Occupational Health Concerns In Interventional Radiology: A Dangerous Complacency

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Main Acknowledgement

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Prologue

One day during whilst standing in fluoroscopy being innocently irradiated I wondered what all this radiation exposure was doing to my body. It is a strange feeling not being able to see or feel the radiation beam, yet knowing it is having a profound effect. I took this a bit too personally and I began thinking about what might happen to me. This was how I conceived the idea of undertaking this project.

When I first became interested in interventional radiology as a career I organized elective placements to observe the interesting procedures undertaken in fluoroscopy units. Interventional procedures are becoming the new way to treat cancer and exciting developments in this field have resulted in novel targeted therapies to treat cancers of the liver, lungs amongst others. Was this technologically driven boom in intervention, so many patients had benefited from, as safe as it was effective? I was deeply concerned about radiation exposure especially as I had not started my career yet.

I felt that undertaking my elective at Columbia University Medical Center, New-York Presbyterian Hospital, New York City would uncover more truth into radiation risks from working as an interventional radiologist. The department has a busy workload and is one of the largest in New York. There is also extensive work undertaken by clinicians at the institution looking at aspects of radiation-induced injury particularly the effect of radiation on the eye.

Introduction

Interventional Radiologists have arguably the highest exposure to radiation of any staff working with medical x-ray techniques[1 2]. The constant improvement in technology allows for increasingly challenging clinical problems to be tackled minimally invasively therefore the number of procedures being performed continues to rise[3]. Fluoroscopically guided IR procedures are performed in large numbers in the UK and USA and there is marked variation in the amount of radiation dose received by those working in IR.

Radiation dose quantities pose two different types of risk to patients and health professionals. Stochastic risks (mostly cancer) and also deterministic risks (tissue reaction) like skin injury. Deterministic effects are characterized by a threshold dose, below which no effect is seen[4]. As the dose increases over the threshold, there is increased effect. Different tissues and people have different threshold doses for deterministic effects[5] for example red bone marrow, breast, colon, lung and stomach are more sensitive to radiation and have a lower threshold for deterministic effects. Stochastic risks account for late effects of radiation including radiation carcinogenesis and hereditary effects. There is no threshold dose however the stochastic risk increases in likelihood as dose increases. The severity is not dose related either.

For adult patients in interventional procedures risk of skin injury is more likely whereas for children the stochastic risk is more important.

Furthermore, lack of innovation in protective apparel design predisposes those working in the interventional suites to orthopaedic injuries due to the adverse effects of heavy burdensome lead aprons.

In a busy work environment, it is not a surprise that most interventional radiologists will accept these as inherent costs of their career choice and underappreciate the impact of their daily radiation exposure and orthopaedically burdensome protective gear. Having not been made aware of the occupational risks of a career in IR I decided to spend some time clarifying the magnitude and impact of such health concerns so that I would be better informed when beginning my own career of the potential risks.

Aims

1. To understand the magnitude of radiation side effects affecting doctors and general public
2. Assess the variation between the radiation exposure standards in the USA and UK
3. To find out the types of personal protective equipment (PPE) used in IR
4. To research the potential radiation induced health problems associated with working in interventional radiology (IR) focusing on radiation cataracts
5. To review the likely incidence of occupational health hazards faced by IR
6. Assess the variation in PPE and advice regarding PPE between the USA and UK

Radiation Exposure Standards and Dose Limits

The radiation dose received by interventional radiologists is dependent on many factors such as the type of procedure done/ length of time using fluoroscopy, patient dose, degree of scatter and effectiveness of protection. International organizations set out recommendations on occupational dosimetry including monitoring arrangements to allow for exposure calculation[6].

For interest in comparing radiation doses, I researched the levels of ionising radiation the general public may be exposed to from both natural sources in the environment and medical sources. Table 1 shows the typical dose of radiation from a number of common sources.

In the UK, the Health Protection Agency (HPA) estimates people on average are exposed to about 2.7 millisieverts (mSv) of radiation per year most coming from naturally occurring radiation from building material and radon gas which seeps from the ground into our homes and workplaces[7]. A mSv is a measure of radiation dose which accounts for the fact that ionising radiation can affect different parts of the body to differing degrees. It also allows for the different effects of different types of radiation, x-rays, gamma-rays, neutrons, alpha particles and beta particles. Another unit, the gray (Gy) is the absorption of one joule of energy in the form of ionising radiation per kilogram of matter. For x-rays and gamma rays one gray is one sievert (Sv) however for alpha particles one gray is twenty sievert.

Table 1: Medical and non-medical sources of radiation and radiation dose (Source: HPA[7])

Source of Exposure	**Dose**
Dental X-ray	0.005 mSv
135g bag of Brazil nuts	0.005 mSv
Chest X-ray	0.02 mSv
Transatlantic flight	0.07 mSv
Nuclear power station worker average annual occupational exposure	0.18 mSv
UK annual average radon dose	1.3 mSv
CT scan of the head	1.4 mSv
UK average annual radiation dose	2.7 mSv
USA average annual radiation dose	6.2 mSv
CT scan of the chest	6.6 mSv
Average annual radon dose to people in Cornwall	7.8 mSv
Whole body CT scan	10 mSv
Annual exposure limit for nuclear industry employees	20 mSv
Level at which changes in blood cells can be readily observed	100 mSv
Acute radiation effects including nausea and a reduction in white blood cell count	1000 mSv
Dose of radiation which would kill about half of those receiving it in a month	5000 mSv

The Health and Safety Executive (HSE), a national independent watchdog for work-related health, safety and illness enforces legal requirements on those working with ionising radiation in the UK. This includes informing the HSE when one is intending to start work with ionising radiation for the first time, with at least 28 days notice prior to starting work.

The Ionising Radiations Regulations 1999 (IRR99) establish a good regulatory framework for reducing employees' exposure to ionising radiations and have generally been successful in helping to ensure the continuing reduction in doses to workers since the making of the previous Regulations in 1985 (IRR85). This is confirmed by analyses of data held on HSE's Central Index of Dose Information (CIDI). Over the period 1986-1998 there was more than a 10-fold reduction in the numbers of classified persons with recorded doses above the statutory investigation level prescribed by IRR85[8].

The limits on effective dose (dose to the whole body) in the UK, introduced by the IRR99 to replace the limits set previously by the IRR85 are[8]:

1. for employees aged 18 years or over, 20 mSv in a calendar year (except that in special cases employers may apply a dose limit of 100 millisieverts in 5 years with no more than 50 mSv in a single year, subject to strict conditions);
2. for trainees, 6 mSv in a calendar year; and
3. for any other person, including members of the public and employees under 18 who cannot be classed as trainees, 1 mSv in a calendar year.

In the USA, individual state governments set occupational dose limits however most adhere to the recommendations developed by the National Council of Radiation Protection (NCRP) where occupational limit is set at 50 mSv in any 1 year and a lifetime limit of 10mSv multiplied by the individuals age in years[9].

Measuring Occupation Exposure

All workers require appropriate monitoring in the form of a personal dosimeter, worn outside of protective garments. This allows for an estimation of the dose delivered to the surface of unprotected skin and to the lens of the eye. At Columbia all staff with dosimeters must exchange their dosimeter at the end of the month so that the radiation exposure can be calculated at an external site.

Inaccurate dosimetry is a consequence of individual mistakes such as forgetting to wear their dosimeter, wearing it inappropriately or in the wrong location of the body and leaving it in a radiation environment. Individuals may purposely not wear their dosimeter in fear that they will me made to stop working if they have reached their dose limit.

Personal Protective Equipment and Radiation Protection

PPE includes lead aprons, thyroid shields, eyewear and gloves. Protective aprons with thyroid shields are the main radiation protection tools for those working in the intervention room. They should be employed at all times. There are two main types of lead apron, a one piece apron and a vest/skirt configuration (which puts less strain on the persons shoulders and back) which is preferred by many operators in order to reduce the risk of musculoskeletal/back injury[10]. There are multiple sizes of aprons and operators and staff who work in the radiation environment should be ideally be provided properly fitted aprons, both to reduce ergonomic hazards and to provide optimal radiation protection[11]. The lead composite within the aprons can be disrupted with age and poor care. Worryingly some of the composite material used in the lead aprons may transmit up to twice the amount of radiation expected, an unacceptable finding[12]. Aprons should be checked fluoroscopically on an annual basis to detect defects in the protective material[13].

Recently there has been development of a weightless aprons including one design that is attached to ceiling mounted rails that can be worn in seconds. This radiation protection system shields from the top of the head to the calves and due to the complex overhead motion system it eliminates weight on the operator and allows freedom of motion[14]. This “zero-gravity” design provided a 16-78-fold decrease in radiation exposure in a simulated clinical setting. Currently it would be unlikely such PPE would be available given the substantial financial costs of implementing such devices. However, these designs hold promise for improve ergonomics and safety. In the future, as new PPE becomes available it will be important to evaluate the designs critically to ensure they improve radiation protection and also reduce ergonomic hazards.

A series of small molecule kinase inhibitors have been developed which are aimed at modifying cell cycle distribution and providing radioprotection[15]. Early results in animal models showed reduced levels of pro-apoptosis proteins such as p53, as well as downstream regulators, which are involved in ionising radiation-induced p53-dependent apoptosis. This is promising and shows alternative methods of tackling radiation side effects.

Radiation Hazards in IR

General societal concerns surrounding medical radiation risk relates to the stochastic risks of cancer however in the early 1990s there were numerous reports of patients developing severe radiation induced skin burns from prolonged fluoroscopy times[16]. Developments in the last decade including x-ray tube shielding, x-ray beam collimators and filters and timers that buzz at 5-inute intervals have improved patient safety significantly. However with complex procedures such as transhepatic portosystemic shunts (TIPS) and vessel embolization’s, which require longer fluoroscopy, there is still a risk of such injury to the patient although the radiologist, being away from the main beam of radiation, should not experience this with reasonable care. The risk of cancer induction from radiation remains a major issue given the lack of understanding of biological effects of radiation on different types of tissue. Similarly, recent epidemiological studies find radiation is linked to cataract formation[17] [18] and worryingly the previously accepted eye dose of 2-5 Gy was too high potentially resulting in many interventionists far exceeding their safe threshold of eye radiation.

Ocular Health Hazards From Radiation

The lens of the eye is known to be one of the most radiosensitive tissues in the body therefore exposure to x-rays during IR procedures can damage this structure leading to opacities, otherwise known as cataracts[19] [20]. Eye lens opacities have been observed in interventionalists who do not use adequate eye protection[21] and with time this can progress to total lens opacification. Only recent research has revealed dose-related lens opacifications at significantly lower doses which lead to the International Commission on Radiological Protection (ICRP) to reduce the human threshold value for radiation cataractogenesis from 2-8 Gy to 0.5 Gy[22]. At the same time, the recommended occupational lens exposure limit was lowered from 150 mSv/year to an average of 20 mSv/year over 5 years with no single year exceeding 50 mSv. It is possible that there is no threshold dose and that radiation induced cataract formation is a stochastic effect rather than a deterministic one as previously believed[23].

Radiation cataracts are believed to arise from damaged or misrepaired DNA and subsequent errors in cell cycle control, division and differentiation[23]. There are three predominant forms of cataract; cortical, nuclear and posterior subcapsular (PSC). PSC cataracts, the most common type associated with radiation, develop from aberrantly differentiating epithelial cells and results in opacity at the posterior pole.
A standard radiation monitor worn at collar level and above all radio-protective garments provides a reasonable estimate of eye dose. Unprotected eyes receive approximately the dose indicated by such a monitor. High-quality radio-protective glasses will reduce the eye dose to approximately 1/3 of the monitor reading. This is less than the nominal attenuation of the radio-protective lenses because radiation reaches the eyes through transmission around the glasses and through scatter in the worker’s head.

However, personal dosimetry varies widely among countries. Some countries require the use of a dosimeter outside the apron, whereas others place the device inside the apron. This difference notwithstanding, the literature suggests staff in cardiac catheterization laboratories and interventional suites may not always use personal dosimetry regularly, making retrospective dose estimates, especially those examining cumulative effects of many years of exposure[24 25].

Unfortunately, with typical reported workloads, there are reports that radiation doses to eye lenses exceed the threshold for deterministic effects (i.e. those causing lens opacities and cataract formation) after several years of work without radiation eye protection. Lens doses were particular high with neuroembolization procedures, exceeding 10mSv per procedure[26].

Continued follow up of occupationally exposed medical staff will lead to precise estimates of radiation cataract threshold and in the meantime appropriate protection should be used to attenuate radiation dose to the eye in the form of protective eyewear and shields available in the intervention suite.

Incidence of Occupational Health Hazards

Elucidating the prevalence of occupational health risks in IR at Columbia was not possible as these issues had not been formerly documented. There have been few epidemiological studies that have produced quantitative evidence to back up theoretical workplace risks that the interventional lab poses. I have found four studies that indicate working in the intervention lab is associated with orthopaedic problems and such injuries result in missed days of work, surgery and also shortened careers. Table 2 summarizes the findings of these studies.

Table 2: Summary of orthopaedic complications associated with working in intervention suite

Author	**Methods**	**Findings**
Ross[27]	Survey of 852 interventional cardiologists. 385 responses.	75% of interventionalists had increased spine problems compared to orthopedists and rheumatologists.
Goldstein[28]	Survey of 1600 interventional cardiologists. 424 responses.	Prevalence of orthopaedic complaints: Spine 42%; Hip, knee or ankle 28%; Spine problem limited work in 1/3
Machan[29]	Survey of interventional radiologists. 308 responded.	60% reported spine problems; in 25%, spine problem limited work.
Moore[30]	Survey of 608 radiologists. 236 responded.	50% prevalence of back pain

Radiation is associated with increased incidence of cancer. It is difficult to quantify the amount of radiation that contributes to the development of malignancy in an individual. There are documented anecdotal reports on thyroid cancer cases where radiation exposure was thought to be a significant risk factor in the development of their cancer. One patient at Columbia was a cardiac catheter lab technician and will have been exposed to significant levels of radiation over her working career. There are many factors that could have contributed to this including other non-radiation risk factors or simply poor adherence to PPE use. One study found death rate from brain cancer in radiologists was nearly three times that of other medical specialists who did not use radiation[31]. A case-control study reported out of 233 patients with brain tumours that working as a physician with fluoroscopy increased the risk of developing a brain tumour although there were only three such individuals among the 233 cases. A limitation of generalizing the results of these studies is the large number of potential confounders. We cannot exclude other biological agents and chemicals unrelated to radiation as causative in these studies. However these results cannot be ignored. The impact of radiation to the brain from chronic low dose exposure is not well studied however ionising radiation is one of the few established causes of neural tumours[32]. Therefore we must address the potential health risk seriously and cautiously.

Differences in Personal Protective Equipment in IR Suite

In the UK there is use of upper body and thigh lead cover as well as thyroid shielding however from my own experiences many IRs and theatre staff do use adequate eye protection. There is no requirement in place for eye protection and it is down to operator preference. This may vary between Trusts (I only have experience of working in the West Yorkshire and South East Scotland trusts) however compared to the USA there appears to be less strict measures for eye protection. In Columbia there is encouragement for all employees to wear suitable eye protection in the form of lead engrained spectacles and the department routinely purchases all staff this gear. With the recent changes in 2011 to the limits for ocular exposure to radiation[22], I hope that appropriate eyewear is advocated to all interventionists in the near future given the low threshold for potential damage and evidence highlighting the risk of chronic low dose exposure[19 20 33].

What I Learnt – Summary of Methods for Reducing Radiation Dose

We bear primary responsibility for protecting our own health. There are several key points that I took away from this entire learning experience:

- Wearing personal dosimeters at all times in the intervention lab. It is important we know our own occupational dose to ensure we are working safely.
- Take every opportunity to reduce dose by using fluoroscopy conservatively, keeping an appropriate distance from the source of radiation (intensity of radiation follows Newton's Inverse Square Law) and using shielding present around the lab.
- If observing keep oneself in low-scatter area such as behind another protected colleague.
- Use all available information to plan the interventional procedure such as pre-procedure imaging (ultrasound, MIR, CT) to define the relevant anatomy and pathology especially for complex procedures. This can minimize fluoroscopy time and the number of images taken.
- Always wear PPE (thyroid collar, lead apron) in the lab. Strive to wear eye protection if working close to the source.
- Educate our colleagues about radiation safety and precautions to take.
- Remember to limit patient dose by adjusting collimator blades so that the focus of radiation is tighter therefore reducing scatter and also improving image quality.

Final Reflections

Raising awareness to risks of radiation exposure is important in the field of medicine and formal radiation safety training should be a compulsory part of any induction for medical staff. Teaching medical students about risks of radiation from medical treatment is also important as many specialties such as vascular, orthopaedics and urology utilize radiation in the operating theatre and students may rotate through these. Secondly, it develops a commitment to radiological protection early on.

Appropriate personal protective equipment is vital to ensure we limit as much radiation as possible. There is room for further developments in this area given the ergonomics of producing lightweight and flexible lead gear that maintains a high level of protection from x-rays. The ultimate goal would be to eliminate all unnecessary radiation exposure to physicians and a starting point is for physicians to work together with industry to improve the work environment (design of fluoroscopy suites) and also PPE design.

Personally, gaining this valuable insight into the occupational hazards in IR has furthered my clinical knowledge and also improved my awareness of wearing PPE allowing me to create a safer work environment for myself and other colleagues. I hope to continue to raise awareness of radiation risks as I progress through my career. Knowing how to reduce the amount of radiation we subject both patients and ourselves to will help to prevent unnecessary levels of radiation exposure minimizing the associated risks. These efforts to enhance workplace safety will undoubtedly make the career of any interventionist healthier and longer.

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