitted.

Backscatter Radiation

One commonly measures the entrance skin exposure rate of an x-ray field without using a scatter-producing phantom positioned immediately adjacent to the detector. Such measurements do not reflect the contribution to exposure from what is termed backscatter radiation. The entrance skin exposure rate is that rate at the point where the x-ray photons enter the patient. Since over 40% of the entrance skin dose may be from backscattered radiation, this must be considered by using the appropriate backscatter radiation correction factors whenever one is attempting to estimate skin dose using measured exposure rates (Wall 1996).

The backscatter factor is defined as the ratio of the entrance skin dose in air at the point equal to the surface of the patient where the beam would enter the patient when they are

present, to that at the same location when the patient is not present (Annals 2004). The backscatter factor depends upon the x-ray energy spectrum, x-ray beam field size, patient thickness, and the distance between the dosimeter used to measure the dose and the surface of the skin or phantom (Wall 1996)(Annals 2004). Typical factors have been described for various beam qualities and field sizes by Wall (1996). The half-value layer (HVL) is the amount of material that is needed to reduce the intensity of an x-ray beam by one half and is often reported in mm of aluminum (Curry 1990). Backscatter factors range from 1.26 for a 10cm x 10cm field size with a HVL of 2.0, to 1.41 for a 30cm x 30 cm field size with a HVL of 4.0. ICRP Publication 93 states typical backscatter factors in the range of 1.2-1.4 (Annals 2004). When dose and dose rate measurements are made with an ionization chamber free in air for x-ray energy spectra and beam sizes common in diagnostic x-ray, these doses must be increased by approximately 20-40% when they are used to describe the entrance skin dose a patient may receive (Wall 1996). It is important to mention that because the radiochromic film utilized in this project is placed virtually next to the subjects' skin, the dose recorded includes the contribution from backscatter radiation.

As noted earlier, deterministic effects, appearing first as early transient erythema, have been observed after absorbed doses to the skin of about 200 rad. We also know there is great variability in the dose rate necessary to achieve acceptable image quality, and that these rates may vary by a factor of ten between small and large patients (Wagner 1996). The typical exposure rate for a medium-sized adult patient is roughly 3 R min^{-1} (Mahesh 2001). The reference level noted by The International Atomic Energy Agency for typical fluoroscopy entrance skin exposure rate is 2.5 R $minute^{-1}$ (IAEA 1996).

As Wall (1996) and others (Annals 2004) have described, a significant contribution to entrance skin dose may be received from backscatter radiation. If one attempts to use exposure rates made without a scatter phantom in place or without considering dose contribution from backscatter radiation, one may significantly underestimate the dose a patient might receive. Using the typical rates of 2.5-3 R minute^{-1} as noted by Mahesh and the IAEA, and considering that actual skin doses may be increased 20-40% due to backscatter radiation, it is apparent that the threshold for observable radiation-induced effects may occur on those patients receiving less than one hour of fluoroscopy. More severe effects can occur if the fluoroscopy times are longer and the subsequent doses are larger. It remains important to stress the great variability in exposure rate due to patient size, and that although less likely, large patients may exceed a threshold for injury after considerably less fluoroscopy time.

Electrophysiology Lab Fluoroscopy Equipment

Except during the period of October 2005 when the EP Lab was closed for renovations, all skin dose measurements took place during procedures performed in the EP Lab. The Lab houses a Toshiba Model XTP—8100G cardiac fluoroscopy system with a 9" image intensifier. During October 2005, procedures were performed in either a hospital operating room utilizing a portable "c-arm" type fluoroscopic system, or in an adult cardiac catheterization lab utilizing Toshiba equipment similar to that found in the EP Lab.

Toshiba cardiac systems are calibrated to take advantage of the ability to use lower pulse frame rates as described earlier; however the dose per pulse is increased relative to the 30 pulses/second mode. The result is higher image quality per image with still lower average patient dose at lower pulse rates than compared to using higher pulse rates. The dose per

pulse at the input surface of the II for the 15 pulses/second mode is 5.24μR/frame, which is 1.5 times the dose per pulse of 3.5 μR/pulse at the 30 pulses/second mode. All pulse rates below 15 pulses/second are at the same dose/pulse as 15, and any pulse rate between 15 and 30 will have a dose/pulse which decreases linearly from 5.24 μR/pulse maximum down to the 3.5 μR/pulse minimum(Bucher 2004).

Another operational difference between continuous and pulse fluoroscopy on the Toshiba cardiac system is that while continuous fluoroscopy ABC responds by increasing the kVp and mA proportionately, pulsed ABC allows independent control of the kVp, mA, and pulse width. This allows the kVp to remain fixed while the mAs product increases in response to ABC demand until the 10 R minute^{-1} limit is reached. Only when this limit is reached and as ABC demand continues to increase, will the kVp begin to rise (in order to increase the penetrating ability) and the mAs product begin to decrease, while keeping the entrance skin exposure rate under the 10 R minute^{-1} limit. This function allows the pulsed mode of operation to provide higher image contrast for a longer period of time relative to the continuously rising kVp of continuous mode fluoroscopy (Bucher 2004). Because more x-rays penetrate the patient at a higher kVp, this mode of automatic control results in higher patient doses (Bushberg 2002).

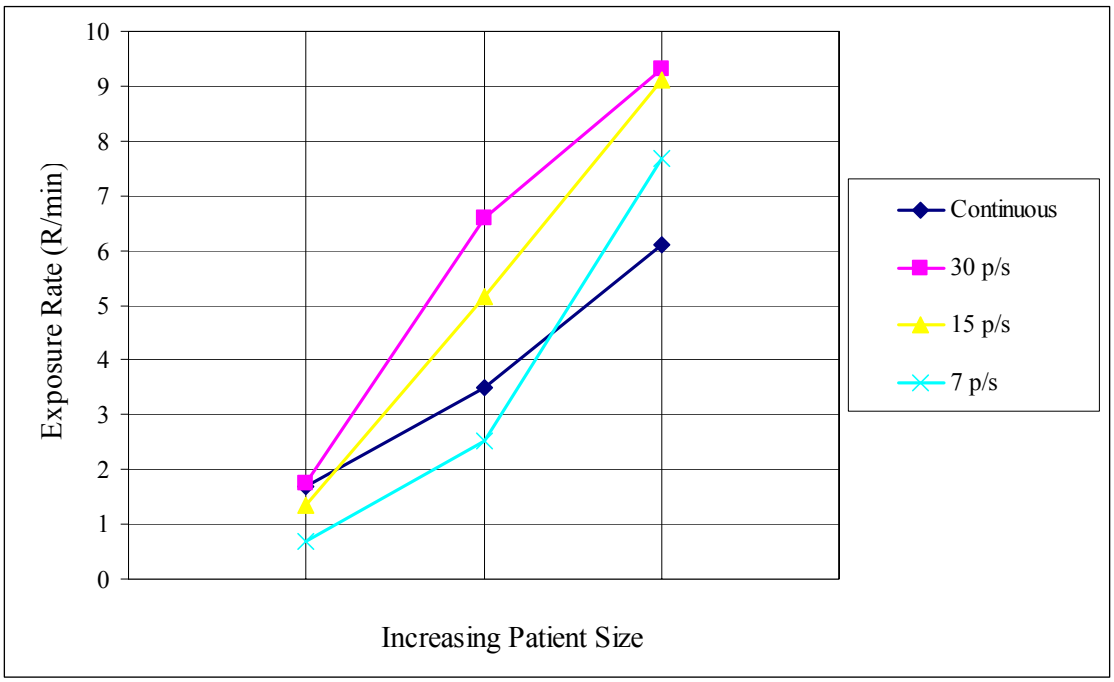
It is important for physicists as well as physicians to understand how selecting different modes of operation such as pulsed vs. continuous during a procedure affects the dose delivered to a patients' skin and the associated risk.

Below is a graphical representation of how the ABC mode of operation for the Toshiba unit in the EP Lab functions clinically. The two variables shown below for four different ABC modes of operation (continuous, 30 pulses/second, 15 pulses/second, 7 pulses/second)

are entrance skin exposure (ESE) rate (R minute^{-1}) and simulated patient size. ESE was measured 30 cm from the input surface of the II, and patient size was simulated by placing increasing thicknesses of aluminum and Lucite material in the x-ray beam.

Graphically we can see that only with relatively smaller patients will we achieve dose reduction through the utilization of pulsed fluoroscopy. Overweight and obese patients cause the equipment to operate near the maximum output of 10 R minute^{-1} and they are exposed to significantly higher dose rates for all pulsed modes of operation than for continuous mode. The physicians taking part in this project were made aware of the information described by this figure. Actual ESE values, phantom thicknesses and ABS modes are found in Appendix A.

Figure 2: Exposure rates for simulated increases in subject size on a Toshiba model XTP—8100G in differing modes of operation (continuous and pulsed fluoroscopy).



As described above, one advantage of pulsed fluoroscopy is better image quality during those procedures involving motion, such as catheter placement in the heart. Often times, the

image quality of continuous fluoroscopy is adequate, and a physician will use this mode to preserve patient dose. However, a physician may utilize pulsed fluoroscopy when improved image quality is necessary, which is most likely to occur for larger patients. The most common mode of pulsed fluoroscopy utilized in the EP Lab is 15 pulses/second.

How the Heart Works

The heart consists of four chambers. Two upper chambers (atria) collect blood returning from the body and lungs, while two lower chambers (ventricles) pump blood from the heart to the lungs and body. The upper atria and lower ventricles are separated by valves which, when working properly, allow for uni-directional blood flow only. Large vessels connect to the ventricles and are separated by additional heart valves. These vessels transport blood from the heart to the lungs (via the pulmonary artery) and the rest of the body (via the aorta) (Minneapolis Heart Institute 2004).

The sequence of pumping that is responsible for the continuous flow of blood through the heart to the lungs and body and is controlled by a built-in electrical system, which is located in the sinus node of the upper right atrium. Electrical signals move from this sinoatrial node through pathways in the atria causing them to beat. An electrical relay station called the atrioventricular (AV) node is located in the middle of the heart, and is where signals pause briefly before continuing to the ventricles of the heart causing them to beat. The electrical system in the ventricles is known as the His-Purkinje system, and the start of this system is called the His bundle (or the bundle of His) (Minneapolis Heart Institute 2004).

Clinical Abnormalities Associated with the Electrical System of the Heart

One of the clinical abnormalities associated with improper heart rhythm is arrhythmia. An arrhythmia is an abnormal heart beat which may be too fast (tachycardia), too slow (bradycardia), or just simply irregular. Symptoms of arrhythmia include lightheadedness, palpitations, blurred vision, chest pain, shortness of breath, dizziness, fainting, and even cardiac arrest. Atrial tachycardias occur in the upper parts of the heart and include atrial flutter and atrial fibrillation (Minneapolis Heart Institute 2004). Ventricular tachycardias occur in the lower parts of the heart. There are also two common types of tachycardia that involve both the upper and lower regions. One is tachycardia due to reentry in the AV node and the other is orthodromic reciprocating tachycardia (ORT). Bradycardia can be caused by sinus node dysfunction or a communication failure between the sinus node and ventricles due to dysfunction of the AV node or His-Purkinje system. (Minneapolis Heart Institute 2004).

Overview of Electrophysiology Procedures

Electrophysiology is a branch of cardiology dealing with heart rhythm management. The EP Lab at this institution offers a variety of procedures for testing and treatment of arrhythmias, and at the time of this research, there were two full-time Cardiologists with special competency in electrophysiology working in the lab.

An electrophysiology study (EPS) is a diagnostic test to identify the presence and type of arrhythmia. Catheter ablation (ABL) is a non-surgical treatment for arrhythmia in which electrode-containing catheters are introduced through blood vessels into the heart. Once problem areas of the heart are identified, radiofrequency energy waves are sent through the catheter where they destroy abnormal electrical pathways which cause the abnormal heart

rhythm (Minneapolis Heart Institute 2004). An EPS and ABL are often performed in conjunction with one other.

Patients with ventricular tachycardia and ventricular fibrillation may be treated by inserting an implantable cardioverter defibrillator (ICD). The ICD is a small, lightweight device that monitors heart rhythm and helps return it to normal during arrhythmia. A pacemaker (PM) is another type of small, lightweight electronic device that is implanted in the body of patients whose heart is beating too slowly, or whose ventricles do not beat in synchronization with each other. Pacemakers work by keeping the right atrium and ventricles working together, a term called AV synchrony, and they are comprised of a pulse generator and typically one or two leads. A lead is the wire that is placed in the heart to control pacing by delivering an electronic pulse. Pacemakers control only the right side of the heart (Minneapolis Heart Institute 2004).

Biventricular devices (BIV) are used to treat heart failure by resynchronization of the pumping action of the left ventricle, thereby pacing both sides of the heart simultaneously. This type of pacing is called cardiac resynchronization therapy (Heart Center Online 2004). Biventricular devices have the advantage of being quite effective treatments for patients with certain health conditions such as congestive heart failure, but also have the disadvantage of being difficult, technically-challenging procedures involving lengthy fluoroscopy times. The ability to timely and successfully place the leads of a biventricular device is user-dependent, suggesting that fluoroscopy times will vary significantly depending upon the experience and skill of the physicians involved, and that institutions should see a decrease in procedure time as these skills improve (Romeyer-Bouchard 2005).

LITERATURE REVIEW

A literature review was conducted to identify information on fluoroscopy times and associated skin doses for common EP procedures. One previous study found the mean duration of fluoroscopy time (±SD) for the ablation of an accessory pathway, the atrioventriclar junction, or atrioventricular nodal re-entrant tachycardia to be 53 ±50 minutes (median 37; range 1-448 minutes) (Rosenthal 1998). The duration of time for adult ablations was 58±55 minutes (median 45). There was no significant difference in duration of fluoroscopy time between the different ablation procedures. This study also identified sex, and success or failure of the procedure as independent predictors of fluoroscopy duration. Men required longer times than women, and those patients undergoing a failed ablation procedure had times that exceeded those with a successful procedure by 50%. The mean dose to the skin was estimated to be 130 ± 130 rad (median 90; range 3-1110 rad), and showed that dose likely to cause injury to the skin (200 rad) was exceeded in 22% of adult procedures performed. One percent of the procedures were associated with a dose of greater than 700 rad, which is likely to cause permanent destruction of the skins epithelium (Rosenthal 1998)(Wagner 1996).

Another study by Park et al have reported mean fluoroscopy times of 47±31 minutes (Park 1996) while Lindsay et al report 50±31 minutes (Lindsay 1992) for ablation procedures.

One study by Manolis at al (2001) found significant differences in fluoroscopy time duration between ablation procedures of accessory pathways, slow AV node pathways, atrial

and ventricular tachycardias, atrial flutter, and AV node/His bundle. Procedures involving the ablation for atrial flutter, multiple accessory pathways and certain atrial and ventricular tachycardia required the longest mean times (68±37, 89±54, 46±35, 45±28 minutes respectively), while ablation of the slow AV nodal pathway and AV node/His bundle required the least amount of fluoroscopy time (27±24, 14±8 minutes respectively). The overall mean fluoroscopy time was 43±40 minutes (Manolis 2001).

Another study reports mean fluoroscopy times of 57±30 minutes for paroxysmal atrial fibrillation (PAF), 20±10 minutes for atrial flutter, and 22±21 minutes for accessory pathway ablation (Macle 2003).

One study shows a positive correlation ($r^2 = 0.41$) between peak skin dose and total fluoroscopy time for different ablation procedures. This same study also shows a positive correlation ($r^2 = 0.34$) between increases in body mass index and the ratio of peak skin dose to fluoroscopy time. Although neither of these variables is of predictive value for individual cases, longer fluoroscopy times and increases in patient size do lead to higher radiation doses to the skin. The mean BMI reported for this study was 28±5. (Paisey 2004).

Chida et al demonstrated a better correlation between the peak skin dose and fluoroscopy time for ablation procedures with an r^2-value of 0.64. They also looked at the correlation between dose and the weight-fluoroscopy time product for non-ablation cardiac interventions and reported r^2-values of 0.50 (Chida 2006).

Iida et al have shown that entrance skin dose correlates well with the product of BMI and fluoroscopy time for general diagnostic (angiography) and interventional (transcatheter arterial embolization) radiology procedures, and obtained r^2-values of 0.91 and 0.78, respectively. BMI and fluoroscopy time products were less than approximately 500 and

1,000 for diagnostic and interventional procedures, respectively. Consistent with other reported studies, a poor correlation was seen between dose and total fluoroscopy time (Iida 2004).

Several articles reported the total fluoroscopy times for biventricular devices. Kostas (2005) reported fluoroscopy times of 35±22 minutes, and Romeyer-Bouchard (2005) reported lower times of 23±19 minutes when utilizing a simplified technique for the implantation of such devices.

Another study (AAMP 2002) looked not only at the fluoroscopy times for BIV systems, but also measured the entrance skin dose using ISP Radiochromic Film XR-R, like that used in this project. They reported fluoroscopy times of 30-200 minutes with a median of 90 minutes, and skin doses of 80-600 rad with a median of 250 rad. A summary of the literature reviewed is given below in Table 2:

Table 2: Summary of literature reviewed for adult ablation and biventricular device (BIV) procedures.

Author	Study Size	Procedure	Diagnosis	Fluoroscopy Time (minutes)	Skin Dose (rad)
Manolis	132	Ablation	Multiple Accessory Pathways	Mean of 89±54	Not Reported
Manolis	15	Ablation	Atrial Flutter	Mean of 68±37	Not Reported
Rosenthal	799	Ablation	Not Specified	Mean of 58±55	130 (estimate)
Macle	43	Ablation	Paroxysmal Atrial Fibrillation	Mean of 57±30	Not Reported
Lindsay	108	Ablation	Supraventricular Tachycardia	Mean of 50±31	Not Reported
Park	500	Ablation	Not Specified	Mean of 47±31	93+/-62 (estimate)
Manolis	24	Ablation	Atrial Tachycardia	Mean of 46±35	Not Reported
Manolis	29	Ablation	Ventricular Tachycardia	Mean of 45±28	Not Reported
Manolis	119	Ablation	AV Nodal Pathway	Mean of 27±24	Not Reported
Macle	16	Ablation	Accessory Pathway	Mean of 22±21	Not Reported
Macle	20	Ablation	Atrial Flutter	Mean of 20±10	Not Reported
Manolis	7	Ablation	AV Node/His Bundle	Mean of 14±8	Not Reported
Paisey	28	Ablation	Not Specified	3.1-53.6 Median of 14.3	2-62 Median of 12
Paisey	10	Biventricular	Not Specified	4.9-40.1 Median of 21.5	5-93 Median of 23
Kostas	14	Biventricular	Not Specified	Mean of 35±22	Not Reported
Romeyer-Bouchard	103	Biventricular	Not Specified	Mean of 23±19	Not Reported
AAPM	13	Biventricular	Not Specified	30-200 Median of 90	80-600 Median of 250

PROJECT APPROVAL PROCESS

Office of Human Research Ethics Institutional Review Board (IRB) Process

Research conducted for this project was subject to review and approval by the UNC School of Medicine Institutional Review Board (IRB). IRB committees at UNC are administered through the Office of Human Research Ethics and serve the primary purpose of protecting the rights and welfare of human subjects. The three levels of IRB review are full board review, expedited review, and review to determine if a project is exempt from continuing review (Office of Human Research Ethics 2006).

IRB approval was gained in two phases. Phase 1 was titled "Identification of Likely High Radiation Dose Procedures through the Evaluation of Fluoroscopic Times in an Electrophysiology Lab" and required submitting the completed "Application for Research Requesting and IRB Waiver of Consent and HIPAA Authorization" (Appendix B). This specific application is used when research involves only a review of existing patient records. HIPAA stands for the "Health Insurance Portability and Accountability Act" of 1996 and focuses on protecting the privacy and security of an individual's protected health information (PHI). PHI consists of individual data that may potentially identify a patient or human subject, such as name or account numbers. Since the first phase of research involved access to PHI, such as patient names, a waiver from the requirement to obtain HIPAA authorization by those patients for which fluoroscopy times were evaluated was necessary. Because strict confidential measures were utilized to protect this information, and because the research

would not be practical without such a waiver or without access to the potential identifiers, the waiver was granted (Office of Human Research Ethics 2006). Phase 1 research was deemed exempt from continuing IRB review, and the approval letter is found in Appendix C.

Phase 2 was titled "The Use of a Radiochromic Film for the Evaluation of Skin Dose During Extended Fluoroscopy Procedures in an Electrophysiology Lab" and required completing and submitting the full "Application for IRB Approval of Human Subjects Research" (Appendix B). The application received expedited review and the research was approved for one year on June 10, 2005 under the assigned IRB study number of 05-RAD-358 (Appendix B). Subject written consent for participation in phase 2 was not necessary, however subjects were supplied with a "Subject Information Sheet" describing the nature of the research they were participating in, as required by the IRB (Appendix C).

Required Training

Effective March 15, 2005, all faculty, staff and students involved in research using human subjects at UNC are required to complete a web-based training program on issues related to human subject research. All IRB applications submitted are required to include evidence that all study personnel have successfully completed with a passing score of 75% the appropriate Collaborative IRB Training Initiative (CITI) modules (Office of Human Research Ethics 2006). Evidence of completing the required biomedical research module is located in Appendix D.

REVIEW OF ELECTROPHYSIOLOGY FLUOROSCOPY LOG

Method of Evaluation

A retrospective review of the electrophysiology log containing date of procedure, type of procedure performed, physician performing the procedure and total fluoroscopy time was conducted. Mean fluoroscopy times for the different categories of electrophysiology procedures were determined, as well as mean fluoroscopy times for each physician performing the procedures. This information was used to identify likely high-dose EP procedures. High-dose procedures are those with times likely to produce doses approaching the threshold for causing injury to the patient.

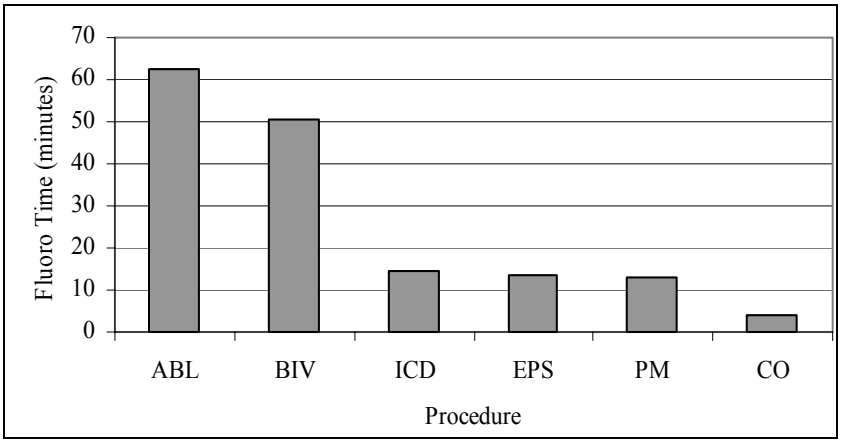
Results

Of the 261 documented procedures for the time period between March 27, 2003 and March 30, 2005, the fluoroscopy times for 247 procedures were analyzed. There were approximately 11 months during this time period for which no information on fluoroscopy time was available. Fluoroscopy time was not properly documented for 11 of the 261 procedures, and the fluoroscopy time for three pediatric cases (66, 28, and 12 minutes) were not used in this study. The physician performing the procedure was not recorded for 22 of the 247 records reviewed. The procedures that were reviewed, including date, physician code, fluoroscopy time, and type of procedure are located in Appendix E.

The 247 procedures evaluated were categorized into six groups of electrophysiology procedures performed at UNC and include: radiofrequency catheter ablation (ABL), biventricular device (BIV), internal cardioverter defibrillator (ICD), electrophysiology study (EPS), pacemaker (PM), and change out (CO).

Mean fluoroscopy times (±SD), with the median and range values in parenthesis, were determined to be 62±48 minutes (44, 1-191 minutes) for ABL, 51±28 minutes (46, 13-121 minutes) for BIV, 14±13 minutes (10, 1-61 minutes) for ICD, 13±14 minutes (10, 2-58 minutes) for EPS, 13±10 minutes (10, 2-53 minutes) for PM, and 4±7 minutes (1, 1-39 minutes) for CO. A graphical representation of the mean fluoroscopy time for EP procedures is shown in Figure 3. Procedures with fluoroscopy times greater than 60 minutes are shown in Table 3.

Figure 3: Mean fluoroscopy time in minutes for the 6 categories of EP procedures evaluated.

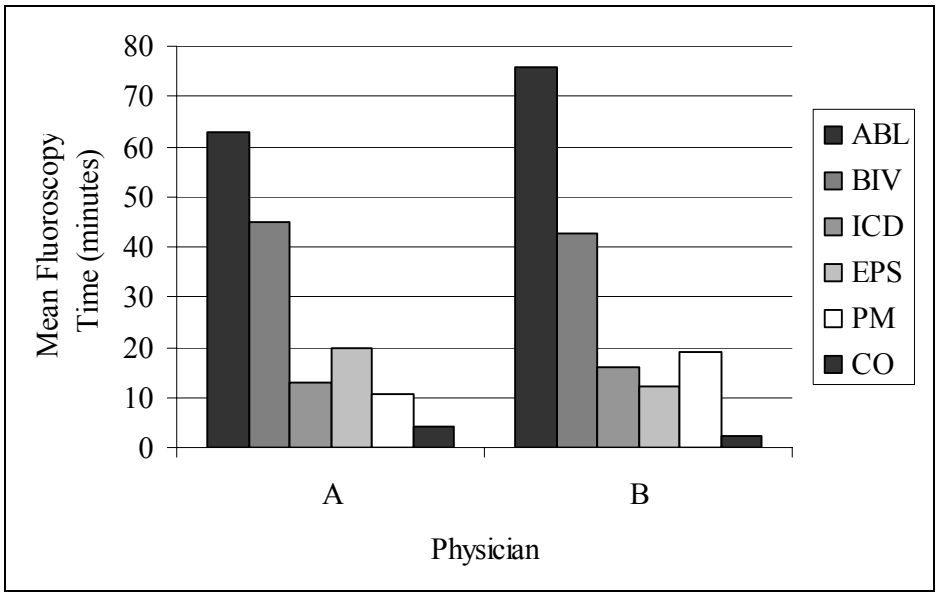


Procedures were also evaluated by physician performing the procedure. Figure 4 shows the average fluoroscopy time for the six categories of procedures for the two primary physicians performing 212 of the 225 adequately documented procedures included in this study.

Table 3: Procedures with fluoroscopy times greater than 60 minutes.

Type of Procedure	Total Procedures	# Procedures >60 min. (%)	# Procedures >90 min. (%)	# Procedures >120 min. (%)
ABL	33	12 (36)	8 (24)	5 (15)
BIV	28	7 (25)	2 (7)	2 (7)
EPS	13	1 (2)	0 (0)	0 (0)
PM	71	0 (0)	0 (0)	0 (0)
CO	46	0 (0)	0 (0)	0 (0)

Figure 4: Mean fluoroscopy time by physician.



Discussion

The data in this study as well as and others in the literature show clearly the great variability in the amount of fluoroscopy time used for a given procedure, as there is great variability in the way a procedure is performed. Conversations with EP staff point out the variability in patient anatomy and pathology which contributes to the wide variability in fluoroscopy times. For example, some ablation procedures require the placement of only one

catheter in the heart, while other types may require up to five and thus necessitate longer fluoroscopy times.

Consistent with the findings of Romeyer-Bouchard (2005), a decrease in the overall mean fluoroscopy time for BIV procedures during the observed time period was observed. However, there has been little change in the overall mean time of ablation procedures.

Based on the retrospective review of the procedures recorded in the EP fluoroscopy log, radiofrequency catheter ablations and biventricular device implants are the two procedures likely to have fluoroscopy times long enough to deliver a dose in excess of the threshold for radiation-induced injury. These two procedures were selected to conduct measurements of patient skin dose, and the results of this research are detailed below.

DOSE MONITORING FOR ABLATION AND BIVENTRICULAR PROCEDURES

Measuring Radiation Dose

The likelihood of injury, such as deterministic effects to a patient, can be predicted by the dose to the skin. Many methods exist for either the indirect estimation or direct measurement of skin dose.

Indirect methods for the estimation of radiation doses often require detailed recording, and thus prove to be time consuming and impractical for routine application. It requires that information on equipment operating parameters (kVp, mA, pulse rate, pulse width, etc), location of the patient with respect to the x-ray source, source-to-image intensifier distances (SID), and other variables be known. One must also know the measured beam intensity for the different operating techniques and any appropriate backscatter factors in order to accurately estimate skin dose. The dynamic nature of the many variables involved in a single procedure compound the complexity and difficulty of indirect estimation of skin dose.

Methods exist for the direct measurement of radiation doses and include the use of thermoluminescent dosimeters (TLDs), diodes or metal-oxide semiconductor field-effect transistor (MOSFET) detectors, and photographic and radiochromic films (Mahesh 2001). In practice, many of these devices are often expensive, require special calibrations, prove difficult or tedious to place on the patient, require a level of expertise for operation, or may even interfere with the procedure by obscuring the region of diagnostic or clinical interest.

Although time and resource consuming, the direct measurement of radiation dose is the only way to determine the actual skin dose received by patients undergoing high-dose fluoroscopy procedures, and may be the best way to evaluate the level of risk for such patients.

Radiochromic Film

The direct measurement of peak skin dose was achieved using a radiochromic dosimetry film that is specifically designed to measure skin dose during fluoroscopically-guided procedures. The film is easy to use, is large enough to intercept the entire x-ray beam, and most importantly does not interfere with the clinical procedure in any way.

The main component of the film is diacetylene, and the underlying mechanism is solid-state polymerization (ISP 2004). The unexposed film is orange in color, turning to a green-black color following exposure to ionizing radiation.

This type of film was developed specifically to measure low-energy photons (<200 keV) and has a range of energy independence from 60-120 keV (the diagnostic energy range used in EP). The dynamic range of the film is 10 rad to 1500 rad, and it is supplied in 14"x17" sheets. The film is self-developing, requires no chemicals, is unaffected by water, blood and other aqueous fluids, is dose rate and dose fractionation independent, and is not light sensitive (ISP 2004).

The film is also relatively inexpensive; costing $20 per 14" x 17" sheet at the time of purchase in June 2005. The University of North Carolina at Chapel Hill Department of Environment, Health and Safety funded the purchase of film used for this research.

For this study, the dose to the film was determined by scanning the exposed film for each subject with a flatbed scanner and using a previously determined calibration curve of known doses and pixel values.

The fluoroscopic x-ray unit used for calibration of the radiochromic film was the Toshiba Model XTP—8100G. A RadCal MDH Model 1515 electronic dosimeter with a 6 cm^3 ionization chamber was used to measure the in-air exposure rates used to generate a dose-response curve for the radiochromic film. The MDH was calibrated by the manufacturer to a NIST-traceable source with an accuracy of +/- 4%.

Calibration Tablet

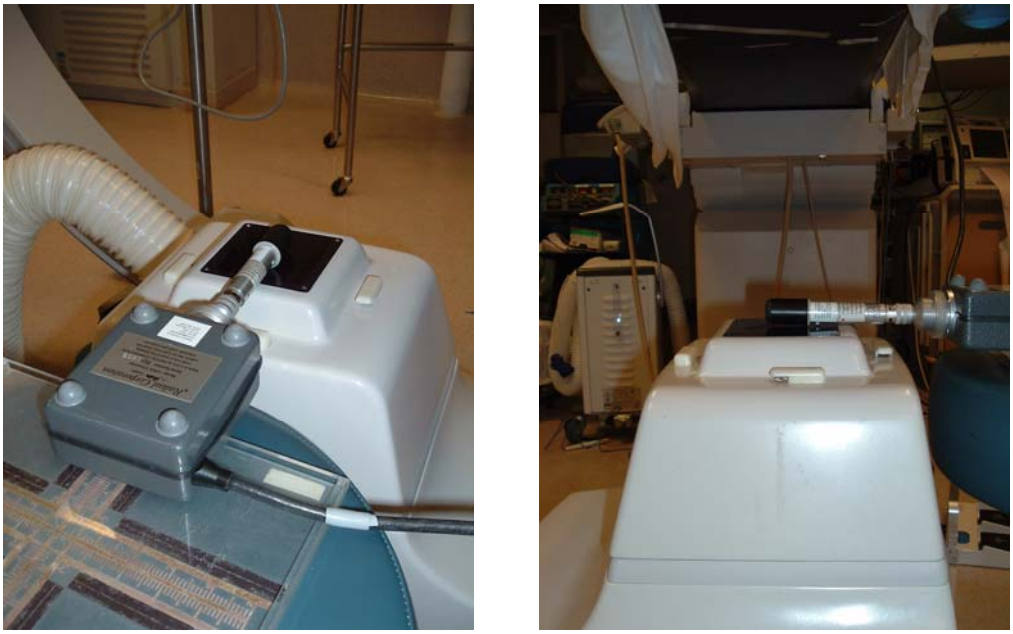
A calibration curve was generated and used to determine the corresponding dose from measured pixel values obtained during film scanning. Necessary equipment included GAFCHROMIC XR Type R dosimetry film, fluoroscopic x-ray unit, calibrated ion chamber with electrometer, color flat-bed scanner, and a computer with Photoshop software.

The calibration procedure was performed using the methods described below:

1. The lot number of the dosimetry film was noted. Although only one lot number of film was used for this study, a separate calibration curve would have been required for each lot number.
2. The x-ray equipment was placed in the orientation in which it is used clinically with the x-ray beam pointing up.
3. The ion chamber was placed in the center of the exposure field, resting on the exit window of the tube housing and connected to the electrometer. The image of the ion chamber was observed on the monitor to ensure that proper centering and that no part of

the chamber was outside of the radiation field. It was repositioned as necessary. The configuration of the ion chamber and x-ray tube housing is shown below in Figure 5.

Figure 5: Ion chamber configuration with respect to the x-ray tube housing.



4. Manual operating techniques of 90 kVp (+/- 1.4%), 100 mA, 10.2 ms pulse width, and 15 pulses/second were used during the calibration process.
5. The exposure rate (R minute^{-1}) was determined 5 times by integrating the total exposure to the ion chamber for a period of 1 minute over different heating stages of the x-ray tube in order to account for any variation. A mean exposure rate of 47.2 R minute^{-1} was obtained, with maximum and minimum values of 47.3 and 47.0 R minute^{-1} respectively. The percent heat load ranged from 5-50% during calibration.
6. Using the measured exposure rate, the exposure times necessary to give total doses of approximately 50R, 100R, 200R, 300R, 400R, 500R, 600R, 700R, 800R, 900, and 1000R

were determined. It was not necessary to hit a dose precisely, but only to be close. The actual dose to the film is the product of the exposure rate and total exposure time to the piece of film. To reduce the time it took to expose the films, stacks of up to three films were exposed simultaneously. After the first dose of D_1 was given to a stack, one film was removed and the remaining two films were given a second dose D_2. The second film was then removed and a third dose D_3 was given to the remaining film. The total dose given to the three films are D_1, D_1+D_2, and $D_1+D_2+D_3$.

7. A sheet of radiochromic film was cut into 12 2"x2" pieces to make up the calibration tablet. The pieces were numbered 1-12 for identification, with tablet number 1 serving as the unexposed reference film.
8. The stacks of film were placed in the same plane as the center of the ion chamber during the exposure rate measurements. A supporting device was used to raise the film to the proper plane, and the films rested on a thin piece of cellophane mounted to a piece of cardstock with a hole in the center. The set-up of the film support device and the device with 2"x2" pieces of film in place is shown below in Figures 6.
9. The remaining calibration tablets were exposed as described in step 6. The date and time of exposure was recorded. The calibration films were kept stored in the dark, unless they were removed for scanning. The date of exposure, minutes exposed, and total exposure is shown below for each tablet in Table 4.

Figure 6: Set-up of the radiochromic film and supporting device with respect to the x-ray tube.

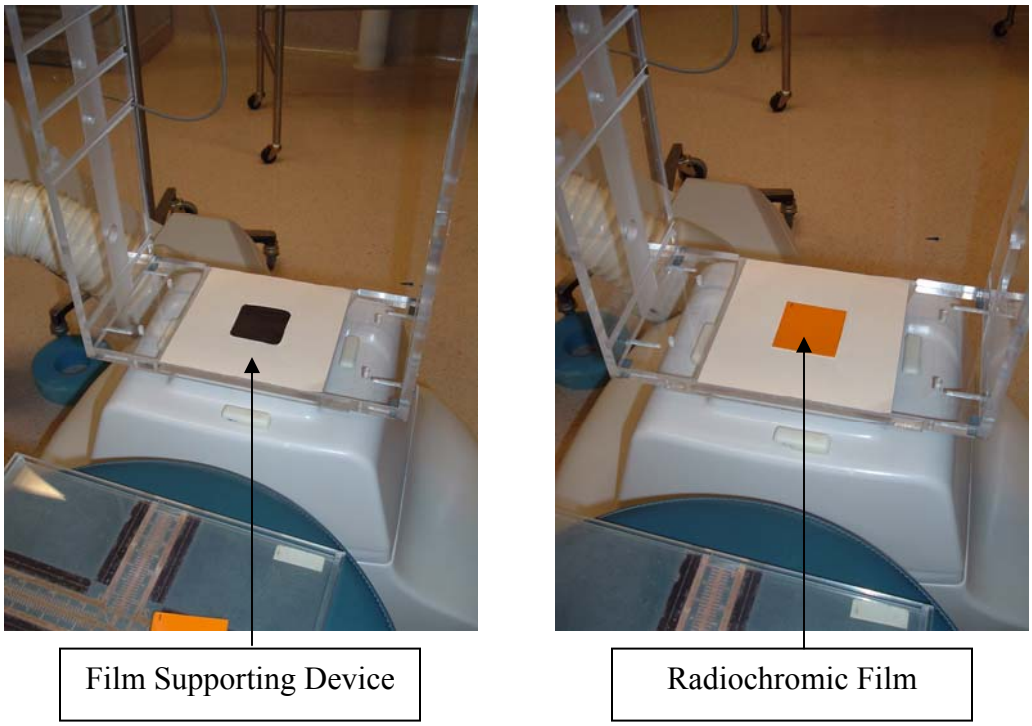


Table 4: Calibration information for tablet #1.

Film Number	Date of Exposure	Minutes Exposed	Total Dose (rad)
1	N/A	0.0	0.0
2	09/02/2005	1.1	51.0
3	09/02/2005	2.2	102.0
4	09/02/2005	4.3	199.3
5	09/02/2005	6.5	301.3
6	09/02/2005	8.7	403.2
7	09/02/2005	10.7	495.9
8	09/02/2005	12.9	597.9
9	09/02/2005	15.0	695.3
10	08/25/2005	17.8	825.0
11	08/25/2005	20.0	927.0
12	08/25/2005	22.5	1042.9

For confirmation and comparison purposes, a second calibration tablet was created using similar methods and techniques described above. A mean exposure rate of 32.2 R minute^{-1} was observed during this calibration which used 90 kVp, 100 mA, 7 ms pulse

width, and 15 pulses/second. Information for the second calibration set is given below in Table 5.

Table 5: Calibration information for tablet #2.

Film Number	Date of Exposure	Minutes Exposed	Total Dose (R)
1	N/A	0.0	0.0
2	02/13/2006	6.0	193.4
3	02/13/2006	12.0	386.8
4	02/13/2006	18.0	580.2
5	02/13/2006	24.0	773.6
6	02/13/2006	30.0	967.0
7	02/13/2006	38.0	1224.9

10. Post-irradiation scans of the calibration tablets were performed on an Epson model 1680 flat-bed scanner. The glass bed of the scanner was wiped with a Kim-Wipe tissue prior to each use to remove any dust or debris. Four calibration tablets were scanned at a time by placing them in the center of an opaque white plastic sheet with a 4" x 4" cutout in the center. This device served to provide consistent centering and border color during scanning. Pertinent scanner information and utilized settings are provided below in Table 6.

Table 6: Epson Model 1680 flatbed scanner settings.

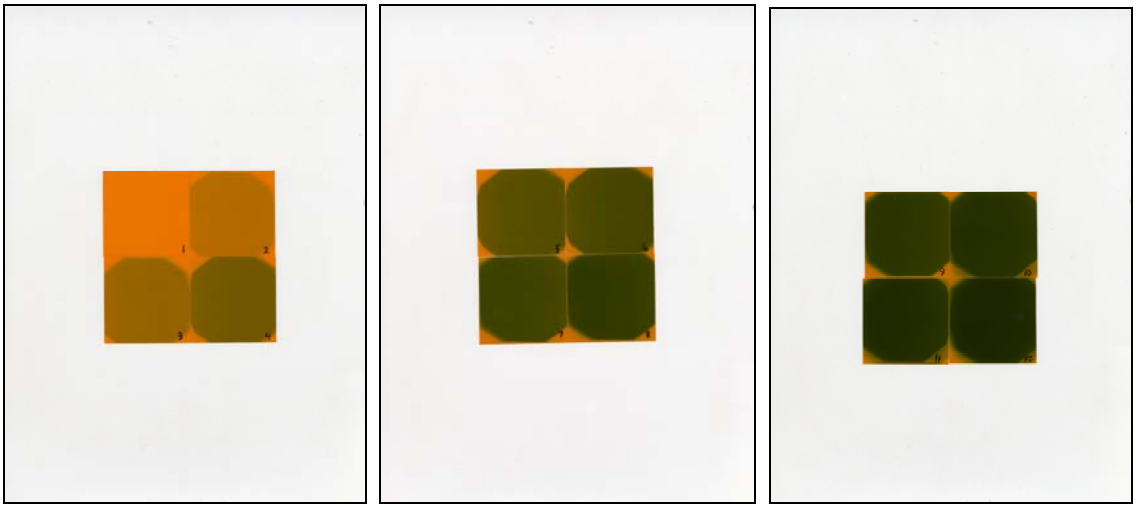
Serial Numbers	39001, 37511
Preview	Yes
Document Type	Reflective
Auto Exposure Type	Photo
Image Type	24-Bit
Scan Quality	Best
Resolution	300 DPI
Target Size	8.5" x 11.7"

11. Film response is defined as the ratio of the color intensity (red, green, or blue) of the non-exposed film to the diminishing same color intensity of the exposed film. The red

component of the scanned image was used in this ratio as it has been shown to have the highest sensitivity, with the blue component shown to be the least sensitive (Thomas 2003).

12. The tablets were scanned into Photoshop software to determine the mean red channel pixel values. These values were obtained for the 0.5" x 0.5" area in the center of each tablet, which corresponds to 22,500 pixels. This area of each tablet was selected and evaluated because it corresponds to the approximate size of the ion chamber and also to the approximate location in the x-ray field where the ion chamber was placed for the initial exposure-rate measurements. The images of the scanned first calibration tablet are shown below in Figure 7, with numbers 1-4 on the left, 5-8 in the middle, and 9-12 on the right. To evaluate the effects of tablet placement, tablets 1 and 2 were scanned together with tablets 11 and 12, which resulted in pixel value percentage changes of 0.2-0.6%.

Figure 7: Scanned images of calibration tablet #1 (numbers 1-4, 5-8, 9-12).



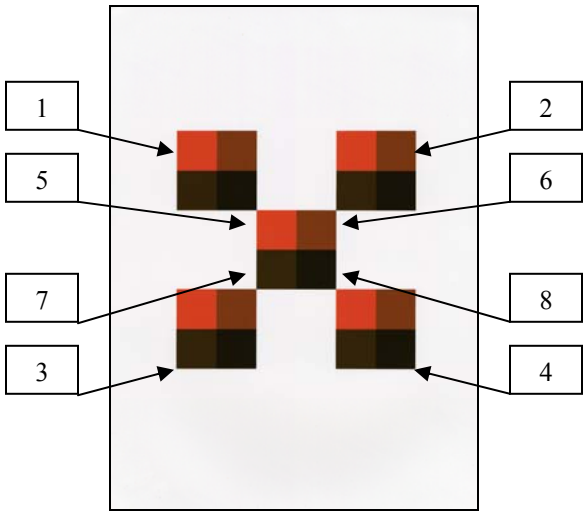
13. Dini et al. (2003) have shown that post-exposure response of the film increases approximately 16% within the first 24 hours of exposure and increases approximately 4% over the next 24 hours. They observed only a growth of approximately 2% for the

following 300 hours (12.5 days). For this project, final pixel values were determined during this stable post-irradiation period of 13 and 14 days for calibration tablets one and two respectively. Since it was thought that waiting two weeks to accurately determine a subject's skin dose may be too long, especially in the event of an exceedingly high dose, calibration tablet two was also scanned at 1, 3, and 7 days post irradiation; thus allowing determination of a subject's dose in a shorter period of time.

14. To ensure consistent operation and performance of the scanner over the time span of this project, a test pattern was created and scanned prior to all other film scans. The pattern was generated using a printing process called dye sublimation, which uses heated printer heads to vaporize solid dyes of yellow, magenta, cyan, and black in color from their plastic sheets into the surface of glossy paper before cooling and returning to a solid form. The result is photo-lab-quality images with images that are not made up as individual dots and have a very uniform appearing color for scanning. Since the dyes actually penetrate the paper, the images are less vulnerable to fading and distortion than with other methods of printing (How Stuff Works 2005).

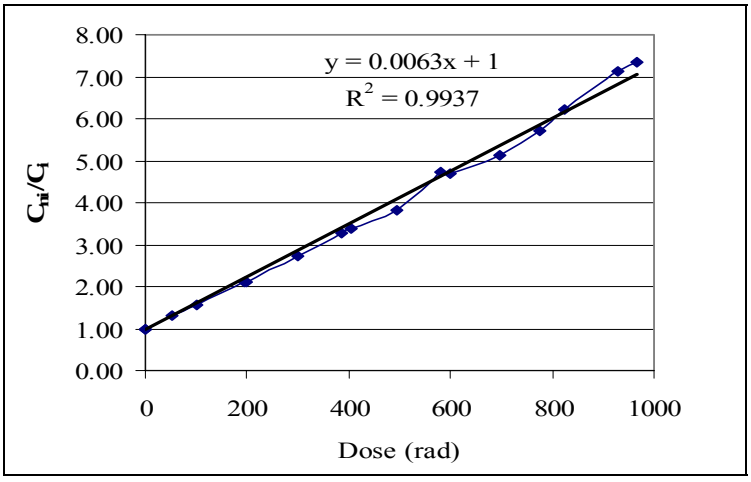
    For the test pattern, the mean red channel pixel values were determined and evaluated for consistency in the eight areas identified in the test pattern image below. Values obtained during the scanning of the daily test pattern is located in Appendix F.

Figure 8: Scanned image of test pattern showing the eight different areas evaluated.



15. The sixteen data points for the 13 and 14-day post-irradiation scans of the two calibration tablets were combined to create one calibration curve for scanner station 1. The ratio of the red channel values for the non-irradiated reference tablet to the irradiated tablet (C_{ni}/C_i) was plotted against the measured dose (rad). Using the fourteen measurements of the non-irradiated reference tablet that were taken from 9/6/2005-2/27/2006, an overall mean C_{ni} value of 229.71 was obtained. This value was used for the "final" calibration curve which was graphed using Microsoft Excel and is shown below in Figure 9.

Figure 9: Final calibration curve for scanner station 1.



16. A 14-day post-irradiation calibration curve was also determined using scanner station 4 and values for the second calibration tablet. This curve was useful because it served as a backup when scanner station 1 suffered failure towards the end of this project. The equation of the linear regression straight line for the 14-day post-irradiation scan on station 4 was determined to be $y = 0.0064x + 1$. The detailed values used to generate the calibration curves for scanners 1 and 4 are located in Appendices G and H.
17. To avoid any non-linear aspect of the curve and because such high doses were not encountered during this project, calibration curves used to determine subject doses did not include the highest measured dose of 1224.9 rad from the second calibration tablet.

Dose Measurement Protocols

Working closely with the Cardiology administrative staff handling the scheduling of all electrophysiology procedures, scheduling information for ablation and biventricular procedures was obtained. Patient dose monitoring began on September 9, 2005 and continued until June 8, 2006.

Prior to the start of each procedure, the research project was described to each subject. They were provided the required Subject Information Sheet, oral approval was obtained and their height and weight values were recorded.

For each subject, a single piece of 14" x 17" film was placed underneath the thin bed sheet on which the subject lies during the procedure. The film rested between the subjects' back and the supporting table top. The top edge of the film was placed at approximately the upper part of the shoulder where it meets the neck, and was centered roughly to the area of the

heart. To prevent contamination of the film with blood or other potentially hazardous materials, each film was place inside of a thin protective plastic cover prior to use.

Variables recorded for each procedure include demographic details of the patient such as age, sex, height and weight, procedure category (i.e. ABL), nature of diagnosis (i.e. atrial flutter), physician(s), and fluoroscopy time. Equipment variables such as continuous vs. specific pulse rate, phosphor size used, and table height information were recorded as available and whenever possible. A procedure information sheet was developed and used to record this information for each subject and is located in Appendix I.

Subject Film Scanning Protocols

The absorbed dose for each subject was determined by first visually identifying the darkest exposed area of the film, which was centered in the same 4"x4" opening in the white plastic device that was used for scanning the calibration tables. Scanning was performed using the protocols described in steps 10-14 of "Calibration Tablet" in this section. Ten attempts were then made to identify the area of the scanned image having the lowest mean red pixel value which represents the area receiving the highest absorbed dose.

Peak skin dose was determined by substituting the lowest mean red pixel value into the appropriate linearly regressed straight line equation ($y=\beta x+\alpha$, where α is the intercept and β is the slope) as determined in steps 15 and 16 of the calibration tablet procedure.

Results

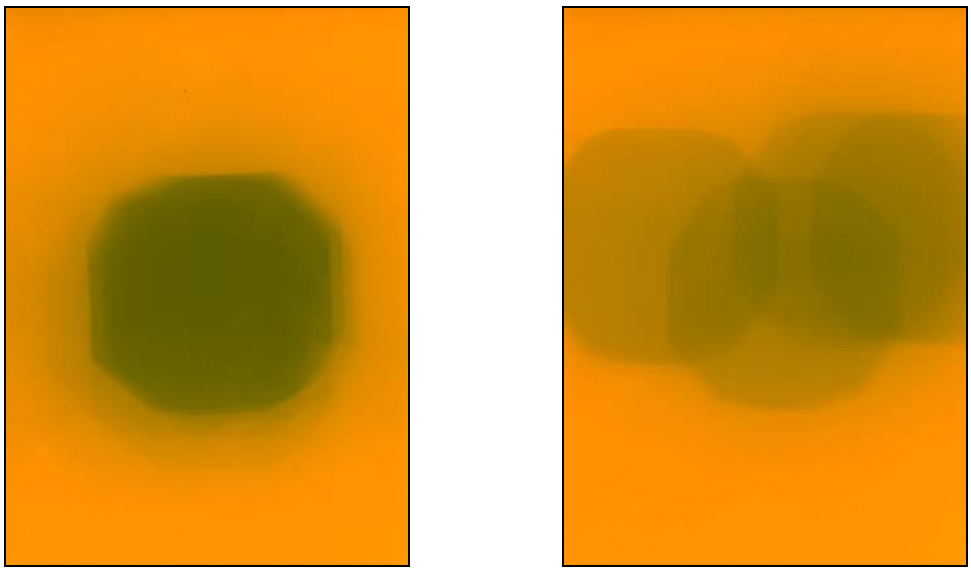
The purpose of the daily test pattern was to identify any irregularity in scanner operation. The daily pattern was comprised of colors having red channel pixel values ranging from

approximately 25-210, which correspond to doses of approximately 15 to 1310 rad. Scanner performance was very good over the range of pixel values evaluated, as demonstrated by the coefficients of variation which ranged from only 0.4% to 2.1%. This is consistent with other reported coefficients of variation for flatbed scanners of 1.8% (Thomas 2005). The red channel pixel values obtained for the daily test pattern are provided in Appendix F.

For the thirty-three subjects, thirty procedures resulted in accurate fluoroscopic time and measurable dose. One procedure was performed with the x-ray tube positioned over the patient so that exit dose was recorded rather than entrance dose; however no visible darkening was noted on this subject's film. An artifact was seen on the video monitor during another case and the film was removed by the physician thinking the artifact might have been caused by the film. The artifact was actually caused by the improper placement of a cardiac mapping system often used during ablation procedures. The third procedure that was omitted was due to the loss of fluoroscopy time because of a procedural error involving the time recording device.

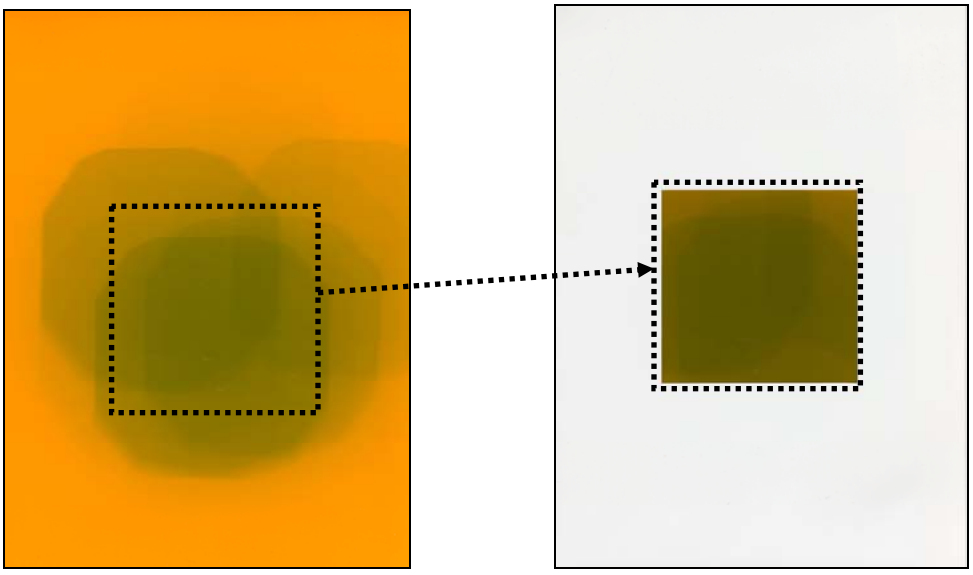
Final red channel values were obtained between 13 and 17 days post-irradiation for the thirty measured skin doses. As an example, the scanned film for subjects 2 and 27 are shown below in Figure 10. Note the stationary position of the x-ray tube during the ablation procedure on the left (subject 2) as compared to the more dynamic irradiation pattern of the BIV procedure for subject 27 (on the right).

Figure 10: Scanned films of subjects 2 and 27.



Scanned images for subject 23 are shown below in Figure 11. The image on the right is with the centering template in place and is the image used for final pixel value determination.

Figure 11: Scanned image for subject 23 with and without centering template.



The mean, standard deviation, maximum, and minimum values for patient weight, BMI, fluoroscopy time, and peak skin dose are given below in Table 7. This table also reports this

information by type of procedure as well as by physician performing the procedure. The number of procedures is given as well.

Table 7: Summary of descriptive statistics for patient weight, BMI, fluoroscopy time, and peak skin dose by type of procedure and physician.

All Procedures	**Mean**	**Standard Deviation**	**Maximum**	**Minimum**
Weight (lbs)	204.0	57.7	331.0	116.0
Body Mass Index (BMI)	30.0	7.0	43.7	19.3
Fluoroscopy time (min)	46.2	24.5	94.0	12.5
Peak skin dose (rad)	149.9	142.1	764.4	31.8
Number of Procedures	30			
Ablation Only	**Mean**	**Standard Deviation**	**Maximum**	**Minimum**
Weight (lbs)	181.4	40.2	240.0	116.0
Body Mass Index (BMI)	27.4	5.3	37.8	19.3
Fluoroscopy time (min)	57.4	27.8	94.0	12.5
Peak skin dose (rad)	133.2	94.0	366.9	31.8
Number of Procedures	14			
BIV Only	**Mean**	**Standard Deviation**	**Maximum**	**Minimum**
Weight (lbs)	223.8	64.4	331.0	146.0
Body Mass Index (BMI)	32.4	7.6	43.7	21.1
Fluoroscopy time (min)	36.4	16.5	71.4	19.3
Peak skin dose (rad)	164.5	175.8	764.4	38.6
Number of Procedures	16			
Physician A	**Mean**	**Standard Deviation**	**Maximum**	**Minimum**
Weight (lbs)	213.1	56.1	331.0	146.0
Body Mass Index (BMI)	30.9	6.9	43.2	21.1
Fluoroscopy time (min)	44.3	25.4	94.0	19.3
Peak skin dose (rad)	144.1	94.6	366.9	38.6
Number of Procedures	18			
Physician B	**Mean**	**Standard Deviation**	**Maximum**	**Minimum**
Weight (lbs)	190.4	59.9	331.0	116.0
Body Mass Index (BMI)	28.8	7.2	43.7	19.3
Fluoroscopy time (min)	49.0	23.9	85.1	12.5
Peak skin dose (rad)	158.6	198.2	764.4	31.8
Number of Procedures	12			

Fifty percent of ablation procedures exceeded 1 hour of fluoroscopy while fourteen percent exceed 90 minutes. Only twelve percent of the BIV cases exceed 60 minutes of fluoroscopy. A summary of the procedures with fluoroscopy times greater than 1 hour is provided below in Table 8.

Table 8: Subjects monitored with fluoroscopy times greater than 60 minutes.

Type of Procedure	Total Procedures	Procedures >60 minutes (%)	Procedures >90 minutes (%)	Procedures >120 minutes (%)
ABL	14	7 (50)	2 (14)	0 (0)
BIV	16	2 (12)	0 (0)	0 (0)

Forty percent of the subjects had a BMI corresponding to a CDC weight classification of obese. Descriptive statistics of the peak skin dose by weight classification are given below in Table 9.

Table 9: Descriptive statistics of the peak skin dose by BMI weight classification.

	Normal BMI of 18.5-24.9	Overweight BMI of 25-29.9	Obese BMI of 30 and greater
Number of Subjects	9	9	12
% of Total Subjects	30%	30%	40%
Mean Dose (rad)	72.4	119.1	231.1
Standard Deviation	30.3	75.4	188.6
Minimum	31.8	38.6	71.6
Maximum	111.0	264.7	764.4
Subjects (%) in BMI Class > 200 rad	0 (0)	2 (25)	5 (38)
Mean Dose Rate (rad minute^{-1})	1.9	2.5	5.3
Standard Deviation	0.6	0.9	3.6
Minimum	1.0	1.2	2.5
Maximum	2.8	3.8	15.7

Overall, male subjects (n=20) weighed more and had a higher BMI than female subjects (n=10). Although fluoroscopy time differed very little between the sexes, male subjects

received mean peak skin doses double that of female subjects. No female subjects exceeded a skin dose of 200 rad. Detailed information related to subject sex is provided below in Table 10.

Table 10: Subject weight, BMI, fluoroscopy time, and peak skin dose by sex.

Weight (lbs)	**Mean**	**Standard Deviation**	**Maximum**	**Minimum**
Male	223.5	54.5	331.0	147.0
Female	165.1	44.2	240.0	116.0
BMI				
Male	31.1	6.9	43.7	21.1
Female	27.8	7.0	39.9	19.3
Fluoroscopy Time (min)				
Male	45.2	24.4	91.7	12.5
Female	48.3	26.0	95.0	25.8
Peak Skin Dose (rad)				
Male	179.8	166.0	764.4	31.8
Female	90.2	31.1	155.8	37.2

The overall mean entrance skin dose rate for this project was determined to be 3.4 rad minute^{-1} for both ablation and BIV procedures. This is consistent with the typical fluoroscopy ESE level of 2.5 R minute^{-1} as noted by the IAEA (1996) when assuming typical backscatter factors of approximately 20-40% (Wall 1996). As one would expect, the mean dose rate increases with higher subject BMI, and these values are provided above in Table 9 for the different BMI classifications. A complete listing of subject information, procedural specifics, and film scanning/dose information that was collected for the thirty study participants is provided in Appendix J.

Scatter plots and statistical parameters were generated using Microsoft Excel. The correlation between different grouped parameters has been described by the r^2-value (the square of the correlation coefficient). This value describes the linear least squares fit relationship between the data sets.

Peak skin dose was correlated to patient weight, weight x fluoroscopy time, BMI, BMI x fluoroscopy time, and fluoroscopy time with r^2-values for all procedures combined of 0.37, 0.41, 0.30, 0.36, and 0.12 respectively. An increasing r^2-value means a stronger relationship between the variables compared. Another way of thinking of this for this project is how much of the variability in peak skin dose is due to variability in weight, BMI and fluoroscopy time. See Figures 12-16. The straight line on each figure below represents a linear regression analysis.

Figure 12: Scatter plot of peak skin dose in rad vs. subject weight in pounds.

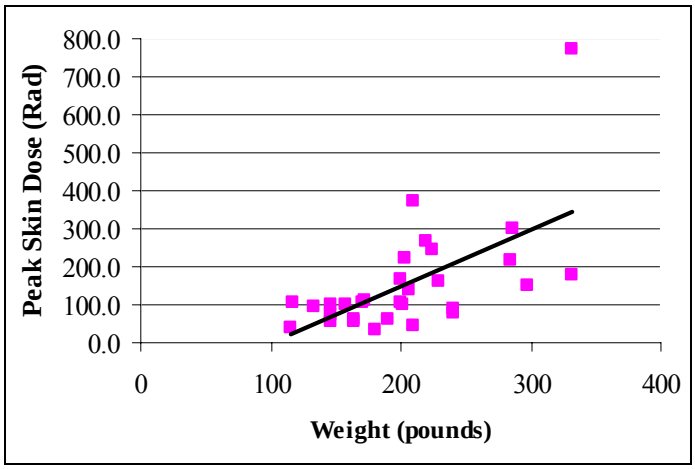


Figure 13: Scatter plot of peak skin dose in rad vs. subject weight x fluoroscopy time.

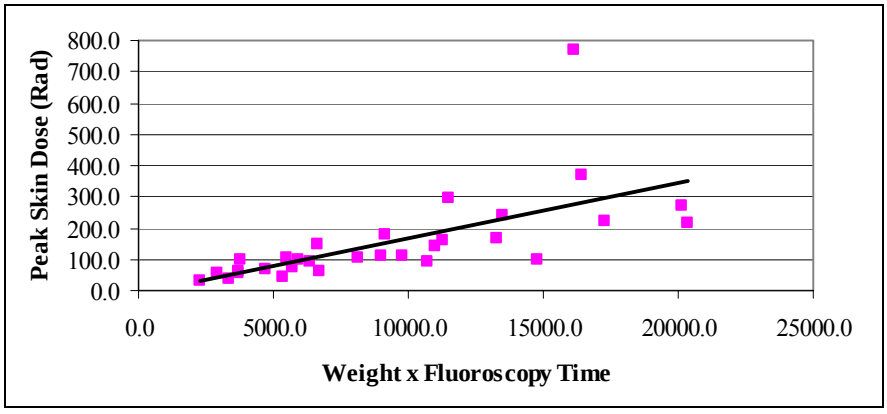


Figure 14: Scatter plot of peak skin dose in rad vs. subject BMI.

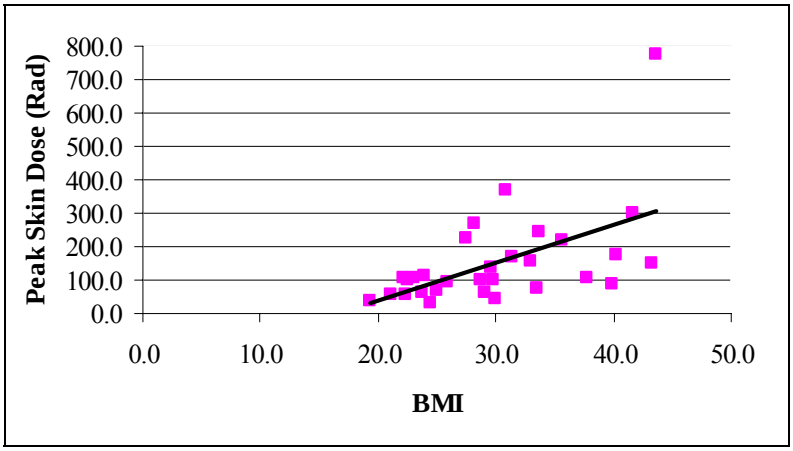


Figure 15: Scatter plot of peak skin dose in rad vs. subject BMI x fluoroscopy time.

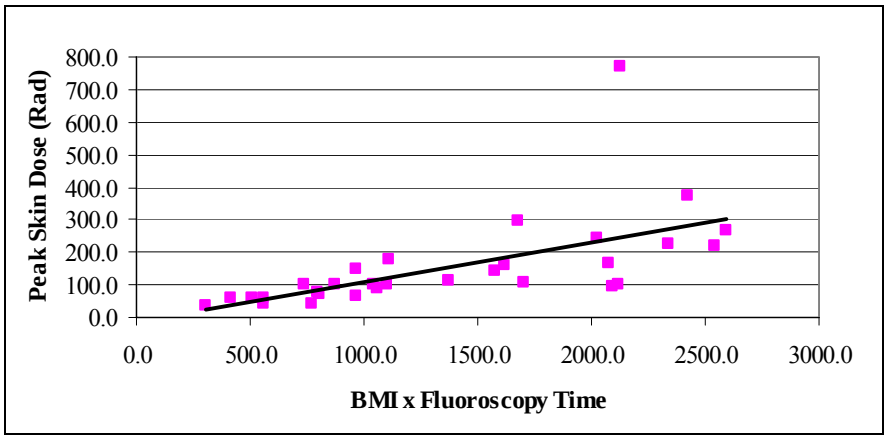
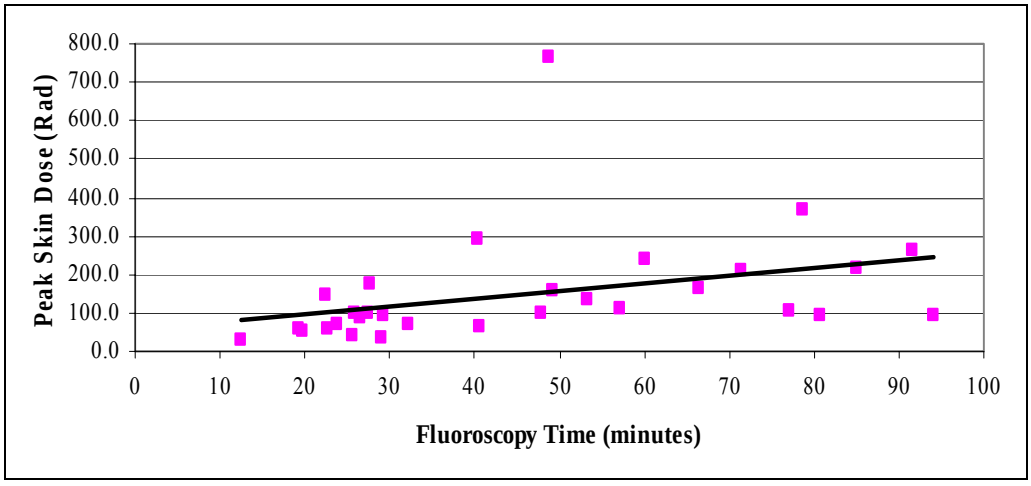


Figure 16: Scatter plot of peak skin dose in rad vs. fluoroscopy time.



The correlation between these parameters was determined for individual procedure types, as well as with and without the outlying data point one. A summary of the calculated r^2-values is presented below in Table 11.

Table 11: Summary of r^2-values for the correlation of peak skin dose to patient weight, weight x fluoroscopy time, BMI, BMI x fluoroscopy time, and fluoroscopy time.

	Dose vs. Weight	Dose vs. Weight x Time	Dose vs. BMI	Dose vs. BMI x Time	Dose vs. Time
Ablation Only	0.23	0.68	0.13	0.61	0.37
BIV Only	0.43	0.44	0.37	0.44	0.18
BIV (No Subject 1)	0.45	0.60	0.42	0.65	0.37
All Procedures	0.37	0.41	0.30	0.36	0.12
All Procedures (No Subject 1)	0.26	0.63	0.21	0.59	0.32

Discussion

During this project, we were able to develop accurate and reproducible procedures for the calibration of radiochromic film to be used for the monitoring of the peak skin dose for subjects undergoing extended fluoroscopy procedures in an EP Lab. The data show a positive correlation between the variables which we compared; however the linear correlation is generally poor. The mean fluoroscopy time (57.4 minutes) and dose (133.2 rad) for ablation procedures were found to be consistent with values of 58 minutes and 130 rad reported by Rosenthal (1998); however peak skin dose does not correlate as well with the product of BMI and fluoroscopy time as reported by Iida (2004). Our data show an overall r^2-value of 0.36 while Iida demonstrated better correlation with r^2-values of 0.91 for

diagnostic and 0.78 for interventional radiology procedures that involved 19 and 26 subjects respectively.

Our r^2-value of 0.41 for the overall correlation between the product of subject weight and fluoroscopy time is lower than the r^2-value of 0.50 reported by Chida (2006); however our r^2-value of 0.68 for the correlation among ablation procedures is much higher.

Overall, fluoroscopy time alone does not correlate well to dose and is a poor predictor of risk to which a subject undergoing ablation or BIV procedures may be exposed. Our r^2-value of 0.37 for ablation procedures is lower than the value of 0.64 reported by Chida (2006) for the same procedure type. The subjects in the Chida study were much smaller than our subjects and had a mean weight of only approximately 130 ± 20 pounds (Chida 2006). This significant difference in weight between the two study groups may explain the different correlation values.

Although a significant positive correlation was demonstrated to exist between peak skin dose and the product of both patient weight and BMI multiplied by the total fluoroscopy time, the variability due to other factors is too large to use any of these as a sole predictor of dose and subsequent risk.

Subject 1 is an outlier in Figures 12-16 and deserves discussion. This BIV subject had the highest BMI of all study participants (43.7), tied for the highest weight at 331 lbs, and received a peak skin dose high enough to cause permanent destruction of the epithelium. Although the dose was unusually high for the fluoroscopy time as compared to other subjects, it points out the importance of other factors in the dose variability. Medical procedures involving fluoroscopy are dynamic in nature and can vary with each subject undergoing the same type of procedure. Body composition, influenced by age and specific

pathology, or placement of the patient with respect to the x-ray tube, and mode of equipment operation may have contributed to the higher peak skin dose for this subject. Assuming no measurement errors, if this subject underwent the lengthiest ablation procedures monitored in this study (94 minutes), then their peak skin dose would have approached 1,500 rad; a dose which the JCAHO considers to be a sentinel event involving serious injury or the risk thereof (JCAHO 2006).

Although the number of subjects evaluated during this project was small (30), none of those having a normal BMI (18.5-24.9) or weighing $\leq$ 200 pounds exceeded a threshold for radiation-induced effects (200 rad) as described by Wagner and Archer (1996). In contrast, 25% of the overweight and 38% of obese subjects exceeded 200 rad peak skin dose.

As with all research, we must consider sources of variability and error throughout the project. There is a strong degree of confidence in the calibration and scanning procedures developed for this project, and errors were most likely to occur during the collection and recording of subject or procedure information. Weight and height specifics were collected indirectly from either the subject or from anesthesia personnel, and erroneous information may have been collected or presented, or the misrecording of information may have occurred. Additionally, fluoroscopy time was often collected after the completion of a procedure from the logbook rather from the equipment directly, and again mistakes may have been made in the transcribing of fluoroscopy time.

CONCLUSIONS AND FUTURE DIRECTION

Overweight and obese subjects undergoing ablation and BIV device implant procedures at this institution during this study received peak skin doses in excess of the threshold for observable radiation-induced effects. One must consider that although rare, the likelihood of a severe radiation-induced injury during such extended fluoroscopy-guided interventional procedures exists. In this study, the correlation between peak skin dose and fluoroscopy time was demonstrated to be poor. Subject peak skin dose correlated best to the product of weight and fluoroscopy time and the product of BMI and time. Although neither is strong enough to accurately predict individual doses, the results are strong enough to make useful conclusions.

We were able to meet five of the six specific project goals. This project did not produce results strong enough to support the development of accurate methods to indicate to a physician when peak skin dose may exceed a threshold for observable radiation-induced effects. However, in the absence of more conclusive information, it is worth noting that if the product of a subject's weight and fluoroscopy time is greater than 11,000 minute-pounds, then it is likely that the subject received a peak skin dose in excess of 200 rad.

Both in hindsight and for the suggestion of future study, the determination of subject thickness at heart level may correlate better to skin dose than either weight or BMI and may better assist in the development of such procedures. This study also did not take into consideration the possibility that a subject may have undergone additional procedures

involving fluoroscopy. Such procedures, both prior to or after our study, are important to consider as they would increase a subject's risk for developing observable radiation-induced effects to a level greater than indicated in this study.

The monitoring of patient dose during extended fluoroscopy procedures remains a complicated and important consideration. A facility should consider the routine monitoring of skin dose, in particular for those overweight and obese patients appearing to be at increased risk.

APPENDICES

Appendix A
Simulated ESE Rates Based Upon Subject Thickness

ABS Mode of Operation	Phantom	kVp	mA	ms	ESE (R min^{-1})
Continuous	3.8 cm Al	82	2.5	n/a	1.7
30 pulses per second	3.8 cm Al	80	32	2.8	1.75
15 pulses per second	3.8 cm Al	80	38	3.8	1.35
7 pulses per second	3.8 cm Al	80	33	4.8	0.7
Continuous	3.8 cm Al + 3" lucite	98	3.5	n/a	3.5
30 pulses per second	3.8 cm Al + 3" lucite	80	90	3.9	6.6
15 pulses per second	3.8 cm Al + 3" lucite	80	91	5.9	5.17
7 pulses per second	3.8 cm Al + 3" lucite	80	69	8.2	2.52
Continuous	3.8 cm Al + 6" lucite	120	3.8	n/a	6.1
30 pulses per second	3.8 cm Al + 6" lucite	99	117	2.7	9.32
15 pulses per second	3.8 cm Al + 6" lucite	93	123	5.8	9.1
7 pulses per second	3.8 cm Al + 6" lucite	81	137	13	7.68

Values obtained on 05/05/2004

Appendix B
IRB Applications and Approvals

APPLICATION FOR RESEARCH REQUESTING AN IRB WAIVER OF CONSENT AND HIPAA AUTHORIZATION

Research for which this form is appropriate generally involves only existing patient records or specimens. If there will be any intervention or interaction (e.g. questionnaires, interviews, randomization), or any direct contact of any kind with the subjects of this research, **STOP HERE**. Consent/authorization will need to be obtained, and a full IRB application will be required.

PROJECT NUMBER (will be assigned by the IRB) _____

TITLE OF PROJECT: Identification of Likely High Radiation Dose Procedures through the Evaluation of Fluoroscopic Times in an Electrophysiology Lab.

PRINCIPAL INVESTIGATOR: Bradford Taylor
UNC-CH DEPARTMENT: Environment, Health and Safety
CAMPUS MAILING ADDRESS: CB# 1650
212 Finley Golf Course Road
Chapel Hill, NC 27517

PID NUMBER OF PRINCIPAL INVESTIGATOR: 7029-00680

PHONE: 919-962-5727 **FAX:** 919-962-0227 **PAGER:** 919-216-4564 **E-MAIL ADDRESS:** Bradford_Taylor@unc.edu

NAME OF SPONSOR: Marija Ivanovic, Ph.D.

Proposal for Research Involving: *(Check all that apply)*

- ☐ Patient Specimens (tissues, blood, serum, etc.)
- ☒ Medical Records (custodian may also require form, e.g. HD-974 if UNC-HCS)
- ☐ Electronic Information from Clinical Database (custodian may also require form)

1. **Scientific purpose of the study:** Provide a brief summary of the background information, state the research question(s), and tell why the study is needed. Include a full description of the study design, methods and procedures.

   The Food and Drug Administration (FDA) has reported that severe radiation-induced burns have occurred in patients undergoing invasive fluoroscopic procedures, and has made recommendations for the avoidance of such x-ray-induced skin injuries.

   Typical absorbed dose rates from fluoroscopic x-ray equipment are between 2 and 5 rad/minute, but can vary greatly depending upon modes of equipment operation,

movement of the x-ray source during the procedure, and patient size. Radiation injury, apparent as early transient erythema, has been observed after absorbed doses to the skin of about 200 rad. Even at typical dose rates, injury to the skin can occur after less than one hour of fluoroscopy time. More severe effects can occur if the fluoroscopy times are longer and the subsequent doses larger.

The objective of this project is to evaluate radiation exposures to patients undergoing x-ray procedures at UNC-Hospitals Electrophysiology (EP) Lab through the collection and evaluation of data on fluoroscopic times, which provide the best overall indicator of relative absorbed doses to the patient.

A log book of fluoroscopic times utilized during EP procedures that is maintained in the UNC-Hospitals EP Lab will be evaluated for this study. Procedures having fluoroscopy times approaching or exceeding 60 minutes will be considered likely high-dose.

2. **Where are the data and/or specimens located now?** In paper format in a logbook in the EP Lab.

3. **The data were originally gathered for**: ☒ clinical use ☐ research use ☐ not applicable

   The specimens were originally gathered for: ☐ clinical use ☐ research use ☒ not applicable

   Has the purpose for which the specimens were collected been met before removal of any excess, as certified by the pathologist in charge or clinical laboratory director?
   ☐ yes ☐ no ☒ not applicable

4. **Will the data be recorded and/or specimens labeled using any of the identifiers on the following list? (remember that "Protected Health Information" = health information + identifiers)** ☐ yes ☒ no *If yes, check all that apply*:

☐ Names
☐ Any geographic subdivisions smaller than a State, including street address, city, county, precinct, zip code and their equivalent geocodes, except for the initial three digits of a zip code
☐ Any elements of dates (except year) for dates directly related to an individual, including birth date, admission date, discharge date, date of death. For ages over 89: all elements of dates (including year) indicative of such age, except that such ages and elements may be aggregated into a single category of age 90 and older
☐ Telephone numbers
☐ Fax numbers
☐ Electronic mail addresses
☐ Social security numbers
☐ Medical record numbers
☐ Health plan beneficiary numbers
☐ Account numbers
☐ Certificate/license numbers
☐ Vehicle identifiers and serial numbers, including license plate numbers
☐ Device identifiers and serial numbers
☐ Web universal resource locators (URLS)

☐ Internet protocol (IP) address numbers
☐ Biometric identifiers, including finger and voice prints
☐ Full face photographic images and any comparable images
☐ Any other unique identifying number, characteristic or code, other than dummy identifiers that are not derived from actual identifiers and for which the re-identification key is maintained by the health care provider and not disclosed to the researcher

If "yes" or any item checked, with whom will Protected Health Information be shared during the course of the research?

☐ Coordinating Center ☐ Statisticians ☐ Consultants ☐ Other researchers ☐ Registries
☐ Sponsors (listed above) ☐ Labs ☐ Journals ☐ Other:
_____

5. **How will confidentiality be protected?** *(must be answered in detail in the space below)*
   Since protected health information is not being gathered and included in this project, confidentiality will remain protected. The only identifier in the data (logbook) to be analyzed is patient name, which will be removed from the data prior to being removed from UNC-Hospitals for analysis.

6. **How will data be protected?** *(Per UNC Security Policy, data should be stored behind at least two of the following safeguards. Please check all that apply).*

   For electronic data:
   ☐ Secure network ☐ Password access ☐ Other:_____

   For hardcopy data:
   ☒ Data de-identified by research team (stripped of 18 identifiers listed above) ☐ Locked suite ☒ Locked office
   ☐ Locked file cabinet ☐ Data coded by research team with a master list secured and kept separately
   ☐
   Other:_____
   ___

7. **Describe your plan to destroy identifiers.**
   The only patient identifier we will have access to is patient name, which will not be gathered for use in this project. Patient names will be removed from the information to be analyzed prior to removing from UNC-Hospitals. Since no identifiers are gathered for this project, there will be no identifiers to destroy.

8. **When will identifiers be destroyed?**
   Identifiers (patient name) will be removed from the information to be analyzed prior to removing it from UNC-Hospitals.

9. To justify a waiver of the requirement to seek informed consent and/or HIPAA authorization from the subjects, you must be able to answer "YES" to items (a)-(f) below. Insert explanations that support your request for waiver.

a) **Will the research involve <u>no greater than minimal risk</u> to subjects or to their privacy?**

☒ yes ☐ no

(Minimal risk means that the probability and magnitude of harm or discomfort anticipated in the research are not greater than those ordinarily encountered in daily life or during the performance of routine physical or psychological examinations or tests.)

b) **Is it true that the waiver will not adversely affect the rights and welfare of subjects?**

☒ yes ☐ no

(Consider the right of privacy and possible risk of breach of confidentiality in light of the information you wish to gather.)

c) **Is the risk to privacy reasonable in relation to benefits to be gained or the importance of the knowledge to be gained?**

☒ yes ☐ no

d) **Would the research be impracticable without the waiver?**

☒ yes ☐ no

(If you checked "yes," explain how the requirement to obtain consent would make the research impracticable, e.g. are most of the subjects lost to follow-up or deceased?).

There are hundreds of electrophysiology procedures performed that we will analyze the fluoroscopy time of, thus contacting all involved individuals is impracticable.

e) **Would the research be impracticable if you could not record protected health information (PHI)?**

☒ yes ☐ no

(If you checked "yes," explain how **not** *recording PHI would make the research impracticable).*

Since no patient identifiers are necessary for this project, we will be gathering no such information.

f) **When appropriate, do you have plans to provide subjects with pertinent information after their participation is over?**

☒ yes ☐ no

(e.g. Will you provide details withheld during consent, or tell them if you found information with direct clinical relevance for the subjects? This may be an uncommon scenario)

No new information will be learned during this analysis of existing records that would be pertinent to the subjects.

STATEMENT OF PRINCIPAL INVESTIGATOR:

I certify that the above information is correct, that it will apply throughout the performance of the proposed research and that I will be responsible for safeguarding the confidentiality of the human subjects who are involved. I am aware of the confidential nature of the information obtained for the purposes of this research. No protected health information (PHI) from this research will be shared with or disclosed to others, for purposes other than conducting the research as described above. I will vouch for any person other than myself who will work with this information under my direction. The names of these persons are:

_____ _____

I agree to a continuing exchange of information with the IRB. I agree to obtain IRB approval before making any changes or additions to the project. I will provide progress reports at least annually, unless this application is determined by the IRB to be exempt from continuing review.

Signed _____ _____
Principal Investigator *Date*

_____ _____
Faculty advisor, if principal investigator is student *Date*

For specimens:_____ _____
Director of laboratory where specimens are stored *Date*

Please remember to submit a copy of the Ethics Education Certificate, printed from the Research Ethics Training Database, for all investigators and study staff. See IRB website for details.

THE UNIVERSITY OF NORTH CAROLINA AT CHAPEL HILL
Office of Human Research Ethics

Biomedical Institutional Review Board (IRB)
(919) 966-1344 FAX (919) 966-7879
www.med.unc.edu/irb/

School of Medicine Bldg. 52, CB 7097
University of North Carolina at Chapel Hill
Chapel Hill, NC 27599-7097

September 8 2004

TO: Bradford Taylor

Your proposal entitled: Identification of Likely High Radiation Dose Procedures Through the Evaluation of Fluoroscopic Times in an Electrophysiology Lab

is exempt from review by The Committee on the Protection of the Rights of Human Subjects (the IRB for the University of North Carolina School of Medicine and the University of North Carolina Hospitals). Exemption is claimed on Number(s) 4 of the criteria for exemption outlined in 45 CFR Part 46 Section 101:

> Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available or if the information is recorded by the investigator in such a manner that subjects cannot be identified directly, or through identifiers linked to subjects.

Since the data, records and specimens referred to (in the regulations) are virtually never publicly available, the second requirement - anonymity - must be met. This precludes the recording of the research data (on worksheets as well as in final form) with a subject's name, initials, social security number, hospital record number, or code that can be used to link the information to the subject.

This exemption should be noted on the Department of Health and Human Services grant application form, and must include the exemption number(s) 4.

NOTE: If the project is changed, it should be re-submitted to the IRB office for a determination of whether it still satisfies exemption criteria.

Stephen A. Bernard, M.D.
Chairman, Committee on the Protection
of the Rights of Human Subjects

OFFICE OF HUMAN RESEARCH ETHICS
Institutional Review Board

APPLICATION FOR IRB APPROVAL OF HUMAN SUBJECTS RESEARCH
Version 19-May-2005

For IRB Use
Behav Bio Dent Nurs PH
IRB Study #_____
Rec'd_____
Full Expedited Exempt

Part A.1. Contact Information, Agreements, and Signatures

Title of Study: The Use of a Radiochromic Film for the Evaluation of Skin Dose During Extended Fluoroscopy Procedures in an Electrophysiology Lab.
Date: May 23, 2005

Name and degrees of Principal Investigator: James Bradford Taylor, BS
Department: Environment Health and Safety Mailing address/CB #: CB# 1650
UNC-CH PID: 702900680 Pager: 216-4564
Phone #: 962-5727 Fax #: 962-0227 Email Address: Bradford_Taylor@unc.edu

For trainee-led projects: __ undergraduate X graduate __ postdoc __ resident __ other
Name of faculty advisor: Marija Ivanovic, Ph.D.
Department: Radiology Mailing address/CB #: CB# 7510
Phone #: 843-0717 Fax #: Email Address: MIvanovi@unch.unc.edu

Name, phone number, email address of project manager or coordinator, if any:

List **all other project personnel** including co-investigators, and anyone else who has contact with subjects or identifiable data from subjects: NONE

Name of funding source or sponsor:
__ not funded __ Federal __ State __ industry __ foundation X UNC-CH
__ other (specify): **Sponsor or award number**:

Include following items with your submission, where applicable. Check the items below and **include in order listed**.

- □ This application. One copy must have original PI signatures.
- □ Consent and assent forms, fact or information sheets; include phone and verbal consent scripts
- □ HIPAA authorization addendum to consent form
- □ All recruitment materials including scripts, flyers and advertising, letters, emails
- □ Questionnaires, scripts used to guide phone or in-person interviews, etc.
- □ Focus group guides
- □ Data use agreements (may be required for use of existing data from third parties)
- □ Addendum for Multi-Site Studies where UNC-CH is the Lead Coordinating Center
- □ Documentation of reviews from any other committees (e.g., GCRC, Oncology)
- □ Documentation of training in human research ethics for all study personnel
- □ Investigator Brochure if a drug study
- □ Protocol, grant application or proposal supporting this submission; (e.g., extramural grant application to NIH or foundation, industry protocol, student proposal)

Principal Investigator: I will personally conduct or supervise this research study. I will ensure that this study is performed in compliance with all applicable laws, regulations and University policies regarding human subjects research. I will obtain IRB approval before making any changes or additions to the project. I will notify the IRB of any other changes in the information provided in this application. I will provide progress reports to the IRB at least annually, or as requested. I will report promptly to the IRB all unanticipated problems or serious adverse events involving risk to human subjects. I will follow the IRB approved consent process for all subjects. I will ensure that all collaborators, students and employees assisting in this research study are informed about these obligations. All information given in this form is accurate and complete.

_____ _____

Signature of Principal Investigator Date

Faculty Advisor if PI is a Student or Trainee Investigator: I accept ultimate responsibility for ensuring that this study complies with all the obligations listed above for the PI.

_____ _____

Signature of Faculty Advisor Date

Department or Division Chair, Center Director (or counterpart) of PI: (or Vice-Chair or Chair's designee if Chair is investigator or otherwise unable to review): I certify that this research is appropriate for this Principal Investigator, that the investigators are qualified to conduct the research, and that there are adequate resources (including financial, support and facilities) available. I support this application, and hereby submit it for further review.

_____ _____

Signature of Department Chair or designee Date

_____ _____

Print Name of Department Chair or designee Department

Part A.2. Summary Checklist

Are the following involved?	Yes	No
A.2.1. Existing data, research records, patient records, and/or human biological specimens?	__	_x_
A.2.2. Surveys, questionnaires, interviews, or focus groups with subjects?	__	_x_
A.2.3. Videotaping, audiotaping, filming of subjects?	__	_x_
A.2.4. Do you plan to enroll subjects from these vulnerable or select populations: a. UNC-CH students or UNC-CH staff? ..... b. Non-English-speaking? ..... c. Decisionally impaired? ..... d. Patients? ..... e. Prisoners, parolees and other convicted offenders? ..... f. Pregnant women? ..... g. Minors (less than 18 years)? **If yes**, give age range: to years	 __ __ __ _x_ __ __ __	 _x_ _x_ _x_ __ _x_ _x_ _x_
A.2.5. a. Is this a multi-site study (i.e., involves organization(s) outside UNC-CH)? b. Will any of these sites be outside the United States? ***If yes***, provide contact information for the foreign IRB. c. Is UNC-CH the sponsor or lead coordinating center? ***If yes***, include the ***Addendum for Multi-site Studies where UNC-CH is the Lead Coordinating Center***.	__ __ __	_x_ __ __
A.2.6. Will there be a data and safety monitoring committee (DSMB or DSMC)?	__	_x_
A.2.7. a. Are you collecting sensitive information such as sexual behavior, HIV status, recreational drug use, illegal behaviors, child/physical abuse, immigration status, etc? b. Do you plan to obtain a federal Certificate of Confidentiality for this study?	 __	_x_ _x_
A.2.8. a. Investigational drugs? (provide **IND #**) b. Approved drugs for "non-FDA-approved" conditions? *All studies testing substances in humans must provide a letter of acknowledgement from the UNC Health Care Investigational Drug Service (IDS).*	__ __	_x_ __
A.2.9. Placebo(s)?	__	_x_
A.2.10. Investigational devices, instruments, machines, software? (provide **IDE #**)	__	_x_
A.2.11. Fetal tissue?	__	_x_
A.2.12. Genetic studies on subjects' specimens?	__	_x_
A.2.13. Storage of subjects' specimens for future research? ***If yes**, see instructions within the form **Consent for Stored Samples**.*	__	_x_
A.2.14. Diagnostic or therapeutic ionizing radiation, or radioactive isotopes, which subjects would not receive otherwise? ***If yes**, approval by the **UNC-CH Radiation Safety** **Committee** is required.*	__	_x_
A.2.15. Recombinant DNA or gene transfer to human subjects? ***If yes**, approval by the **UNC-CH Institutional Biosafety** **Committee** is required.*	__	_x_
A.2.16. Does this study involve UNC-CH cancer patients? ***If yes**, submit this application directly to the **Oncology Protocol Review Committee**.*	__	_x_
A.2.17. Will subjects be studied in the General Clinical Research Center (GCRC)? ***If yes**, obtain the **GCRC Addendum** from the GCRC and submit complete application (IRB application and Addendum) to the GCRC.*	__	_x_

Part A.3. Potential Conflict of Interest

The following questions apply to **all investigators and study staff involved with this research, and/or their immediate family members (spouse, dependent children, parents, significant others).** With respect to this study, will any of the study investigators or study staff or their immediate family members:

A.3.1. Have an intellectual property interest in any technology or invention used in this study, including patent rights, copyright, etc.?	__ yes	_x_ no
A.3.2. Receive support from a non-UNC source (**other than through a sponsored research agreement**) for this research study?	__ yes	_x_ no
A.3.3. Receive any form of personal compensation (**other than as specified in the budget of a sponsored research agreement**) from a Sponsor of this study, including salary, consulting fees, honoraria, royalties, equipment, gifts, etc.? a. **If yes**, does or will that personal compensation exceed $10,000? b. **If yes**, is that personal compensation tied to any performance within this study such as enrollment goals for the study?	__ yes __ yes __ yes	_x_ no __ no __ no
A.3.4. Have an ownership interest of any nature in the Sponsor or a product used in this study, including equity, stock options, etc? a. **If yes**, does or will that interest exceed $10,000 in value or 5% equity in a publicly traded Sponsor? b. **If yes**, does that interest include any equity interest in a non-publicly traded Sponsor?	__ yes __ yes __ yes	_x_ no __ no __ no
A.3.5. Hold any position with the Sponsor, including officer, employee, director, trustee, consultant, member of advisory board, etc.?	__ yes	_x_ no
A.3.6. Have a conflict of interest previously disclosed through the University's conflict of interest evaluation process that relates to this research study?	__ yes	_x_ no

If the answer is "yes" to any of the questions above, please include an explanation with this application. As with any changes to the research itself, relationships or interests that develop later should be brought to the attention of the IRB for further consideration. Please contact the Office of University Counsel for guidance or assistance regarding the University's Conflict of Interest Policy. See http://www.unc.edu/campus/policies/coi.html for the policy.

Part A.4. Questions Common to All Studies

For all questions, if the study involves only secondary data analysis, focus on your proposed design, methods and procedures, and not those of the original study that produced the data you plan to use.

A.4.1. **Brief Summary**. Provide a *brief* non-technical description of the study, which will be used for internal and external communications regarding this research. Include purpose, methods, and participants. Typical summaries are 50-100 words.

The purpose of this study is simple. We will monitor patients undergoing high radiation dose procedures in the Electrophysiology Lab of UNC-Hospitals. Dose to the patients skin will be monitored using an x-ray sensitive film that will be placed beneath the patient on top of the table that the patient lies on for the procedure. Participants will be those patients undergoing a clinically necessary Electrophysiology procedure.

A.4.2. **Purpose and Rationale**. Provide a summary of the background information, state the research question(s), and tell why the study is needed. If a complete rationale and literature review are in an accompanying grant application or other type of proposal, only provide a brief summary here. If there is no proposal, provide a more extensive rationale and literature review.

The Food and Drug Administration (FDA) has reported that severe radiation-induced burns have occurred in patients undergoing invasive fluoroscopic procedures, and has made recommendations for the avoidance of such x-ray-induced skin injuries.

Typical absorbed dose rates from fluoroscopic x-ray equipment are between 2 and 5 rad/minute, but can vary greatly depending upon modes of equipment operation, movement of the x-ray source during the procedure, and patient size. Radiation injury, apparent as early transient erythema, has been observed after absorbed doses to the skin of about 200 rad. Even at typical dose rates, injury to the skin can occur after less than one hour of fluoroscopy time. More severe effects can occur if the fluoroscopy times are longer and the subsequent doses larger.

The primary objective of this project is to evaluate radiation dose to patients undergoing extended x-ray procedures at UNC-Hospitals Electrophysiology Lab (EP). Those EP procedures associated with likely high-doses have been determined using information collected and analyzed in the IRB-approved study titled "Identification of Likely High Radiation Dose Procedures through the Evaluation of Fluoroscopic Times in an Electrophysiology Lab".

Until now, we have only estimated dose to patients, but this study will allow us to directly measure radiation dose using a wide-area dosimetry film described below. Determining actual dose will allow us to better evaluate the risk to patients undergoing extended fluoroscopy EP procedures. The results of the dosimetry film will be used to correlate patient skin dose with fluoroscopy time, patient weight, and patient body mass index (BMI). We hope to determine which of these variables are better at predicting radiation dose and risk.

Using knowledge gained from this study, we hope to be able to providing physicians with the information necessary to make informed decisions concerning the management of high-dose procedures, determine the need for any dose-reduction measures necessary for high-dose procedures, and assist with demonstrating compliance with FDA Public Health Advisories and proposed rule changes in the NC Regulations for Protection Against Radiation.

A.4.3. **Full description of the study design, methods and procedures.** Describe the research study. Discuss the study design; study procedures; sequential description of what subjects will be

asked to do; assignment of subjects to various arms of the study if applicable; doses; frequency and route of administration of medication and other medical treatment if applicable; how data are to be collected (questionnaire, interview, focus group or specific procedure such as physical examination, venipuncture, etc.). Include information on who will collect data, who will conduct procedures or measurements. Indicate the number and duration of contacts with each subject; outcome measurements; and follow-up procedures. If the study involves medical treatment, distinguish standard care procedures from those that are research. If the study is a clinical trial involving patients as subjects and use of placebo control is involved, provide justification for the use of placebo controls.

Variables to be recorded during each procedure include date of procedure, and demographic details of the patient such as age, sex, height and weight, procedure category (i.e. ablation), nature of procedure (i.e. atrial flutter), physician, fluoroscopic time, success or failure of the procedure, and operating characteristics of the equipment such as continuous vs. specific pulse rate, phosphor size used, and SID variability.

The dose measurements will be performed using a wide-area radiochromic dosimetry film, specifically designed to measure skin dose during fluoroscopically-guided x-ray procedures. The film will be placed on the table between the patient and x-ray tube. The film will be placed immediately adjacent to the patient and will effectively record the skin dose. The film will not be apparent by the patient and will not interfere with the fluoroscopic image or procedure in any way.

These radiochromic films were developed to measure low-energy photons (<200 keV) and has a range of energy independence from 60-120 keV (the diagnostic energy range used in the Electrophysiology Lab). The film is supplied in 14"x17" sheets, and may be cut down to smaller sizes for more efficient use. The film is self-developing, requires no chemicals, and is unaffected by water, blood and other aqueous fluids. The dose to the patient is determined by reading the maximum optical density present on the film after the procedure with a densitometer or flatbed scanner.

A.4.4. **Benefits to subjects and/or society.** Describe any potential for direct benefit to individual subjects, as well as the benefit to society based on scientific knowledge to be gained; these should be clearly distinguished. Consider the nature, magnitude, and likelihood of any direct benefit to subjects. If there is no direct benefit to the individual subject, say so here and in the consent form (if there is a consent form). Do not list monetary payment or other compensation as a benefit.

Knowledge gained from this study will assist with development of an effective program for the safe use of fluoroscopic x-ray which will serve to provide physicians the information necessary to make informed decisions concerning the management of future high-dose procedures.

A.4.5. **Full description of risks and measures to minimize risks.** Include risk of psychosocial harm (e.g., emotional distress, embarrassment, breach of confidentiality), economic harm (e.g., loss of employment or insurability, loss of professional standing or reputation, loss of standing within the community) and legal jeopardy (e.g., disclosure of illegal activity or negligence), as well as known side effects of study medication, if applicable, and risk of pain and physical injury. Describe what will be done to minimize these risks. Describe procedures for follow-up, when necessary, such as when subjects are found to be in need of medical or psychological referral. If there is no direct interaction with subjects, and risk is limited to breach of confidentiality (e.g., for existing data), state this.

There are no risks to the subjects associated with this study.

A.4.6. **Data analysis.** Tell how the qualitative and/or quantitative data will be analyzed. Explain how the sample size is sufficient to achieve the study aims. This might include a formal power calculation or explanation of why a small sample is sufficient (e.g., qualitative research, pilot studies).

Since the primary purpose of this study is to evaluate fluoroscopic times and measure peak skin doses, only simple statistics will be necessary.

A.4.7. **Will you collect or receive any of the following identifiers as part of the study data?** Does not apply to consent forms.

__ No **_x_** Yes *If yes, check all that apply*:

a. __ Names
b. __ Telephone numbers
c. **_x_** Any elements of dates (other than year) for dates directly related to an individual, including birth date, admission date, discharge date, date of death. For ages over 89: all elements of dates (including year) indicative of such age, except that such ages and elements may be aggregated into a single category of age 90 and older
d. __ Any geographic subdivisions smaller than a State, including street address, city, county, precinct, zip code and their equivalent geocodes, except for the initial three digits of a zip code
e. __ Fax numbers
f. __ Electronic mail addresses
g. __ Social security numbers
h. __ Medical record numbers
i. __ Health plan beneficiary numbers
j. __ Account numbers
k. __ Certificate/license numbers
l. __ Vehicle identifiers and serial numbers (VIN), including license plate numbers
m. __ Device identifiers and serial numbers (e.g., implanted medical device)
n. __ Web universal resource locators (URLs)
o. __ Internet protocol (IP) address numbers
p. __ Biometric identifiers, including finger and voice prints
q. __ Full face photographic images and any comparable images
r. __ Any other unique identifying number, characteristic or code, other than dummy identifiers that are not derived from actual identifiers and for which the re-identification key is maintained by the health care provider and not disclosed to the researcher

A.4.8. **Data sharing.** With whom will *identifiable* (contains any of the 18 identifiers listed in question 7 above) data be shared outside the immediate research team? For each, explain confidentiality measures. Include data use agreements, if any.

_x_ No one
__ Coordinating Center**:**
__ Statisticians**:**
__ Consultants**:**
__ Other researchers**:**
__ Registries**:**
__ Sponsors:
__ External labs for additional testing:
__ Journals:
__ Publicly available dataset:
__ Other:

A.4.9. **Confidentiality of the data**. Describe procedures for maintaining confidentiality of the data you will collect or will receive. Describe how you will protect the data from access by those not authorized. How will data be transmitted among research personnel? Where relevant, discuss the potential for deductive disclosure (i.e., directly identifying subjects from a combination of indirect IDs). Describe your plan to destroy identifiers. When will identifiers be destroyed?

Data collected, including date of the procedure monitored, will be kept in a locked file drawer in the PI's office in the Department of Environment, Health and Safety. This office is also kept locked after-hours. Identifiers will be shredded once the research is complete and the information is no longer necessary.

A.4.10. **Data security for storage and transmission**. Please check all that apply.

For electronic data:

_x_ Secure network _x_ Password access __ Encryption
__ Other (describe):
__ Portable storage (e.g., laptop computer, flash drive)
Describe how data will be protected for any portable device:

For hardcopy data (including human biological specimens, CDs, tapes, etc.):

__ Data de-identified by research team (stripped of the 18 identifiers listed in question 7 above)
_x_ Locked suite or office
_x_ Locked cabinet
__ Data coded by research team with a master list secured and kept separately
__ Other (describe):

Part A.5. The Consent Process and Consent Documentation (including Waivers)

The standard consent process is for all subjects to sign a document containing all the elements of informed consent, as specified in the federal regulations. Some or all of the elements of consent, including signatures, may be altered or waived under certain circumstances.

- If you will obtain consent in any manner, complete **section A.5.1**.
- If you are obtaining consent, but requesting a waiver of the requirement for a signed consent document, complete **section A.5.2**.
- If you are requesting a waiver of any or all of the elements of consent, complete **section A.5.3**.

You may need to complete more than one section. For example, if you are conducting a phone survey with verbal consent, complete sections A.5.1, A.5.2, and possibly A.5.3.

A.5.1. **Describe the process of obtaining informed consent from subjects**. If children will be enrolled as subjects, describe the provisions for obtaining parental permission and assent of the child. If decisionally impaired adults are to be enrolled, describe the provision for obtaining surrogate consent from a legally authorized representative (LAR). If non-English speaking people will be enrolled, explain how consent in the native language will be obtained. Address both written translation of the consent and the availability of oral interpretation. *After you have completed this part A.5.1, if you are not requesting a waiver of any type, you are done with Part A.5.; proceed to Part B.*

Informed consent will not be obtained, but the subjects will be provided with an information sheet which provides details about their involvement in the study. See section A.5.3.

A.5.2. **Justification for a waiver of *written* (i.e., signed) consent**. *The default is for subjects to sign a written document that contains all the elements of informed consent.* Under limited circumstances, the requirement for a signed consent form may be waived by the IRB if either of the following is true:

a. The only record linking the subject and the research would be the consent document and the principal risk would be potential harm resulting from a breach of confidentiality (e.g., study involves sensitive data that could be damaging if disclosed). __ yes __ no

Explain.

b. The research presents no more than minimal risk of harm to subjects and involves no procedures for which written consent is normally required outside of the research context (e.g., phone survey). __ yes __ no

Explain.

If you checked "yes" to either, will consent be oral? Will you give out a fact sheet? Use an online consent form, or include information as part of the survey itself, etc?

A.5.3. **Justification for a full or partial waiver of consent.** *The default is for subjects to sign a written document that contains all the elements of informed consent.* A waiver might be requested for research involving only existing data or human biological specimens (see also Part C). More rarely, it might be requested when the research design requires withholding some study details at the outset (e.g., behavioral research involving deception). In limited circumstances, parental permission may be waived. This section should also be completed for a waiver of HIPAA authorization if research involves Protected Health Information (PHI) subject to HIPAA regulation, such as patient records.

__ Requesting **waiver of some elements** (specify; see SOP 28 on the IRB web site):
_x_ Requesting **waiver of consent entirely**
If you check either of the boxes above, answer items a-f.. To justify a full waiver of the requirement for informed consent, you must be able to answer "yes" (or "not applicable" for question c) to items a-f. **Insert brief explanations that support your answers.**

a. Will the research involve no greater than minimal risk to subjects or to their privacy? _x_ yes __ no
Explain. We are simply placing a piece of thin film beneath the patient during their procedure. The patient will not notice the film and the film will not interfere with their procedure in any way. There is no risk to the patient.

b. Is it true that the waiver will *not* adversely affect the rights and welfare of subjects? *(Consider the right of privacy and possible risk of breach of confidentiality in light of the information you wish to gather.)* _x_ yes __ no
Explain. The subjects will notice nothing or be exposed to any additional risk related to this study. They would have their Electrophysiology procedure performed in the same manner regardless of this study being conducted.

c. When applicable to your study, do you have plans to provide subjects with pertinent information after their participation is over? *(e.g., Will you provide details withheld during consent, or tell subjects if you found information with direct clinical relevance? This may be an uncommon scenario.)* __ yes _x_ not applicable
Explain.

d. Would the research be impracticable without the waiver? *(If you checked "yes," explain how the requirement to obtain consent would make the research impracticable, e.g., are most of the subjects lost to follow-up or deceased?).* _x_ yes __ no
Explain. There is no risk to the patient from this study. Taking the additional time to receive consent would be an unnecessary requirement for this study which simply involves placing a piece of film underneath them.

e. Is the risk to privacy reasonable in relation to benefits to be gained or the importance of the knowledge to be gained? _x_ yes __ no
Explain. The risk to patient privacy is very small, and we have procedures for maintaining identifiable data, such as date, confidential. There is great benefit to measuring and knowing radiation skin doses for patients undergoing Electrophysiology procedures that relate to the development of a program for managing such high-dose fluoroscopy procedures.

If you are accessing patient records for this research, you must also be able to answer "yes" to item f to justify a waiver of HIPAA authorization from the subjects.

f. Would the research be impracticable if you could not record (or use) Protected Health Information (PHI)? *(If you checked "yes," explain how* not *recording or using PHI would make the research impracticable).* _x_ yes __ no

Explain. It would be impracticable to coordinate scheduling of the dose monitoring if I were not allowed to access, know, or otherwise use the procedure date.

Part B. Questions for Studies that Involve Direct Interaction with Human Subjects

→ *If this does not apply to your study, do not submit this section.*

B.1. **Subjects.** Specify number, gender, ethnicity, race, and age. Specify whether subjects are healthy volunteers or patients. If patients, specify any relevant disease or condition and indicate how potential subjects will be identified.

This study involves the estimation and measuring of radiation dose to patients 18 years or older who are undergoing a clinically necessary electrophysiology procedure. Monitoring will be performed on up to 50 subjects. Participation is not age, gender, ethnicity, or pregnancy dependent.

B.2. **Inclusion/exclusion criteria.** List required characteristics of potential subjects, and those that preclude enrollment. Justify exclusion of any group, especially by criteria based on gender, ethnicity, race, or age. If pregnant women are excluded, or if women who become pregnant are withdrawn, specific justification must be provided.

Subjects will be eligible for inclusion in the dose estimation and measuring part of the study if their clinical care requires undergoing an electrophysiology procedure identified as likely high-dose.

B.3. **Methods of recruiting.** Describe how and where subjects will be identified and recruited. Indicate who will do the recruiting, and tell how subjects will be contacted. Describe efforts to ensure equal access to participation among women and minorities. Describe how you will protect the privacy of potential subjects during recruitment. *For prospective subjects whose status (e.g., as patient or client), condition, or contact information is not publicly available (e.g., from a phone book or public web site), the initial contact should be made with legitimate knowledge of the subjects' circumstances. Ideally, the individual with such knowledge should seek prospective subjects' permission to release names to the PI for recruitment. Alternatively, the knowledgeable individual could provide information about the study, including contact information for the investigator, so that interested prospective subjects can contact the investigator.* Provide the IRB with a copy of any document or script that will be used to obtain the patients' permission for release of names or to introduce the study. Check with your IRB for further guidance.

Prospective subjects will be approached initially by their electrophysiology physician performing the procedure about participation in this project. Subjects will be provided with an information sheet which provides details about their involvement in the study.

B.4. **Protected Health Information (PHI).** If you need to access Protected Health Information (PHI) to identify potential subjects who will then be contacted, you will need a *limited waiver of HIPAA authorization*. If this applies to your study, please provide the following information.

a. Will the information collected be limited only to that necessary to contact the subjects to ask if they are interested in participating in the study?
   I will call or otherwise contact the Electrophysiology Lab to learn of the dates that high dose procedures are being performed in order to coordinate monitoring. The Lab may also contact me with the date and time that high dose procedures are scheduled for.

b. How will confidentiality/privacy be protected prior to ascertaining desire to participate?
   Neither subject name nor any other PHI (with the exception of procedure date) will be known.

c. When and how will you destroy the contact information if an individual declines participation?
   Not applicable to this project.

B.5. **Duration of entire study and duration of an individual subject's participation, including follow-up evaluation if applicable.** Include the number of required contacts and approximate duration of each contact.

A subject's participation in this study is only for the duration of the time necessary to complete their clinical electrophysiology procedure.

B.6. **Where will the subjects be studied?** Describe locations where subjects will be studied, both on and off the UNC-CH campus.

Subjects will be studied in UNC-Hospitals Electrophysiology Lab.

B.7. **Privacy.** Describe procedures that will ensure privacy of the subjects in this study. Examples include the setting for interviews, phone conversations, or physical examinations; communication methods or mailed materials (e.g., mailings should not indicate disease status or focus of study on the envelope).

We will not know any subject identifiers other than the date of the procedure. This information will be kept secured and available only to the immediate research team.

B.8. **Inducements for participation.** Describe all inducements to participate, monetary or non-monetary. If monetary, specify the amount and schedule for payments and how this will be prorated if the subject withdraws (or is withdrawn) from the study prior to completing it. For compensation in foreign currency, provide a US$ equivalent. Provide evidence that the amount is not coercive (e.g., describe purchasing power for foreign countries). Include food or refreshments that may be provided.

Not applicable to this project.

B.9. **Costs to be borne by subjects.** Include child care, travel, parking, clinic fees, diagnostic and laboratory studies, drugs, devices, all professional fees, etc. If there are no costs to subjects other than their time to participate, indicate this.

There are no costs to the subjects associated with this research.

Part C. Questions for Studies using Data, Records or Human Biological Specimens without Direct Contact with Subjects

→ *If this does not apply to your study, do not submit this section.*

C.1. What records, data or human biological specimens will you be using? *(check all that apply)*:

__ Data already collected for another research study
__ Data already collected for administrative purposes (e.g., Medicare data, hospital discharge data)
__ Medical records (custodian may also require form, e.g., HD-974 if UNC-Health Care System)
__ Electronic information from clinical database (custodian may also require form)
__ Patient specimens (tissues, blood, serum, surgical discards, etc.)
__ Other (specify):

C.2. For each of the boxes checked in 1, how were the original data, records, or human biological specimens collected? Describe the process of data collection including consent, if applicable.

C.3. For each of the boxes checked in 1, where do these data, records or human biological specimens currently reside?

C.4. For each of the boxes checked in 1, from whom do you have permission to use the data, records or human biological specimens? Include data use agreements, if required by the custodian of data that are not publicly available.

C.5. If the research involves human biological specimens, has the purpose for which they were collected been met before removal of any excess? For example, has the pathologist in charge or the clinical laboratory director certified that the original clinical purpose has been satisfied? Explain if necessary.

__ yes __ no __ not applicable (explain)

C.6. Do all of these data records or specimens exist at the time of this application? If not, explain how prospective data collection will occur.

__ yes __ no If no, explain

THE UNIVERSITY
of NORTH CAROLINA
at CHAPEL HILL

OFFICE OF HUMAN
RESEARCH ETHICS

BIOMEDICAL INSTITUTIONAL
REVIEW BOARD (IRB)

MEDICAL SCHOOL BUILDING 52
CAMPUS BOX 7097
CHAPEL HILL, NC 27599-7097

T 919.966.1344
F 919.966.7879
http://ohre.unc.edu

TO: Bradford Taylor
C/O Marija Ivanovic, PhD
Radiology CB# 7510
Carolina Campus

FROM: The Biomedical Institutional Review Board (IRB)

DATE: June 10 2005

SUBJECT: Research Application Review

STUDY: IRB# 05-RAD-358 Title: The Use of a Radiochromic Film for the Evaluation of Skin Dose During Extended Fluoroscopy Procedures in an Electrophysiology Lab

This research proposal has been considered by the Committee and it has been approved until June 10 2006.

(1) Review Type: Expedited

(2) This Committee complies with the requirements found in Part 56 of the 21 Code of Federal Regulations and Part 46 of the 45 Code of Federal Regulations. The assurance of compliance with DHHS regulations is on file in the Committee office for your perusal. Federalwide Assurance: FWA-4801.

(3) Re-review of this proposal is necessary before:
(a) making any significant alterations or additions to the proposal, except when necessary to eliminate apparent immediate hazards to the subject, or
(b) continuing beyond the approval date.

Authorized Signature on behalf of the Committees

THE UNIVERSITY
of NORTH CAROLINA
at CHAPEL HILL

OFFICE OF HUMAN
RESEARCH ETHICS

BIOMEDICAL INSTITUTIONAL
REVIEW BOARD (IRB)

MEDICAL SCHOOL BUILDING 52
CAMPUS BOX 7097
CHAPEL HILL, NC 27599-7097

T 919.966.1344
F 919.966.7879
http://ohre.unc.edu

Information Supplement to IRB approval document (page 2)

Date: June 10, 2005

Submission Type: New

Review type: Expedited

IRB Study#: 05-RAD-358: The Use of a Radiochromic Film for the Evaluation of Skin Dose During Extended Fluoroscopy Procedures in an Electrophysiology Lab

This study was reviewed in accordance with all applicable regulations governing human subjects research found at 45 CFR 46 (Common Rule) and 45 CFR 164 (HIPAA).

The primary objective of this project is to evaluate radiation dose to patients undergoing extended X-ray procedures at UNC Hospitals Electrophysiology Lab (EP). This study will allow direct measurement of radiation dose using a wide-area dosimetry film. The film will be placed immediately adjacent to the patient and will effectively record skin dose. The film poses no risk to the patient and will not interfere with the procedure. No personally identifying information will be collected. Informed consent will not be obtained, but subjects will be provided with an information sheet describing the study. Criteria are satisfied for waiver of research consent [45 CFR 46.116(d)] and waiver of HIPAA authorization [45 CFR 164.512(i)(2)(ii)]. The risk is no more than minimal. This study is approved by expedited review per category 4.

Authorized Signature on Behalf of the Committees

Appendix C
IRB Subject Information Sheet

University of North Carolina-Chapel Hill
Subject Information Sheet

Medical IRB Study #: 05-RAD-358
Title of Study: The Use of a Radiochromic Film for the Evaluation of Skin Dose during Extended Fluoroscopy Procedures in an Electrophysiology Lab
Principal Investigator: James Bradford Taylor
UNC-CH Department: Environment, Health and Safety
Phone Number: 919-962-5727

What are some general things you should know about research studies? Your participation in this study is voluntary. Details about this particular study are described below. Thank you for your time and interest.

What is the purpose of this study? You are being asked to participate in a research study to evaluate the use of an x-ray sensitive film for the measurement of radiation dose to your skin. The Principal Investigator for this study is a graduate student in the UNC School of Public Health.

You are being asked to participate in this study because your electrophysiology procedure may involve the extended use of fluoroscopic x-ray.

What will happen to you during this study? Information that will be gathered during your procedure includes the type of procedure you are having, your height, and your weight.

This study involves the use of a thin piece of film which will be placed on the procedure tabletop beneath your back, and will remain in place for the duration of your procedure. You will not notice the film, and it will not interfere with your procedure in any way. During your procedure, the film will record radiation dose to your skin.

What are the possible risks or discomforts? There is no risk or discomfort to you associated with this research study.

How will your privacy be protected? No identifying information will be gathered during this study, thus protection of your privacy is assured.

What if you have question about this study?
If you have general questions about this study, please use the contact information listed above. This research has been reviewed and approved by the Committee on the Protection of the Rights of Human Subjects (Medical IRB) at the University of North Carolina at Chapel Hill.

APPROVED
JUN 10 2005
BIOMEDICAL IRB - UNC

Appendix D
Documentation of Required Training

THE UNIVERSITY OF NORTH CAROLINA AT CHAPEL HILL
Office of the Vice Chancellor for Research and Economic Development

Campus Box 4100, 301 Bynum Hall
Chapel Hill, NC 27599-4100
(919) 962-7757 FAX: (919) 962-6769
http://research.unc.edu

August 22, 2006

To Whom It May Concern:

In accordance with the National Institutes of Health (NIH) notices OD-00-039 of August 25, 2000 and OD-01-061 of September 5, 2001, The University of North Carolina at Chapel Hill submits the following information concerning the education in the protection of human research participants undertaken by the key personnel involved with this project. The following persons have been trained in the ethical and regulatory requirements for protection of human research participants in compliance with NIH requirements and The University of North Carolina at Chapel Hill "Policy on Education and Certification of Investigators Involved in Human Subjects Research." http://ohre.unc.edu/irbtraining/

Name	Dept	Training
James Taylor	Environment, Health & Safety	CITI- Biomedical
Marija Ivanovic	Radiology	CITI- Data only

Should any additional persons come to work on this project and meet the definition of key personnel, they will be trained similarly; their names and certification of their training in the protection of human research participants will be forwarded.

Sincerely,

James E. Peterson

James E. Peterson, Ph.D.
Associate Vice Chancellor and Director,
Office of Sponsored Research

Appendix E
Fluoroscopy Time Log

DATE	PHYSICIAN CODE	TOTAL FLUOROSCOPY MINUTES	ASSIGNED PROCEDURE CODE
3/27/2003	C	4	PM
3/28/2003	C	50	ABL
4/1/2003	C	4	EPS
4/4/2003	C	29	ABL
4/7/2003	A	4	PM
4/7/2003	A	62	BIV
4/10/2003	A	13	BIV
4/11/2003	C	50	BIV
4/14/2003	A	36	BIV
4/17/2003	A	25	PM
4/21/2003	A	9	PM
4/21/2003	A	17	PM
4/22/2003	C	5	EPS
4/22/2003	C	8	ICD
4/23/2003	C	22	ABL
4/24/2003	C	8	ICD
4/24/2003	A	3	CO
4/25/2003	C	1	ABL
4/28/2003	A	1	CO
4/29/2003	C	12	ICD
4/29/2003	C	61	ICD
4/30/2003	A	9	PM
5/1/2003	A	2	EPS
5/1/2003	A	76	BIV
5/2/2003	C	8	PM
5/7/2003	A	9	PM
5/7/2003	A	46	BIV
5/8/2003	A	1	CO
5/8/2003	A	1	CO
5/8/2003	A	1	CO
5/12/2003	A	4	PM
5/12/2003	A	5	ICD
5/12/2003	A	6	ICD
5/12/2003	A	12	PM
5/21/2003	NOT AVAILABLE	1	CO
5/21/2003	NOT AVAILABLE	9	ICD
5/28/2003	NOT AVAILABLE	6	PM
6/2/2003	NOT AVAILABLE	9	PM
6/2/2003	NOT AVAILABLE	9	PM
6/2/2003	NOT AVAILABLE	87	BIV
6/4/2003	NOT AVAILABLE	1	CO
6/4/2003	NOT AVAILABLE	16	PM
6/4/2003	NOT AVAILABLE	59	BIV

DATE	PHYSICIAN CODE	TOTAL FLUOROSCOPY MINUTES	ASSIGNED PROCEDURE CODE
6/6/2003	NOT AVAILABLE	9	ABL
6/6/2003	NOT AVAILABLE	10	ICD
6/9/2003	NOT AVAILABLE	121	BIV
6/11/2003	NOT AVAILABLE	7	PM
6/11/2003	NOT AVAILABLE	33	ABL
6/12/2003	NOT AVAILABLE	20	PM
6/13/2003	NOT AVAILABLE	13	PM
6/16/2003	NOT AVAILABLE	8	ICD
6/16/2003	NOT AVAILABLE	80	BIV
6/17/2003	NOT AVAILABLE	6	ICD
6/17/2003	NOT AVAILABLE	62	ABL
6/25/2003	NOT AVAILABLE	15	PM
12/3/2003	B	54	BIV
12/4/2003	A	7	PM
12/5/2003	B	17	PM
12/8/2003	A	121	BIV
12/9/2003	B	7	EPS
12/10/2003	B	28	ABL
12/10/2003	B	29	ABL
12/11/2003	A	40	BIV
12/15/2003	A	1	CO
12/15/2003	A	10	EPS
12/17/2003	B	28	ABL
12/19/2003	B	18	PM
12/19/2003	B	36	ABL
12/22/2003	A	86	ABL
12/29/2003	B	15	PM
12/29/2003	B	23	ICD
12/30/2003	B	8	PM
12/31/2003	B	33	PM
1/7/2004	A	80	ABL
1/12/2004	A	1	CO
1/12/2004	A	1	CO
1/16/2004	B	6	ICD
1/16/2004	B	9	PM
1/20/2004	B	1	ICD
1/20/2004	B	13	PM
1/22/2004	A	22	BIV
1/23/2004	B	5	ICD
1/23/2004	B	9	EPS
1/28/2004	A	12	PM
1/30/2004	B	9	PM
2/5/2004	A	2	CO
2/5/2004	A	19	PM
2/6/2004	A	23	ICD
2/9/2004	n/a	34	PM
2/10/2004	B	12	PM

DATE	PHYSICIAN CODE	TOTAL FLUOROSCOPY MINUTES	ASSIGNED PROCEDURE CODE
2/10/2004	B	25	ABL
2/11/2004	A	4	PM
2/11/2004	A	100	ABL
2/12/2004	A	7	PM
2/12/2004	A	15	PM
2/13/2004	B	87	ABL
2/15/2004	A	34	PM
2/17/2004	B	10	EPS
2/17/2004	A	23	BIV
2/18/2004	B	7	ICD
2/18/2004	B	58	BIV
2/19/2004	B	48	ICD
2/20/2004	B	9	PM
2/20/2004	B	102	ABL
2/23/2004	B	28	ICD
2/25/2004	A	25	ABL
2/26/2004	A	1	CO
2/26/2004	A	10	PM
3/1/2004	A	13	PM
3/2/2004	A	45	BIV
3/3/2004	B	36	ABL
3/4/2004	A	1	CO
3/4/2004	A	5	PM
3/5/2004	A	140	ABL
3/9/2004	B	11	PM
3/11/2004	A	1	CO
3/15/2004	B	17	PM
3/15/2004	A	7	PM
3/15/2004	A	9	ICD
3/16/2004	B	7	ICD
3/19/2004	A	53	BIV
3/20/2004	B	11	ICD
4/29/2004	B	44	ABL
4/30/2004	A	1	CO
4/30/2004	A	56	ICD
5/1/2004	B	112	ABL
5/3/2004	B	1	CO
5/3/2004	A	4	PM
5/3/2004	A	7	PM
5/4/2004	B	37	BIV
5/5/2004	B	5	CO
5/5/2004	A	39	CO
5/6/2004	A	3	CO
5/6/2004	A	3	PM
5/13/2004	A	1	CO
5/13/2004	A	1	CO
5/13/2004	A	2	CO

DATE	PHYSICIAN CODE	TOTAL FLUOROSCOPY MINUTES	ASSIGNED PROCEDURE CODE
5/14/2004	B	192	ABL
5/17/2004	A	1	CO
5/17/2004	A	6	ICD
5/17/2004	A	11	PM
5/18/2004	B	46	BIV
5/19/2004	B	41	ABL
5/20/2004	B	8	ICD
5/20/2004	B	38	BIV
5/21/2004	B	6	PM
5/21/2004	B	15	PM
5/24/2004	A	7	CO
5/24/2004	A	9	ICD
5/24/2004	A	12	PM
5/25/2004	B	1	CO
5/25/2004	B	4	CO
5/26/2004	A	10	EPS
5/27/2004	A	4	ICD
5/27/2004	A	20	ICD
5/28/2004	B	18	BIV
6/1/2004	B	3	ICD
6/2/2004	A	5	ABL
6/2/2004	A	15	CO
6/3/2004	A	1	CO
6/3/2004	A	6	ICD
6/4/2004	B	38	ABL
6/7/2004	A	26	BIV
6/8/2004	B	10	ICD
6/8/2004	B	21	ICD
6/9/2004	B	129	ABL
6/10/2004	A	10	PM
6/10/2004	A	10	PM
6/10/2004	A	14	ICD
6/10/2004	A	19	PM
6/11/2004	B	131	ABL
6/14/2004	A	4	PM
6/14/2004	A	16	PM
6/14/2004	A	24	BIV
10/13/2004	B	9	EPS
10/13/2004	B	22	ICD
10/14/2004	B	12	ICD
10/14/2004	B	16	EPS
10/18/2004	A	17	PM
10/20/2004	A	58	ABL
10/21/2004	A	5	PM
10/21/2004	A	24	ICD
10/22/2004	B	33	PM
10/25/2004	A	58	EPS

DATE	PHYSICIAN CODE	TOTAL FLUOROSCOPY MINUTES	ASSIGNED PROCEDURE CODE
10/26/2004	A	3	CO
10/27/2004	B	23	ICD
10/28/2004	A	14	CO
11/4/2004	A	2	PM
11/4/2004	A	3	PM
11/5/2004	B	12	ICD
11/5/2004	B	13	EPS
11/8/2004	A	3	CO
11/11/2004	A	14	ICD
11/15/2004	A	15	ICD
11/16/2004	B	22	EPS
11/17/2004	B	171	ABL
11/18/2004	B	47	BIV
11/22/2004	A	5	ICD
11/22/2004	A	12	ICD
11/23/2004	B	18	ICD
11/24/2004	B	46	PM
11/30/2004	B	20	PM
12/2/2004	A	1	CO
12/2/2004	A	8	CO
12/2/2004	A	29	BIV
12/3/2004	B	45	ICD
12/6/2004	A	1	CO
12/6/2004	A	20	ICD
12/6/2004	A	28	CO
12/8/2004	B	58	ABL
12/9/2004	A	25	BIV
12/10/2004	B	7	ICD
12/13/2004	A	9	ICD
12/14/2004	B	1	CO
12/14/2004	B	53	PM
12/16/2004	A	1	CO
12/16/2004	A	1	CO
12/16/2004	A	16	ICD
12/20/2004	A	4	CO
2/28/2005	A	1	CO
2/28/2005	A	5	ICD
2/28/2005	A	5	PM
3/2/2005	A	9	PM
3/3/2005	A	1	CO
3/4/2005	A	1	CO
3/4/2005	A	81	BIV
3/7/2005	A	1	CO
3/9/2005	A	26	ABL
3/10/2005	A	2	CO
3/10/2005	A	16	ICD
3/11/2005	A	4	PM

DATE	PHYSICIAN CODE	TOTAL FLUOROSCOPY MINUTES	ASSIGNED PROCEDURE CODE
3/11/2005	A	11	PM
3/14/2005	A	7	ICD
3/16/2005	A	5	CO
3/17/2005	A	5	ICD
3/18/2005	A	19	ICD
3/21/2005	A	10	PM
3/21/2005	A	20	ICD
3/22/2005	A	45	ABL
3/23/2005	A	9	CO
3/23/2005	A	9	ICD
3/24/2005	A	21	PM
3/28/2005	A	2	ICD
3/28/2005	A	11	ICD
3/28/2005	A	19	PM
3/30/2005	A	10	PM
3/30/2005	A	17	PM

Appendix F
Daily Test Pattern Information – Including Measured Red Channel Pixel Values and Coefficient of Variation

Scanner Station	Date	Orientation	Area (1)	Area (2)	Area (3)	Area (4)	Area (5)	Area (6)	Area (7)	Area (8)
1	08/17/2005	Standard	212.19	121.28	52.26	26.29	213.75	122.88	52.83	26.85
1	08/22/2005	Standard	211.99	121.12	52.29	26.17	213.75	122.91	52.86	26.77
1	08/25/2005	Standard	213.10	121.38	52.10	26.47	214.83	122.60	52.42	26.52
1	08/30/2005	Standard	212.51	120.23	52.16	25.51	214.92	121.62	52.19	25.69
1	09/06/2005	Standard	212.07	120.08	51.76	25.95	214.05	121.56	52.17	25.99
1	09/12/2005	Standard	212.10	120.28	51.32	24.98	214.12	122.18	51.75	25.31
1	09/15/2005	Standard	212.81	120.72	52.49	26.02	214.79	122.73	52.88	26.34
1	09/26/2005	Standard	212.52	120.54	51.57	25.01	214.26	122.29	51.05	25.43
1	09/28/2005	Standard	212.09	120.08	51.80	24.88	214.37	121.55	52.00	25.05
4	08/17/2005	Standard	213.49	120.86	51.69	25.51	214.53	122.05	52.28	26.01
4	08/17/2005	Standard	213.41	120.78	51.62	25.41	214.05	121.88	52.10	25.87
4	08/17/2005	Upside down	211.71	120.33	51.97	25.86	214.45	121.58	51.92	25.79
4	08/22/2005	Standard	212.85	120.80	51.62	25.79	213.83	121.94	52.26	26.08
1	10/17/2005	Standard	212.11	120.17	51.51	25.10	213.94	121.93	51.89	25.32
1	10/17/2005	Upside down	210.50	119.43	51.89	25.11	214.23	122.22	51.95	25.51
1	10/17/2005	Upside down	210.43	119.56	51.82	25.15	214.44	122.32	51.96	25.48
1	10/17/2005	Upside down	210.59	119.79	51.81	25.03	214.60	122.36	51.93	25.51
1	10/26/2005	Standard	211.49	119.97	51.34	24.92	213.13	121.49	51.63	25.14
1	11/14/2005	Standard	211.85	120.03	51.36	24.91	213.56	121.80	51.68	25.07
1	11/16/2005	Standard	210.88	119.81	51.47	24.75	213.45	121.20	51.95	25.01
1	12/01/2005	Standard	210.16	119.32	51.41	24.64	212.48	120.80	51.69	24.88
1	12/30/2005	Standard	211.70	119.99	51.66	24.92	213.54	121.22	52.03	25.09
1	02/01/2006	Standard	211.99	120.45	51.69	25.24	213.86	122.38	52.16	25.67
1	02/14/2006	Standard	211.94	120.42	51.73	25.25	213.81	122.38	52.13	25.59
1	02/16/2006	Standard	211.18	119.80	51.66	24.84	212.82	121.70	51.80	25.28
1	02/20/2006	Standard	210.87	119.88	51.47	25.08	212.67	121.75	51.91	25.45
1	02/24/2006	Standard	212.52	120.61	51.83	25.17	214.24	122.19	51.98	25.63
1	02/27/2006	Standard	210.19	119.73	51.83	24.97	212.73	121.41	52.06	25.22
4	02/27/2006	Standard	212.23	120.08	51.77	24.27	213.36	121.52	51.92	24.83
1	03/03/2006	Standard	210.90	119.69	51.49	24.93	212.54	121.61	51.77	25.30
1	03/08/2006	Standard	210.40	119.55	51.30	24.87	212.18	121.32	51.73	25.26
1	03/17/2006	Standard	211.52	120.23	51.80	25.12	213.31	122.19	52.02	25.49
1	03/22/2006	Standard	210.35	119.56	51.46	24.72	212.53	121.19	51.93	25.14
1	03/30/2006	Standard	211.13	119.92	51.33	24.89	212.81	121.74	51.74	25.29
1	04/03/2006	Standard	210.82	119.61	51.51	24.70	212.82	121.08	51.90	25.12
1	04/27/2006	Standard	211.55	119.98	51.75	24.80	214.07	121.67	52.39	25.46
4	05/03/2006	Standard	213.71	121.11	52.01	24.45	214.49	122.74	52.49	25.28
4	05/16/2006	Standard	213.75	121.13	51.94	24.60	214.56	122.62	52.54	25.44
4	06/01/2006	Standard	213.26	120.55	52.34	25.03	213.93	122.16	52.94	25.74
4	06/15/2006	Standard	214.14	121.41	53.07	25.70	215.03	123.03	53.37	26.01
4	06/23/2006	Standard	214.41	120.85	51.62	24.39	215.19	122.63	52.51	25.04
Coefficient of Variation:			**0.54%**	**0.47%**	**0.07%**	**2.06%**	**0.37%**	**0.46%**	**0.83%**	**0.88%**

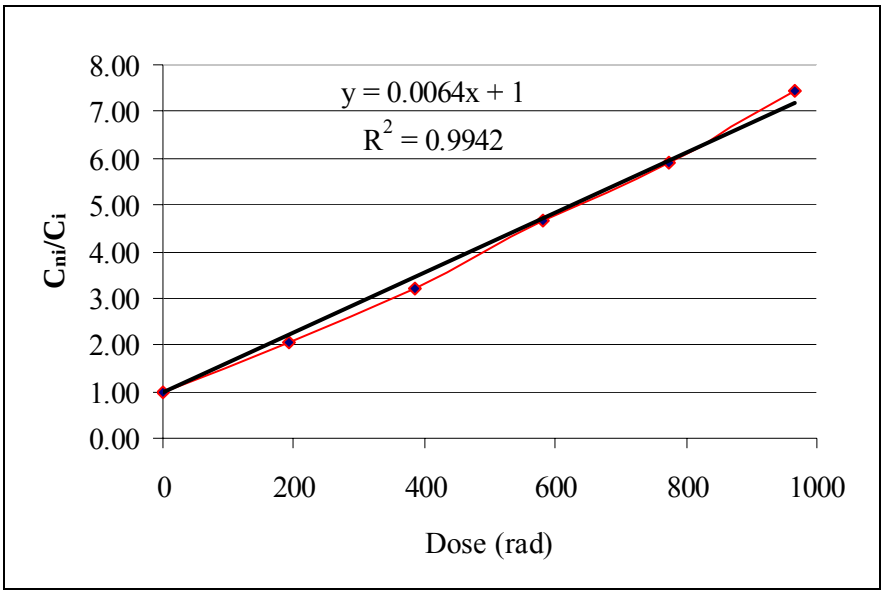
Appendix G
Final Post-Irradiation Calibration Curve Information for Scanner Station 1

Number	Red Channel Pixel Value (C)	C_{ni}/C_i	Dose (rad)
1	229.71 (Mean C_{ni}*)	1.00	0.0
2	175.40	1.31	51.0
3	145.41	1.58	102.0
4	109.80	2.09	193.4
5	108.72	2.11	199.3
6	84.07	2.73	301.3
7	69.86	3.29	386.8
8	68.15	3.37	403.2
9	60.25	3.81	495.9
10	48.77	4.71	580.2
11	48.82	4.71	597.9
12	44.81	5.13	695.3
13	40.17	5.72	773.6
14	36.99	6.21	825.0
15	32.29	7.11	927.0
16	31.27	7.35	967.0

Red Channel Pixel Values (C_{ni}) 9/6/2005-2/27/2006
225.23
227.69
226.17
227.09
226.17
227.45
230.67
226.71
228.80
231.61
233.86
234.65
235.41
234.48
Coefficient of Variation: 1.6%
***Mean C_{ni}: 229.71**

Appendix H
14-Day Post-Irradiation Calibration Curve and Information for Scanner Station 4

Film Number	Red Channel Pixel Value (C)	C_{ni}/C_i	Dose (rad)
1	227.83	1.00	0.0
2	111.18	2.05	193.4
3	71.08	3.21	386.8
4	49.02	4.65	580.2
5	38.62	5.90	773.6
6	30.69	7.42	967.0
7	26.71	8.53	1224.9



Appendix I
Procedure Information Sheet

University of North Carolina-Chapel Hill
Procedure Information Sheet

Medical IRB Study #: 05-RAD-358
Title of Study: The Use of a Radiochromic Film for the Evaluation of Skin Dose during Extended Fluoroscopy Procedures in an Electrophysiology Lab
Principal Investigator: James Bradford Taylor
UNC-CH Department: Environment, Health and Safety
Phone Number: 919-962-5727

Subject Number (Corresponding to Number on Film) _____

Procedure Date _____

Subject Date of Birth _____ Subject Sex (circle one) M F

Patient Height (include units) _____ Patient Weight (include units) _____

Patient BMI (if available) _____

Procedure (circle one) ABL BIV

Nature of Ablation Procedure (i.e.: atrial flutter) _____

Attending Physician _____

Assisting Fellow (if applicable) _____

Total Fluoroscopy Time (minutes) _____

Optional Comments:
kVp range during procedure _____ mA/ms range during procedure _____

SID range during procedure _____ Phosphor Size Used (circle one) 5 7 9

Mode of Operation (i.e.: continuous, pulsed) _____

FILM SCANNED ON _____ USING SCANNER STATION _____

CALIBRATION CURVE USED:_____RED CHANNEL VALUE _____

DOSE (RAD) _____ (1Gy = 100 RAD)

Appendix J
Subject, Procedure, and Scanning Information for Study Participants

Subject Number	Sex	Height (inches)	Weight (lbs)	BMI	Weight Status
1	Male	73.0	331	43.7	Obese
2	Male	69.0	209	30.9	Obese
3	Male	72.0	165	22.4	Normal
4	Male	76.0	331	40.3	Obese
5	Female	64.0	146	25.1	Overweight
6	Male	74.0	220	28.2	Overweight
7	Male	72.0	170	23.1	Normal
8	Male	67.0	200	31.3	Obese
9	Female	60.0	147	28.7	Overweight
10	Male	70.0	147	21.1	Normal
11	Male	72.0	180	24.4	Normal
12	Female	61.0	200	37.8	Obese
13	Male	68.0	191	29.0	Overweight
14	Male	68.5	225	33.7	Obese
15	Female	65.0	240	39.9	Obese
16	Female	70.0	165	23.7	Normal
17	Female	60.0	133	26.0	Overweight
18	Female	70.0	230	33.0	Obese
19	Male	69.0	202	29.8	Overweight
20	Male	69.5	286	41.6	Obese
21	Male	71.0	172	24.0	Normal
22	Female	65.0	116	19.3	Normal
23	Female	61.0	117	22.1	Normal
24	Male	75.0	285	35.6	Obese
25	Male	70.0	206	29.6	Overweight
26	Male	70.0	209	30.0	Overweight
27	Male	69.5	297	43.2	Obese
28	Male	71.0	240	33.5	Obese
29	Male	72.0	203	27.5	Overweight
30	Female	70.0	157	22.5	Normal

Subject Number	Procedure Date	Procedure	Nature of Diagnosis	Physician	Fluoro Time (minutes)
1	09/09/2005	BIV	N/A	B	48.7
2	09/14/2005	ABL	AVNRT	A	78.6
3	09/15/2005	BIV	N/A	A	22.7
4	10/03/2005	BIV	N/A	A	27.6
5	10/03/2005	BIV	N/A	A	32.2
6	11/02/2005	ABL	WPWS	A	91.7
7	11/16/2005	ABL	Atrial Flutter	B	47.9
8	11/18/2005	ABL	WPWS	B	66.4
9	12/15/2005	BIV	Upgrade	A	25.8
10	01/18/2006	BIV	N/A	A	19.7
11	02/10/2006	ABL	WPWS	B	12.5
12	02/17/2006	ABL	AVNRT	B	27.5
13	02/22/2006	BIV	N/A	A	19.3
14	03/02/2006	BIV	N/A	A	60.1
15	03/08/2006	BIV	N/A	A	26.5
16	03/03/2006	ABL	AVNRT/WPWS	B	40.7
17	03/10/2006	ABL	Supra Ventricular Tachycardia	B	80.7
18	03/17/2006	ABL	Premature Ventricular Contractions	B	49.1
19	03/20/2006	BIV	N/A	A	29.3
20	03/20/2006	BIV	Upgrade	A	40.3
21	04/12/2006	BIV	N/A	A	57.1
22	04/13/2006	ABL	AVNRT	B	29.1
23	04/18/2006	ABL	AVNRT	B	77.0
24	04/20/2006	BIV	N/A	A	71.4
25	05/01/2006	BIV	N/A	A	53.4
26	05/03/2006	BIV	N/A	A	25.6
27	05/18/2006	BIV	N/A	A	22.4
28	06/02/2006	ABL	Supra Ventricular Tachycardia	B	23.7
29	06/06/2006	ABL	Atrial Tachycardia	B	85.1
30	06/08/2006	ABL	Left-sided Atrial Tachycardia	A	94.0

AVNRT=Atrioventricular Nodal Reentry Tachycardia
WPWS=Wolf Parkinson White Syndrome

Subject Number	Final Scan Date	Days Post-Irradiation	Scan Station	Lowest Red Channel Pixel Value	Skin Dose (Rad)
1	09/26/2005	17	1	39.50	764.4
2	09/28/2005	14	1	69.37	366.9
3	09/28/2005	13	1	169.93	55.8
4	10/17/2005	14	1	109.21	175.1
5	10/17/2005	14	1	160.78	68.1
6	11/16/2005	14	1	86.11	264.7
7	12/01/2005	15	1	140.20	101.3
8	12/01/2005	13	1	113.29	163.1
9	12/30/2005	15	1	141.70	98.6
10	02/01/2006	14	1	170.73	54.8
11	02/24/2006	14	1	191.40	31.8
12	03/03/2006	14	1	140.23	101.3
13	03/08/2006	14	1	166.63	60.1
14	03/17/2006	15	1	91.65	239.1
15	03/22/2006	14	1	147.77	88.0
16	03/17/2006	14	1	165.15	62.1
17	03/22/2006	12	1	144.87	93.0
18	03/30/2006	13	1	115.92	155.8
19	04/03/2006	14	1	143.24	95.8
20	04/03/2006	14	1	80.46	294.4
21	04/27/2006	15	1	135.19	111.0
22	04/27/2006	14	1	186.05	37.2
23	05/03/2006	15	4	137.02	103.6
24	05/03/2006	13	4	97.10	210.4
25	05/16/2006	15	4	122.27	134.9
26	05/16/2006	13	4	182.74	38.6
27	06/01/2006	14	4	118.71	143.6
28	06/15/2006	13	4	156.27	71.6
29	06/23/2006	17	4	95.16	217.8
30	06/23/2006	15	4	142.13	94.2

REFERENCES

American Association of Physicists in Medicine (AAPM). 2002 Annual Meeting Abstract ID: 8455. Assessment of radiation dose to patient skin during implantation of a pacemaker designed for congestive heart disease.

21 CFR 1020.32. Food and Drug Administration, Department of Health and Human Services, Performance Standards for Ionizing Radiation Emitting Products, Fluoroscopic Equipment, May 19, 1994.

Annals of the International Commission on Radiological Protection (ICRP). Publication 93. Managing Patient Dose in Digital Radiology. March 2004;Vol 34(1).

Centers for Disease Control and Prevention, Body Mass Index Website. Retrieved May 11, 2005, from http://www.cdc.gov/nccdphp/dnpa/bmi/adult_BMI/about_adult_BMI.htm# Definition

Bucher, Lee. Imaging specialist for Toshiba American Medical Systems. E-mail correspondence dated June 2, 2004.

Bushberg, JT. *The Essential Physics of Medical Imaging*. Second edition. 2002. pp.55, 231-254.

Cember H. *Introduction to Health Physics*. Second edition. 1983. pp.142.

Chida K, Saito H, Otani H, Kohzuki M, Takahashi S, Yamada S, Shirato K, Zuguchi M. Relationship between fluoroscopic time, dose-area-product, body weight, and maximum radiation skin dose in cardiac interventional procedures. American Journal of Roentgenology. 2006;186:774-778.

Curry III, TS, Dowdey, JE, Curry, RC. *Christensen's Physics of Diagnostic Radiology*. Fourth edition. 1990. pp.33-35.

Dini SA, Koona RA, Ashburn JR, Meigooni AS. Dosimetric evaluation of Gafchromic XR type T and XR type R films. Journal of Applied Clinical Medical Physics. 2005;6(1):114-34.

FDA Public Health Advisory: Avoidance of serious x-ray-induced skin injuries to patients during fluoroscopically-guided procedures. Rockville, Md: Food and Drug Administration, September 9, 1994.

FDA Center for Devices and Radiological Health Website. Recording information in the patient's medical record that identifies the potential for serious x-ray-induced skin injuries (September 15, 1995). Retrieved October 26, 2004, from http://www.fda.gov/cdrh/xrayinj.html

Giles ER and Murphy PH. Measuring skin dose with radiochromic dosimetry film in the cardiac catheterization laboratory. Health Physics. 2002;82(6)875-880.

Heart Center Online Website. Retrieved November 12, 2004, from http://www.heartcenter online.com/Biventricular_Pacemaker.html

How Stuff Works Website. Retrieved August 16, 2005, from http://science.howstuffworks. com/question583.htm

Iida H, Horii J, Chabatake M, Take E, Shimizu M, Mizushima T. Evaluation and estimation of entrance skin dose in patients during diagnostic and interventional radiology procedures (article in Japanese). Nippon Hoshasen Gijutsu Gakkai Zasshi. 2004 Jan;60(1). From the abstract.

International Atomic Energy Agency (IAEA). International Basic Safety Standards. Protection against Ionizing Radiation and for the Safety of Radiation Sources. Safety Series No 115, 1996.

ISP. International Specialty Products, Product Information Brochure for Gafchromic XR Type R. August 2004.

JCAHO (Joint Commission on Accreditation of Healthcare Organizations) Website. Retrieved March 28, 2006, from http://www.jointcommission.org/SentinelEvents/ PolicyandProcedures/

Kostas P, Theocharopoulas N, Damilakis J, Manios E, Vardas P, Gourtsoyiannis N. Fluoroscopy guided implantation of modern cardiac resynchronization devices. Journal of the American College of Cardiology. 2005; 46(12):2335-2339.

Koenig T, Wolff D, Metter F, Wagner F. Skin injuries from fluoroscopically guided procedures: Part 1, characteristics of radiation injury. American Journal of Roentgenology. 2001;177:3-11.

Lindsay B, Eichling J, Ambos H, Cain M. Radiation exposure to patients and medical personnel during radiofrequency catheter ablation for supraventricular tachycardia. American Journal of Cardiology. 1992;70:218-223.

Mahesh, M. Fluoroscopy: Patient radiation exposure issues. Radiographics. 2001;21:1033-1045.

Manolis AS, Vassilikos V, Maounis T, Chiladakis J, Cokkinos D. Radiofrequency ablation in pediatric and adult patients: Comparative results. Journal of Interventional Cardiac Electrophysiology. 2001;5:443-453.

Macle L, Weerasooriya R, Jais P, Scavee C, Raybaud F, Choi K-J, Clementy J, Haissaguerre M. Radiation exposure during radiofrequency catherter ablation for atrial fibrillation. Pacing and Clinical Electrophysiology. 2003;26(1 Pt 2):288-291.

Minneapolis Heart Institute, Electrophysiology (Heart Rhythm Management) Website. Retrieved November 3, 2004, from http://www.mplsheart.com/pages/TestDetails.asp?SpecID=1

Office of Human Research Ethics (OHRE) at The University of North Carolina at Chapel Hill. Retrieved August 22, 2006, from http://www.ohre.unc.edu/

Paisey JR, Yue AM, White A, Moss A, Morgan JM, Roberts PR. Radiation peak skin dose to risk stratify electrophysiology procedures for deterministic skin damage. The International Journal of Cardiovascular Imaging. 2004;20:285-288.

Park TH, Eichling JO, Schechtman KB, Bromberg BI, Smith JM, Lindsay BD. Risk of radiation induced skin injuries from arrhythmia ablation procedures. Pacing and Clinical Electrophysiology. 1996;19(9):1363-1369.

Romeyer-Bouchard C, DaCosta A, Abdellaoui L, Messier M, Thevenin J, Afif Z, Kihel A, Cerisier A, Convert G, Isaaz K. Simplified cardiac resynchronization implantation technique involving right access and a triple-guide/single introducer approach. Heart Rhythm. 2005 July;2(7):714-719.

Rosenthal SR, Mahesh M, Beck TJ, Saul JP, Miller JM, Kay N, Klein LS, Huang S, Gillette P, Prystowsky E, Carlson M, Berger RD, Lawrence JH, Young P, Calkins H 1998. Predictors of fluoroscopy time and estimated radiation exposure during radiofrequency catheter ablation procedures. American Journal of Cardiology. 1998;82:451-458.

Seeram, E. *Radiation Protection*. 1997. pp.63-64.

Thomas G, Chu RYL, Rabe F. A study of Gafchromic XR type R film response with reflective-type densitometers and economical flatbed scanners. Journal of Applied Clinical Medical Physics. 2003;4(4):307-314.

Thomas G, Li, Y, Chu RYL, Cheung JY, Maqbool F, Rabe F, Burns GS. Measurement of dose-area product with Gafchromic XR Type R Film. Journal of Applied Clinical Medical Physics. 2005;6(3):122-132.

Wagner LK, Archer BR. Minimizing Risks from Fluoroscopic X-Rays: Bioeffects, Instrumentation, and Examination. 1996. A credentialing program by Partners in Radiation Management, pp.6-31.

Wall, BF. Ninth International Congress of the International Radiation Protection Association (IRPA9). How to assess the dose to the patient in diagnostic radiology. April 16, 1996, pp.5, 23.