The Clinical Scientist

Volume I

A Compendium of Faculty of Clinical Sciences Lectures

College of Medicine, University of Ibadan

A.A. Abdus-Salam & T.K. Hamzat, editors

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Editors

Abbas A. Abdus-Salam

Talhatu K. Hamzat

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Faculty of Clinical Sciences
College of Medicine
University of Ibadan
Ibadan, Nigeria
email: fcs@comui.edu.ng
gsm: 02 2414425

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IMAGE GENTLY
One Size Does Not Fit All*

Omolola Mojisola Atalabi

Introduction and Historical Background to the Discovery of X-ray

The accidental discovery of x-rays in December 1895 by Wilhelm Röntgen in Germany holds the records for the fastest translational research in history. He submitted his discovery and it got published within three days in the annals of the Würstberg Society of Physical Medicine. By January 9th 1896, the discovery was heralded in Vienna (Austria) press, on the 23rd of January, Röntgen presented his data at the meeting of the Physical Medicine Society of Würstberg and by mid 1896 incredibly, the use of x-ray had gone from bench to practice.

The first ever child that was x-rayed had a 14-minute exposure (with great sedation) and the procedure was published in the Archives of Skiagraphy in 1896. The use of x-rays was even employed by shoe sellers to determine how well shoes fit children's feet. Foot x-ray machines were used in shoe stores during the 1940s and 1950s, to check shoe sizes, especially for children. The radiation dosages given out by these machines were approximately 10 Röntgens per minute. Their use was discontinued around the latter half of the 1950s. Children were not the only 'proud users of x-ray'; adults too had their bones imaged, oblivious to the inherent great danger.

The early radiologists who will be regarded as the martyrs of radiology and nuclear radiation include Madame Curie, Codman, Albers-Schoenberg, and

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* This paper was delivered as a faculty lecture on July 12th 2010.

many other famous radiologists who were martyred as a result of the deterministic effect of radiation that they suffered. In 1901 Röntgen received the first Nobel Prize for his discovery.

One hundred years of observation on British radiologists showed that mortality from cancer and other causes from 1897–1954 was a 41% higher in the practitioners of radiology. Whereas from 1954–1997, there was a zero excess mortality from cancer in the practitioners of radiology. We have become smart and protect ourselves, but unfortunately, have shifted the risk to our patients.

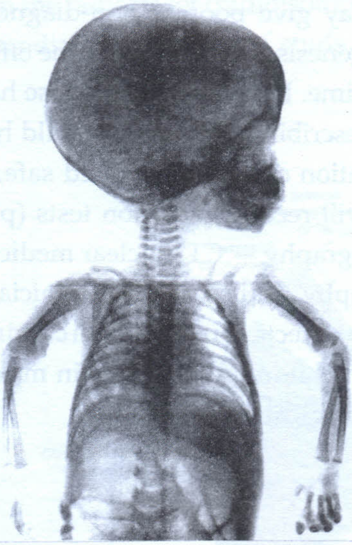
The topic of this lecture 'Image gently, one size does not fit all' was chosen to trigger a wake-up call from our deep sleep to the reality of the dangers that are inherent in our choice to image the children and generations yet unborn.

> *Lo, children are a heritage of the Lord: and the fruit of the womb is his reward. As arrows are in the hand of a mighty man; so are children of the youth. Happy is the man that hath his quiver full of them: they shall not be ashamed, but they shall speak with the enemies in the gate.*
> Psalm 127 verses 3-5.

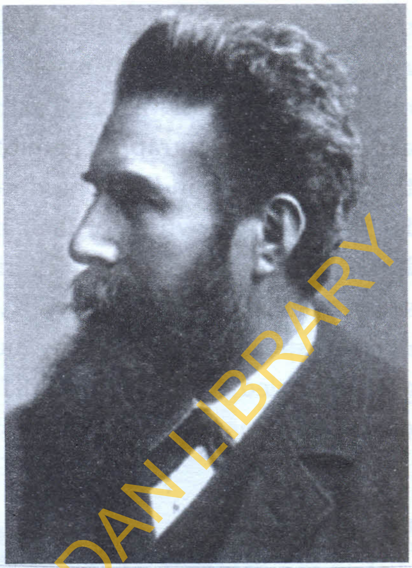
From the above Bible verses, it is obvious that children are fundamental to the future of any nation and that the prosperity/wealth of a people depends on them. Although the Bible does not qualify the kind of children, it goes without saying that these children must be healthy. When we must pay attention to the health of our children, so they grow to become healthy adults. The decision to use a particular imaging method may contribute to or accelerate a disease condition not only in a child-patient, but also in their offspring for generations to come.

This paper will take you through the rudiments of radiation physics, including, how radiation affects human cells and how to reduce the radiation dose during imaging. The 'image gently campaign' is also discussed and along with recommendations for safe imaging.

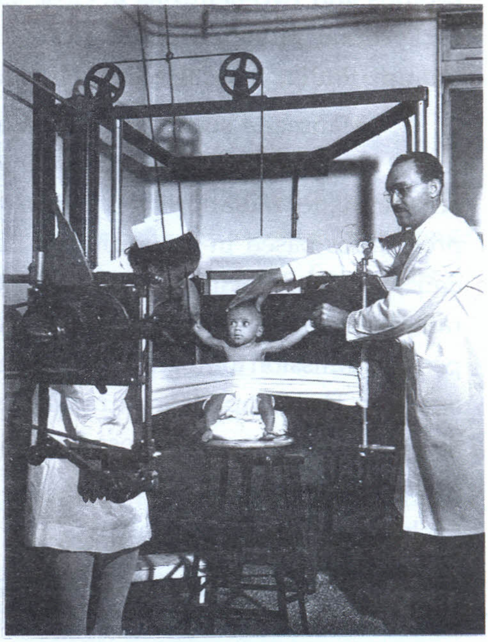
It is very important to keep in mind the fact that diagnostic tests and therapeutic medications are generally safe. The benefits of making a diagnosis and curing the disease outweigh the risks of the procedure or medication. Each test or medication has risks: with medication, incorrect doses can lead to idiosyncratic reactions which can be fatal; the dangers inherent in incorrect imaging doses is the thrust of this lecture.



The first child ever radiograph-ed– an infant who had a 14 minute exposure (great sedation) and was published in the Archives of Skiagraphy, published in 1896.



Willhelm Röntgen, discovered the X-ray, 1895.



Imaging tests that use radiation can also be perceived as a form of medication, with a 'correct dose'. Too little radiation may give poor or non-diagnostic images, while too much may result in carcinogenesis. This is because the effects of radiation are cumulative and last for a life time. In fact, radiation dose has a linear non-threshold graph. Therefore, the prescribing physician, should have at the back of his mind that no dose of radiation can be considered safe, in order to determine which of their patients will receive radiation tests (plain radiographs, fluoroscopy, computerised tomography – CT, nuclear medicine, positron emission tomography-PET, angiography, and so on). The clinician is therefore responsible for knowing the biological effects of radiation on children. A good knowledge of the biological effects on children will aid us in making informed decisions when we request for radiological investigations.

Sources of Radiation

Radiation is either natural or manmade. Natural radiation constitutes 50% of radiation that might affect us. We are all exposed to small amounts of background radiation daily from soil, rocks, building materials, air, water, and the cosmos. Alpha particles (nuclei of helium atom which are made up of two protons and two neutrons in close association), are a major source of natural background radiation. They are emitted during the decay of uranium and radium. Radon gas is the largest source of natural radiation (figure 1).

Manmade sources of radiation have been increasing dramatically in recent years and now account for 50% of our exposure. The largest component of manmade radiation is medical procedures and incidentally these are procedures based in the radiology department. Computed tomography (CT) and nuclear medicine contribute 75% of medical exposure and 36% of total radiation exposure. Conventional nuclear medicine uses gamma rays and positron emission tomography (PET) uses positron annihilation with short-lived isotopes. The comparison of radiation used in x-ray and CT with background radiation that we are exposed to daily is helpful in understanding relative radiation doses to the patient.

Background	1 day
Chest x-ray (single)	1 day
Head CT	up to 8 months
Abdominal CT	up to 20 months

The radiation exposure that is received from a nuclear medicine study comes from the radiotracer (radioisotope) and the amount of radiation exposure varies depending on the type of study. The radiation dose used in nuclear medicine

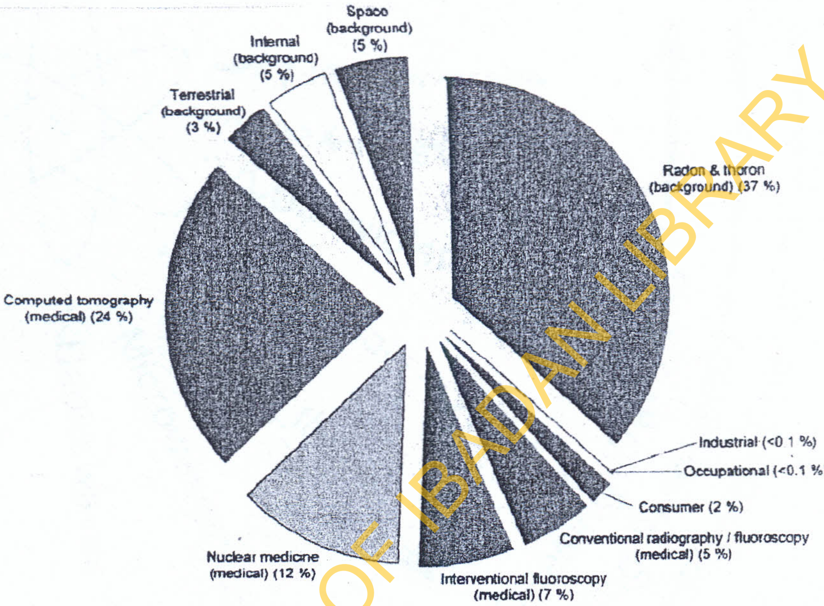


Figure 1. Reprinted with permission from the National Council on Radiation Protection (www.NCRPonline.org).

is within the lower range of what is received from routine diagnostic imaging procedures using x-rays. Nuclear medicine studies have been done on babies and children of all ages for more than 40 years without any known adverse effects. The functional nature of these examinations and the low doses of radiation used make them a safe and effective diagnostic tool in children.

Electromagnetic Spectrum

X-rays and gamma rays are forms of electromagnetic radiation (figure 2). Other forms of electromagnetic radiation are ultraviolet light, microwaves, and radio-waves. They differ in their wave lengths and therefore, their energies. X-rays and gamma rays can be considered packets of energy –photons. It is the deposition (absorption) of these packets of energy that determine their biological effects.

Computed tomography (CT) is the largest source of environmental (man-made) radiation.

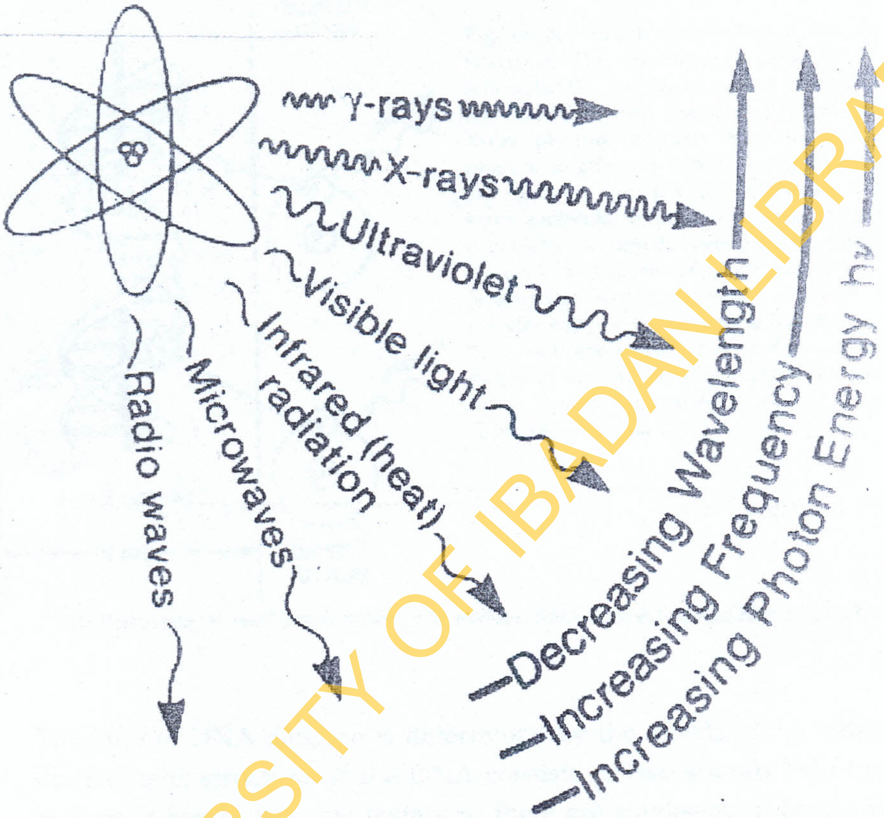


Figure 2. Illustration of the electromagnetic spectrum. X–rays and γ- rays have the same nature as visible light, radiant heat, and radio waves. However, they have a shorter wavelength and consequently larger photon energy. As a result, x–rays and γ- rays can break chemical bonds and produce biological effects.

With permission: *Radiology for the Radiologist*, Hall, Giaccia (2006) page 7.

How Radiation Affects Human Cells

An x-ray can pass through the body or be absorbed. Absorption causes release of the x-rays or photon energy (figure 3). The photon energy either indirectly (most often) or directly causes damage to the DNA. The indirect mechanism occurs when the energy of the recoil electron interacts with water (H_2O) to produce a hydroxyl radical (OH-), which then damages the DNA. The direct mechanism is when the absorbed energy directly damages the DNA.

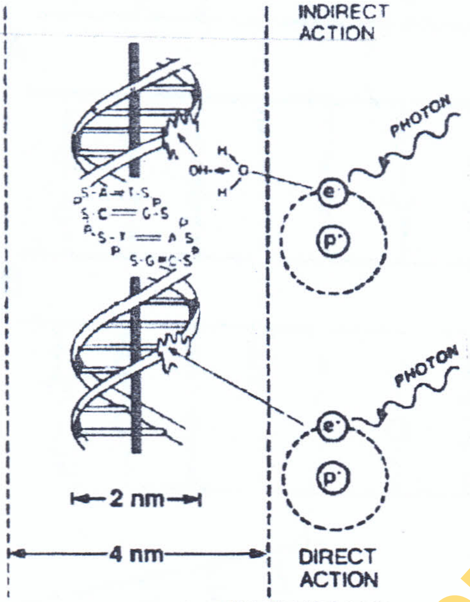


Figure 3. Direct and indirect actions of radiation. The structure of DNA is shown schematically. In direct action, a secondary electros resulting from absorption of an X-ray photon interacts with the DNA to produce an effect. In indirect action, the secondary electron interacts (for example) with a water molecule to produce a hydroxyl radical (CH-) which in turn damages the DNA. The DNA helix has a diameter of about 20A (2mm). It is estimated that free radicals produced in a cylinder with a diameter double that of the DNA helix can affect the DNA. Indirect action is dominant for sparsely ionizing radiation, such as X-rays, *S. sugar P. phosphorus, A. Adenine, T. thymire G. guanine, C cytosine*

With Permission : E Hall Radiation Biology for Pediatric Radiologist in Ped Rad 2009 39 S1: 57

The kind of DNA damage is determined by the effects of the radiation. The double helix structure of the DNA consists of two strands held together by hydrogen bonds. In some instances, there are single-strand breaks which are usually repairable using the opposite strands as a template (figure 3). Therefore, these breaks are of little lasting significance. Double-strand breaks are more of a problem—they can cause chromosomal breakage which can result in cell death or new combinations of chromosomal linkages. This results in various chromosomal sequences that can lead to a translocation or other mal-alignments (figure 5). At times, this can cause an oncogene (a gene that contributes to cancer formation when mutated or inappropriately expressed) to be created.

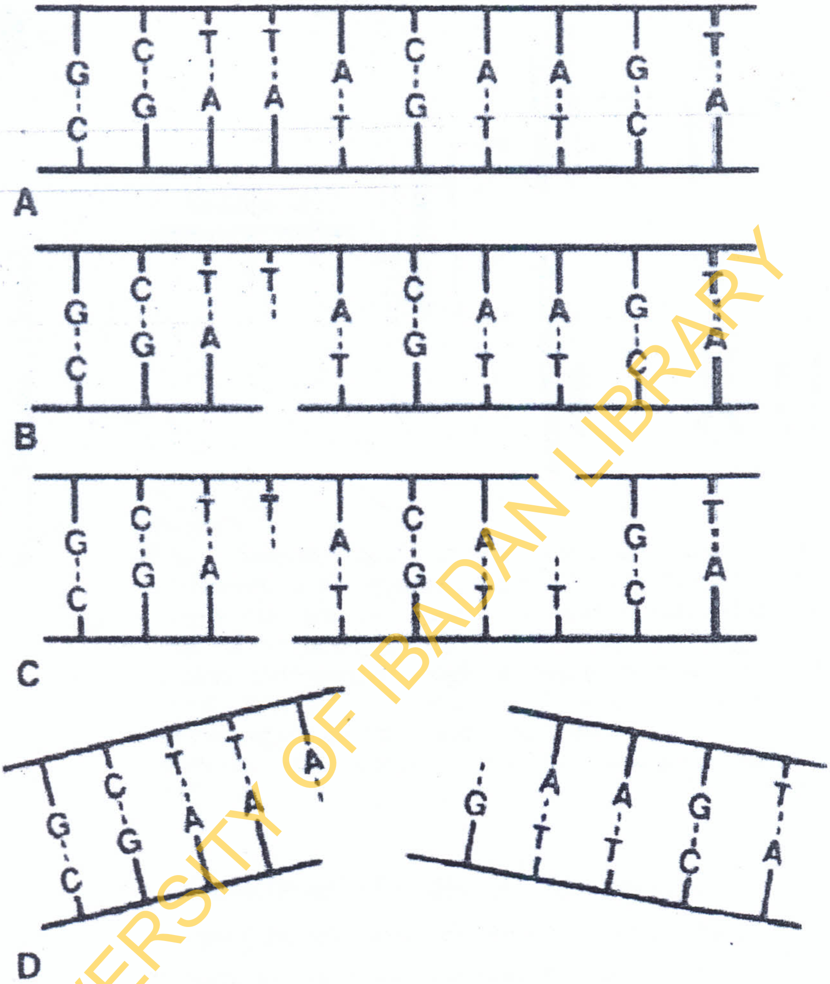


Figure 4
Diagrams of single-and double-strand DNA breaks caused by radiation A: Two-dimensional representation of the normal DNA helix. The base pairs carrying the genetic code are complementary, (i.e., Adenine pairs with thymine, quanine pairs with cytosine). B: A break in one strand is of little significance because it is repaired readily, using the opposite strand as a template. C: Breaks in both strands; if well separated, are repaired as independent breaks. D: If breaks occur in both strands and are directly opposite or separated by only a few base pairs, this may lead to a double-strand break in which the chromatin snaps into two pieces. (Courtesy Dr. John Ward).

With permission: Radiology for the Radiologist, Hall, Giaccia, p. 17.

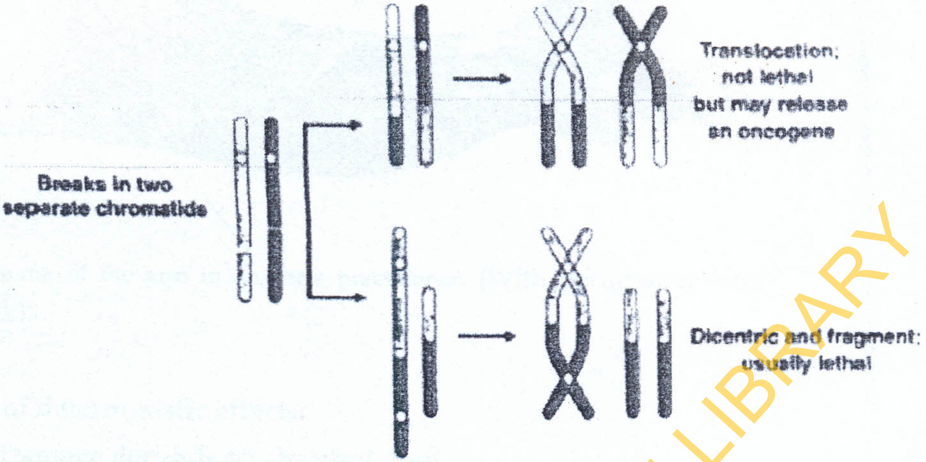


Figure 5
Most biological effects of radiation are caused by the incorrect joining of breaks in two chromosomes. For example, the two broken chromosomes might recombine to form a dicentric (a) chromosomes with two centremeres) and an accentric fragment (a fragment with no chromosome). This is a lethal lesion resulting in cell death. Alternately, the two broken chromosomes might exchange broken ends. This called an asymmetrical translocation. It does not result in cell death, but in a few special cases activates an oncogene by moving it from a quiescent to an active site
With permission from E. Hall Radiation Biology for Pediatric Radiologist in *Ped Rad*, 2009; 39 S1: 57.

Adverse Effects of Radiation – Carcinogenesis

Judging by the biological effects of radiation on the human body, radiation effects are generally divided into two categories: 'deterministic effects' and 'stochastic effects'.

Deterministic Effects

Based on a large number of experiments involving animals and other specimens and further supplemented by theoretical studies, it was discovered that the severity of certain effects on human beings will increase with increasing doses. There exists a certain level, the 'threshold' as depicted below, where the effect will be absent. This kind of effect is called 'deterministic effects'. Radiologists and other radiation workers are the most affected.

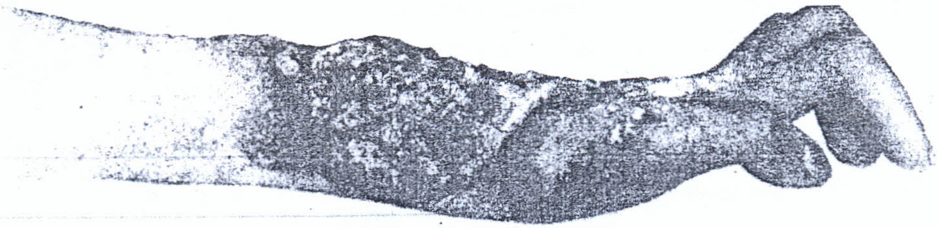


Figure 6. Carcinoma of the arm in an early practitioner. (With permission from Eisenberg's book).

Characteristics of deterministic effects:

- Damage depends on absorbed dose
- Threshold exists

Examples: cataract, erythema, infertility, hair loss etc.

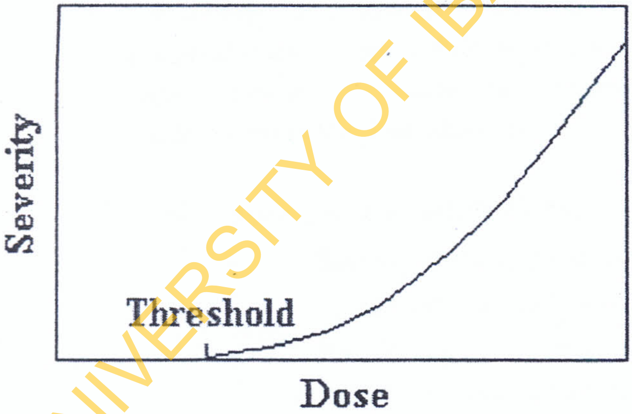


Figure 7. Deterministic effects and dose relationship.

The severity of deterministic effects depends on dosage. However, thresholds exist only above which the effects will occur. The International Commission on Radiological Protection (ICRP) considers that if the annual radiation doses to the lens of the eyes of radiation workers are restricted to 150 mSv (equivalent to 150 mGy for x-ray), cataract is unlikely to occur during their life, assuming a working period of 50 years. For other major organs, the annual dose limits for preventing deterministic effects are as follows:

Figure 8. Threshold for deterministic effects (Sv)

	Effects	One single absorption (Sv)	Prolonged absorption (Sv-year)
Testis	permanent infertility	3.5 - 6.0	2
Ovary	permanent infertility	2.5 - 6.0	> 0.2
Lens of eyes	milky part of lens cataract	0.5 - 2.0 5.0	>0.1 > 0.15
Bone marrow	Blood forming deficiency	0.5	> 0.4

Source: 1990 Recommendations of the International Commission on Radiological Protection (ICRP Publication No. 60).

Stochastic Effects

The severity of stochastic effects on the other hand is independent of the absorbed dose. Under certain exposure conditions, the effects may or may not occur. There is no threshold and the probability of experiencing the effects is proportional to the dose absorbed.

Characteristics of stochastic effects

- Severity is independent of absorbed dose
- Threshold does not exist
- Probability of occurrence depends on absorbed dose. Example: radiation induced cancer, genetic effects.

The most important deleterious effect on the DNA at low doses (5-20 mSv) is carcinogenesis. A stochastic effect is an all-or-nothing effect; the severity of the effect does not depend on the dose, though the probability of it occurring increases with dose. Stochastic means random, that means it may or may not cause damage. By contrast, high doses of radiation (>2,000 mSv) can cause a deterministic effect, such as a cataract, where the severity increases with dose. For example, if a child receives >2,000 mSv acutely to the eyes, the child will develop cataracts. We are mainly concerned however, about the stochastic effects.

A good example of a stochastic effect is noted in (figure 9) showing that it is random even when a cell gets hit by radiation and the effects of DNA damage might not be seen for many generations. This explains the 20 to 40 year lag in the expression of radiation-induced cancer.

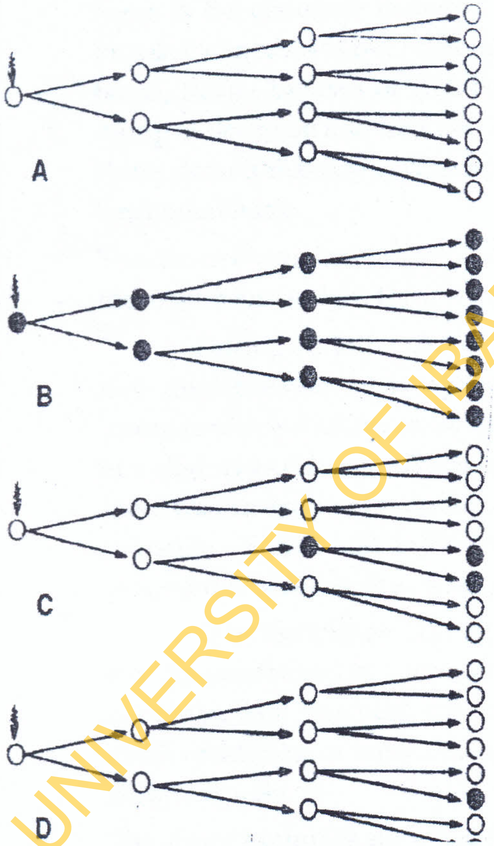


Figure 9. Evidence of carcinogenesis secondary to irradiation.

The best evidence for radiation-induced cancers involves the famous study of atomic bomb survivors by Pierce and Preston. The study has lasted more than over $500 million. In contrast, how much is the Nigerian government ready to spend on this type of research when toxic wastes with radiation components are

60 years, involved more than 100,000 people, and has cost American taxpayers being dumped at various locations on our shores with impunity? In the April 22nd, 2010 edition of *Daily Independent Newspaper*, it was reported that "The National Environmental Standards and Regulations Enforcement Agency (NESREA) is insisting that the alarm raised over the controversial container (UESU463595-0) shipped into Nigeria by a foreign ship, MV Maersk Nashville, was for the interest of Nigerians irrespective of people's contrary opinion. The items in the container included toxic substances, the volume of which, some people claimed, was not commensurate with the alarm raised on it. Closer to home, *Daily Champion* of 26th February, 2010 reported the case of toxic waste dump at Ile-Igbon and Lalupon local government areas of Oyo State. The local chiefs denied that it was responsible for the hospitalizations and deaths of the local inhabitants.

The above examples show the level of ignorance that is prevalent and how far those who know right from wrong will go to protect their selfish interests.

During the latter part of the study by Pierce and Preston, it was noticed that solid tumours were appearing at a greater rate than expected. These tumours affected adults as well as children and appeared in a great number and at a slightly earlier age. The most startling facts arising from this study is that there was an excess of number of cancers in patients exposed to lower doses of radiation - from 5 mSv to 200 mSv (500 mrad to 20 rad) (figure 10). Simply put, cancers can occur even at what we consider a very low dose.

It is clear (figure 11) that the doses we are now using in CT overlap these low doses acquired in young individuals at the time of the atomic bomb blast. All of the data provided are related to *mortality* figures; that is, study of the death certificates of individuals exposed to radiation. The *incidence* of cancer is at least double.

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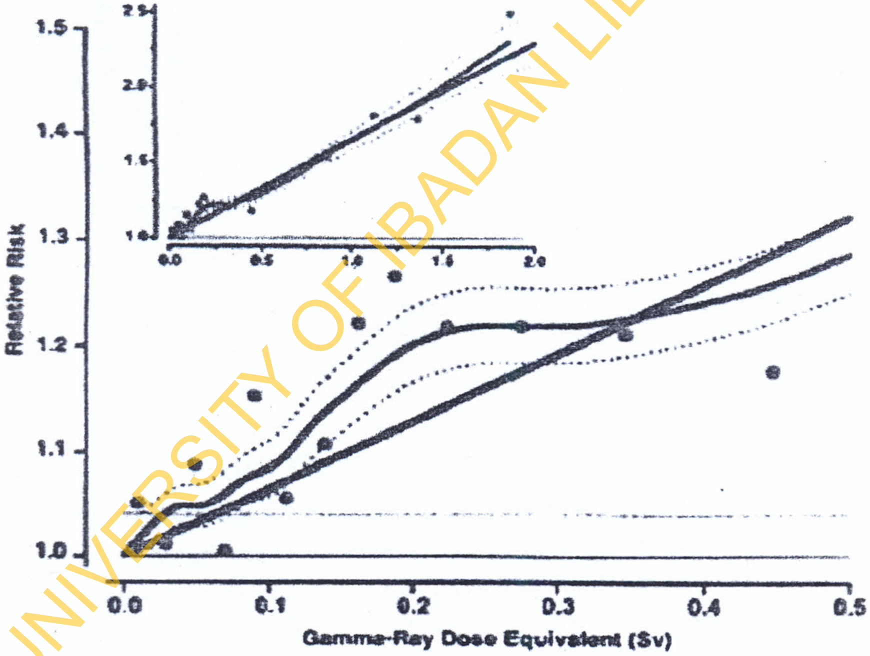


Figure 10. Estimated relative risk for cancer rates in bomb survivors during the 1958-1994 follow up period relative to unexposed individuals. The dashed curve represents ± 1 standard error for the smoothed curve. The inset shows data over the whole dose range 0 to 2Sv (0-200rem), to which a straight line is fitted, i.e. relative risk is proportional to dose with no threshold. The main figure is an expanded version of the low-dose region up to 0.5Sv (500rem). The straight line is taken from the insert data for the whole dose range. There is a suggestion that the low dose risk is above the line.
With Permission: Pierce DA, Preston DL, 2000 *Paediatric Research* 154: 178- 186.

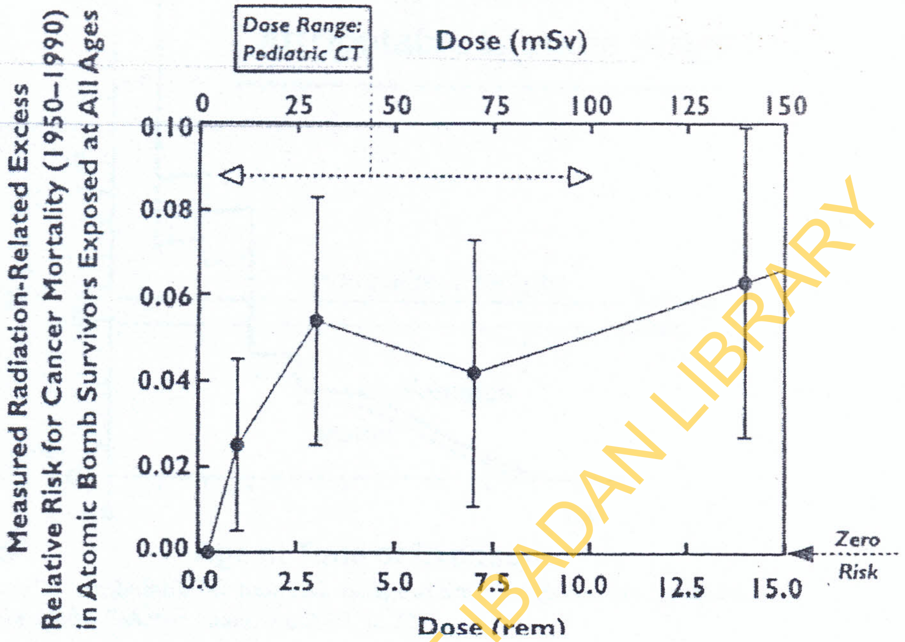


Figure 11. Dose range in paediatric CT in relation to relative risk for cancer mortality in atomic bomb survivals (1950-1990).

Evidence Based Biologic Effects of Radiation in Children

When indicated, radiation can be used to diagnose illness; however children are more sensitive to radiation than adults. Too much of it gives deterministic effects and any amount can have stochastic effects. It has been proven (figure 12) that those who acquired cancer were those exposed at younger ages and that the newborn is 10-15 times more sensitive to radiation than adults. It also became obvious that females developed more cancers than males, principally because of the risk of breast cancer.

The effect of radiation in children can be lifelong and cumulative, particularly when given in adult dose, hence no dose of radiation can be considered safe.

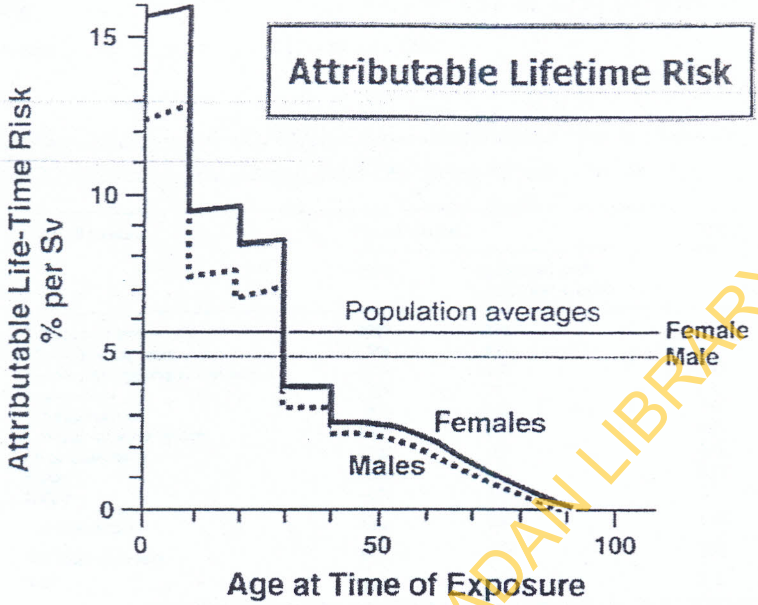


Figure12: Attributable life time risk vs. age at time of exposure to radiation.
Source: Hall's Pediatric Radiology, 2002, p. 226.

Dr. Alice Stewarts, an epidemiologist, did a lot of work on the effect of x-ray on pregnant women and on diseases in children. In this study, which was published in British Medical Journal in 1958, the pre-natal and post-natal experiences of a large group of children who recently died of malignant diseases was compared, point by point, with the experiences of a similar group of living children. This study cumulated in what is known today as the Oxford Survey of Childhood Cancer (OSCC).

The study showed that:

1. The frequency of three pre-natal events namely: direct foetal irradiation, virus infections and threatened abortion was significantly higher among the dead children than among the living children.
2. The frequency of three post-natal events namely: x-ray exposures in infancy and severe injuries, was significantly higher for children who subsequently died of leukaemia than for the other children.

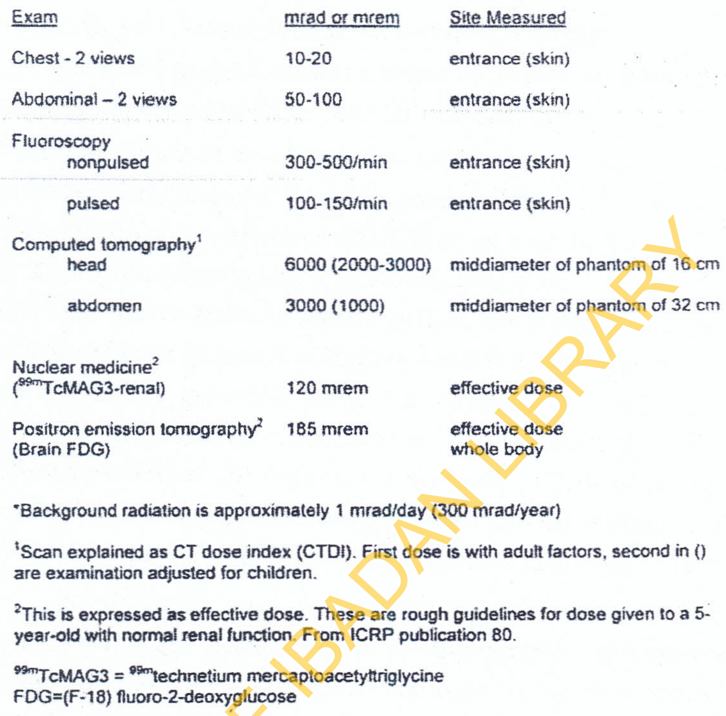
These materials have been studied with long-term follow-ups and have now shown that the risk of all cancers is 1.47 or 47% (approximately 50%) above baseline in infants irradiated *in utero*.

Table 1. Relative risk of different types of childhood cancer following irradiation *in utero* OSCC data for deaths during 1953-1967 (after Bithell and Stewart).

Type of cancer	No. of deaths		Relative risk	95% confidence interval
	Total	Associated with irradiation *in utero*		
Lymphatic leukaemia	2007	290	1.54	(1.34, 1.78)
Myeloid leukaemia	866	120	1.47	(1.20, 1.81)
Other and undefined leukaemia	1179	159	1.43	(1.19, 1.71)
Lymphoma	719	92	1.35	(1.07, 1.69)
Wilm's tumour	590	87	1.59	(1.25, 2.01)
Central nervous system	1332	179	1.42	(1.20, 1.69)
Neuroblastoma	720	99	1.46	(1.17, 1.83)
Bone	244	26	1.11	(0.74, 1.66)
Other	856	129	1.63	(1.33, 1.98)
All leukaemias	4052	569	1.49	(1.33, 1.67)
All solid tumours	4461	612	1.45	(1.30, 1.62)
All cancers	8513	1181	1.47	(1.34, 1.62)

We are all exposed to about 1mrad of background radiation per day. Radiation exposure from one view of chest x-ray is about 3-15 mrad, while from one view of x- ray of the abdomen it is 50 mrads. In contrast, when a CT of the head is carried out on a child, that child is exposed to 2000 mrads, while that from a CT of the abdomen is about 1000 mrads.

It can therefore be deduced that the risk of developing cancer from a single CT of the brain is about 1000-2000 times more than that of background radiation and 66-130 times more than that from a chest x-ray!



Exam	mrad or mrem	Site Measured
Chest - 2 views	10-20	entrance (skin)
Abdominal – 2 views	50-100	entrance (skin)
Fluoroscopy		
nonpulsed	300-500/min	entrance (skin)
pulsed	100-150/min	entrance (skin)
Computed tomography[1]		
head	6000 (2000-3000)	middiameter of phantom of 16 cm
abdomen	3000 (1000)	middiameter of phantom of 32 cm
Nuclear medicine[2] (^{99m}TcMAG3-renal)	120 mrem	effective dose
Positron emission tomography[2] (Brain FDG)	185 mrem	effective dose whole body

*Background radiation is approximately 1 mrad/day (300 mrad/year)

[1] Scan explained as CT dose index (CTDI). First dose is with adult factors, second in () are examination adjusted for children.

[2] This is expressed as effective dose. These are rough guidelines for dose given to a 5-year-old with normal renal function. From ICRP publication 80.

^{99m}TcMAG3 = ^{99m}technetium mercaptoacetyltriglycine
FDG=(F-18) fluoro-2-deoxyglucose

Figure 13. Radiation dose by imaging test.

Many scientists have raised a lot of questions on the relative risk of radiation exposure from CT and especially on the abuse of this imaging modality. Brenner et al, in their study concluded that –

> the time available risk estimates suggest that paediatric CT will result in a significantly increased life time risk over adult CT because of the increased dose per milliampere /sec, and the increased life time risk per unit dose. Although the risk-benefit balance is still strongly tilted toward benefit, because the frequency of paediatric CT is rapidly increasing, quantitative lifetime radiation risk for children undergoing CT is not negligible, we have to stimulate more active reduction of CT exposure setting in paediatric patients.

How Do We Respond?

In the northern hemisphere, news about the hazards of radiation regularly makes the front page. Clinicians must be ready to rise up to the challenge because we cannot afford to wait for our clients to sound the alarm before we realize that it cannot be business as usual. A release by General Electric (GE) dated March 29, 2010 and titled 'Important Product Information' was circulated in the radiology department of UCH sometime in May this year. The subject was 'Computed tomography protocols and dose'. According to the release, it was found that over an 18 month period, 260 patients at a particular facility in the United States received radiation doses that were approximately eight times higher than the expected level; this resulted in hair loss and erythema. In another facility still in the USA and around the same time, 10 patients received 3-4 times more than the expected dose during CT head perfusion scans. In this release, GE instructed that every GE user should review all their CT protocol and monitor dose-related information before and after CT scans.

Radiologists and radiographers/imaging scientists have at their disposal through manipulation of the various parameters of all digital radiographic examinations (plain radiograph, fluoroscopy, CT), the ability to lower the dose involved in any test and still have diagnostic images. Therefore, the technologists and radiologists who perform the tests should use the least radiation resulting in diagnostic pictures, employing the concept of 'As Low as Reasonably Achievable' (ALARA) dose. It is the responsibility of the ordering physician to order appropriately and to be familiar with the biological effects of radiation on children and make an informed decision as to whether:

1. A test is indicated/ necessary, i.e., if there is a clear medical benefit.
2. The test is the correct one, as compared to a test without ionizing radiation.
3. To seek advice by discussing imaging options with the radiologist.
4. A CT test is the right thing to do, considering the child's size, the kVp and the mA. And whether to use the lowest amount of radiation (one scan (single phase) is often enough, avoid multiple scans).
5. To image only the indicated area.
6. To use alternative diagnostic studies such as ultrasound and MRI when possible.

7. Where necessary, to inform the parents of the risks of radiation producing tests. Parents should be encouraged to keep a radiation record for their children. This is a simple record which can be in form of the current 'Blue card'

Name:—————— Date of Birth ——————

Name of Clinician ______________________

Date	Examination	Where exam was performed

Image Gently Campaign

The image gently campaign website was announced in January 2008, by the Alliance for Radiation Safety in Paediatric Imaging, with four founding member societies: Society for Paediatric Radiology (SPR), American Association of Physicists in Medicine (AAPM), American College of Radiology (ACR), and American Society of Radiologic Technologists (ASRT), all of them concerned with paediatric imaging. The image gently campaign is promoting optimal scanning strategies for children based on the seven points listed above. This campaign has rapidly expanded with many other international organizations joining in. However as has been observed, there is no Africa or Nigeria based imaging organization within this campaign group. As expected, the bulk has been passed on to us, that we have to be proactive since belonging to this group is open and free; after all, the heavens help those who help themselves. It is the responsibility of organizations and individuals to join these groups and look for information concerning the practice of radiology; after all they say the world is now a global village. Interested parties can start by taking the pledge to image gently on the website **www.imagegently.com** today.

Africa and Nigeria-based imaging organizations should let the world 'hear their cry' from their wilderness of exclusion and let the echoes be carried to the whole world that they also want to 'Image Gently'.

Recommendations

The recommendation proffered by this study is directed towards the government, health institutions, clinicians and other health-care providers as well as individuals including parents. It is recommended that:

1. The law on child's right and protection should include adequate protection of children against excessive ionizing radiation.
2. The Nigerian Nuclear Radiation Authority (NNRA) should be more vigilant to ensure adequate radiation protection for children.
3. Training and retraining of radiation personnel on the importance of quality control and radiation safety should be ensured.
4. A well trained Medical physicist should be employed to monitor the use of ionizing radiation; it is the responsibility of the medical physicist to develop protocols with reduction in radiation dosage without compromising quality and to regularly calibrate the equipment thus ensuring that these machines deliver the appropriate radiation doses.
5. Imaging scientists should be scientists indeed. They should in collaboration with the medical physicist, research and develop protocols that will minimize radiation without compromising image quality.
6. The hospital should empower the departmental radiation safety committee to meet regularly and also provide the committee with appropriate and modern equipment for radiation monitoring.
7. There should be constant auditing of the imaging practice especially those involving equipment that use ionizing radiation, by the established departmental radiation safety committee, so as to enforce quality assurance (QA).
8. There should be provision of shields like lead jackets, goggles, groin pads, lead gloves and so on, to shield body parts from unwanted radiation.
9. Radiologists should exercise their inherent power of refusal when asked to perform procedures that can cause cumulative radiation injury to a child, including 'ordinary chest x-rays'.
10. Concerted efforts should be made by Nigeria and Africa based imaging organizations to join the international campaign groups so that they are

not left behind current happenings in the international arena on reduction of radiation to children.

11. Equipment manufacturers/ vendors/ suppliers should be compelled to adequately train radiographers, medical physicists and radiologists on the efficient use of equipment and to especially emphasize that these equipment's inbuilt facilities can be used to drastically reduce radiation without compromising image quality.
12. In the same vein, the manufacturers and their agents should be made to be part of the QA processes of their equipment by ensuring adequate calibration and function.
13. The manufacturers and their agents should sponsor researches geared towards quality assurance control.
14. Clinicians should not hesitate to consult their radiologist colleagues on the best imaging methods for investigating a disease entity in a child; after all they are also consultants.
15. Parents should be involved at all levels of care of their children. The radiation dose record form can be duplicated, with that of the department incorporated onto the back of the current x-ray jacket, while the parents or guardians keep a duplicate as their child/ ward's radiation record. This will help ensure that the radiation doses to these children during the course of their investigation are scientifically monitored.

In summary, everybody shares a joint responsibility for the potential biological effects of radiation on children.

Children are 10-15 times more sensitive to radiation than adults. Though the exact excess risk of cancer is not known, it is estimated that a child that undergoes a CT abdominal scan stands a 1/1,000 to 1/5,000 excess risk of developing cancer at a later date.

We must make sure that it is appropriate to order an imaging test, that we choose the correct test and that we perform the test in line with the ALARA principle.

Ultrasound is particularly useful for children because of the inherent advantages both in the equipment and to the children themselves. Ultrasound uses sound waves rather that ionizing radiation, and no adverse effect has been documented as at present. It is widely available, cheap (it is at least 30 times cheaper that CT), does not need contras medium and can be repeated as many times as possible.

Children have less fat, so ultrasound images are sharper and clearer, making for better diagnostic accuracy. The brain can be imaged in neonates and toddlers using the fontanelles. These children do not need sedation and older children, when not too ill, found it to be fun—hence sonologists can count on their cooperation.

In the realm of interventional radiology, USS recorded the first USS guided interventional procedure in this hospital, hitherto, children with intussusception had to be operated upon but now the current routine is to hydrostatically reduce the intussuception under USS guidance unless when the there are signs of intestinal perforation. Thus many of these children (thanks to USS) do not have to be subjected to surgery with all its attendant complications, and in addition, reduction by USS is more than ten times less expensive.

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