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Hazards of diagnostic radiation

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Introduction

X-rays were discovered by Professor Wilhelm Konrad Röntgen at the University of Würzburg, Bavaria in 1895. During his experiments on electrical conductivity through evacuated tubes, he noted the fluorescence of some crystals nearby and also observed that various substances placed between his tube and the crystals would cast a shadow. Since these rays would penetrate objects that were opaque to ordinary light, their possible use in medicine was quickly recognized and it was not long until these rays, named x-rays for sake of brevity and because of unknown constitution, were put to their first medical use of locating a bullet in the calf of a patient's leg. The technique of using x-rays developed so rapidly that it was in comparatively general use as early as 1896.

It occurred to several scientists that ordinary substances which were made phosphorescent by exposure to x-rays might also emit similiar radiation. It was Becquerel, a French physicist, who demonstrated that rays from uranium were also penetrating like x-rays. M. and Mme. Curie isolated radium in 1898 which was three to five times as radioactive, weight for weight, as uranium. Rutherford, a British physicist, studied the emissions from uranium and noted that there were two types of radiation: (a) a type of radiation which could be stopped by a sheet of paper and went only a few centimeters through the air. He called these rays alpha (α) rays, and (b) a more penetrating type of radiation which would pass through several millimeters of aluminum which he called beta (β) rays. Villard later discovered rays which would penetrate twenty centimeters of iron or several centimeters of lead before being absorbed and called these gamma (γ) rays. The achievement of nuclear fission in the twentieth century added a new source of radiation. The atomic pile (nuclear reactor) produces energy by a controlled reaction; the atomic bomb produces energy in the same manner but this form of energy release is uncontrolled. The by-products of nuclear fission are radioactive and this is the source of isotopes which have such wide use in medicine and industry.

When the first atom bomb exploded over Hiroshima, there was mass exposure to radiation such as never had occurred before. The sensational nature of this "new" form of energy brought it to the attention of everyone. Now the hazard of radiation faced the world at large and was no longer confined to the physicist's laboratory, industrial uses, or medical applications. Public anxiety was aroused by this new danger and in a desperate search for understanding, the people turned to the newspapers for their education. The public learned the consequences of massive radiation from the sensational news stories which followed the atomic blasts in a manner that could not be easily forgotten or ignored. The impact of the blast and heat and pressure waves soon became of secondary news importance but the radiation effects continued to make headlines for many weeks. Radiation sickness appeared in many victims of high exposure within an hour. The radio-sensitive organs and tissues such as the blood and blood forming tissues suffered the most marked changes depending on the degree of exposure. Leukopenia developed rapidly and caused many deaths in the first week or two after exposure. Many deaths were caused by hemorrhage due to thrombocytopenia, reaching a peak during the third to sixth week. Next followed anemia and radiation cachexia. (1) Later, studies showed that there was about a twelve fold increase in the incidence of leukemia in those near the bomb hypocenter compared to those at the periphery. (2)

The fear of mass exposure disappeared with the end of hostilities. The public being aware of the consequences of mass exposure but not used to weighing and evaluating uncertainties of this nature had the fear of radiation exposure fanned into flame by an article which appeared in Time magazine (3) stating, "Last week, at the First International Congress of Radiation Research in Burlington, Vermont, Brookhaven National Laboratory's Dr. Howard J. Curtis reported evidence that a single modern fluoroscopic examination of a pregnant woman's pelvis will shorten her life by two weeks." It is unfortunate that an article which appeared in Science (4) at the same time was not so widely read. It is quoted in part: "The shortening of life span on small rodents exposed to large doses has suggested the possibility that certain degenerative processes may be aggravated by continued exposure to low radiation levels. Such a shortening has also been inferred from an analysis of published death rates of United States radiologists compared to those of certain other groups of medical men. However, studies in the United Kingdom have failed to demonstrate such an effect. . .Hence, it is impossible at the present time to estimate with any assurance the effect upon biometrical characters of any given level of irradiation of human populations. Much further research throughout this field is therefore needed. . .Any present attempt to evaluate the effects of sources of radiation to which the world is exposed can produce only tentative estimates with wide margins of uncertainty."

The radiation consciousness of the undiscriminating lay person was thus stimulated to the extent that a new syndrome, radiophobia, has been described! (5) The fear generated by the publicity given radiation hazards could have an adverse effect on mass screening x-ray studies of the chest which has been so important in early detection of lung lesions such as tuberculosis or neoplastic processes. It would be most unfortunate if the unreasonable fear of exposure were to become more important in the minds of the lay public than the need for early detection of lung lesions. Boeck (5) polled two New York Counties and found that 8% of the persons expressed fear of radiation exposure.

Whether this syndrome has actually caused anyone to decline needed diagnostic roentgenology is hard to determine but the public awareness of the hazards of x-radiation may have a bright side, too. Dr. Zach (6) suggests that it may have helped curb excess use and make competent users more aware of the fact that exposure often can be reduced without sacrificing the diagnostic value. Public radiation consciousness, likewise, may be the means of eliminating dangerous nonessential uses of x-ray such as shoe store fluoroscopy and its use by quacks and cultists. A well informed physician can do much to convert public hysteria into realistic public thoughtfulness.

Definitions

In order to discuss the hazards in terms of dosage, a few basic definitions are reviewed as follows:

Roentgen--This is a measure of radiation exposure and means the quantity of radiation (such as x-rays) which will produce 2.083 billion ionizations in 1 cc. of air at standard temperature and pressure conditions (STP) through which it passes. 2.083 billion ionizations equals 1 electrostatic unit of charge of either sign. This term applies only to x-rays or gamma rays with energy levels below 3 Mev.

RAD--(radiation absorbed dose) This is a measure of the amount of energy absorbed by a material; one rad equals 100 ergs per gram. X-rays will produce about 1 rad per roentgen of exposure in soft tissue.

REM--(rad equivalent man) This is the product of rad and biological effectiveness of the radiation used. This term is used in integrating exposures involving various kinds of radiation. For x-rays 1 rem is equal to 1 rad.

Alpha (α) ray--This is particulate radiation consisting of a charged helium nucleus that is projected at velocities of about 10,000 miles per second and has a range of about 3 cm. to 11 cm. in air at STP. This is the form of energy emitted by most radioactive bodies.

Beta (β) ray--These rays are streams of electrons ejected with varying velocities some of which approach 186,300 miles per second.

Gamma (γ) ray--These are high frequency electromagnetic rays that are not deflected by magnetic fields such as alpha and beta rays are.

Half Value Layer (h.v.l.)--This is the thickness of a material which will absorb 50% of a beam striking it, thus allowing 50% of the beam to be transmitted.

Tolerance dose--The dose which can be tolerated over a prolonged period of time without ultimately causing injury.

Maximum permissible dose--The dose of radiation that in light of present knowledge is not expected to cause any bodily injury or effect regarded as objectional or deleterious to health and well being of an individual during his lifetime. This term does not imply absolute safety like the earlier term tolerance dose. It is only an attempt to find a workable balance between the possible benefits and risks it may involve. Note that the permissible dose of radiation is always the same regardless of previous exposure, that is, the smallest amount of radiation consistent with clinical need.

Threshold dose--The minimal dose which must be exceeded before some biological change can be discerned.

Biological Hazards

The first indication of the possible injurious effects of these new rays was noticed in 1896 when a peculiar dermatitis appeared among the operators which was found to be due to the action of the rays. This stimulated further study into the biological effects of these rays. It was early noted that these rays seemed to have inconsistent effects on biological tissues. Some cells seemed to be stimulated while others were caused to degenerate or die. Many of the injurious effects of the use of x-rays could not be foreseen, but the need for protection of the operators became obvious. The monument which stands in front of the Roentgen Institute in Hamburg, Germany is inscribed with the names of 197 martyrs to radiation who were unwittingly over exposed before the hazards were fully recognized. With the appreciation of the hazards and better understanding of how to minimize the danger of exposure, the situation today has dramatically changed. In spite of the tremendous increase in radiation uses, The United States Atomic Energy Commission has reported only 77 cases of accidental overexposure with only 2 deaths from 1955 to 1957. (7)

The early recorded radiation injuries include the following: erythematous dermatitis, epilation of hair, inhibition of bone growth, alteration of bone marrow and sterilization.

The effects of acute whole body exposure to radiation have been fairly well established. According to the manual published by the American College of Radiology (8) when large amounts of radiation are delivered throughout the whole body as during an atomic blast, the following effects may be expected:

0	25	rads--no observable effect
25	50	rads--possible blood cell changes, no serious injury apparent
50	100	rads--blood cell changes, some injury, no disability
100	200	rads--injury, possible disability or death
Over	450	rads--probable death

It is seen here that anything over 100 rads of whole body radiation is likely to cause notable damage, however, if the area of exposure is restricted, as many as 50,000 rads may be received without any general harmful effect. The doses delivered by diagnostic procedures are usually partial body doses.

The effects of chronic radiation delivered to limited areas of the body are not easily determined. The International Commission on Radiological Protection (ICRP) has been charged with the establishment of the maximum permissible doses and must base their estimates on past experience of radiation workers. The extreme biological variability of humans and the long latent period must also be considered. The established maximum dose is, therefore, an arbitrary estimate. The recommendations are not to be interpreted as limiting use of higher dosage for good clinical reasons, and they do not imply in any sense that the person using ionizing radiation either for treatment or diagnosis has no responsibility to keep the dose as low as possible. Arbitrary limits are no substitute for informed personnel and careful application.

The biological hazards will be discussed in this paper under two headings: (1) The Reproductive Tissues, and (2) The Somatic Tissues.

The Reproductive Tissues

The data concerning genetic hazards in the human population is extremely limited. Some experimental genetic evidence indicates that no dose is too small to produce mutations and that the damaging effects of ionizing radiation in the genes, unlike somatic tissue where some recovery takes place, are totally additive and there is no recovery from damage in the reproductive cells. The incidence of gene mutations is related directly to the total dose and is independent of the intensity of exposure. This cumulative effect may extend through several generations producing a final effect as great as if the exposure had been given in one generation. But we should not become preoccupied with the dangers; it is imperative that we know that ionizing radiation is not novel in its effects but is only one of a number of dysgenic forces in operation. Until more conclusive information is available, however, we will be wise to follow a conservative approach. Consistent with this, it is interesting to note that the ICRP, which is charged with the responsibility of establishing the maximum permissible dose levels, has consistently revised its recommendations in a downward direction.

The record of their recommendations over the years is as follows:

Maximum Permissible Doses (9)

	Rem/year
Prior 1934	100
1934--1950 (at 0.2 rem/day)	60
1950--1956 (at 0.3 rem/week)	15
April 1956	5

The National Committee on Radiation Protection and Measurements (10) states, "It has been decided by the NCRP, on the basis of present evidence, that the most important new limitation should be one relative to gonadal exposure to individuals during the reproductive period." No injuries have ever been detected in individuals receiving the earlier higher permissible doses.

A comprehensive review of genetics is beyond the scope of this paper. The genetic hazard concerns only the reproductive segment of the population. Before a mutation can become manifest there must be a fortituous combination of two similar genes from both parents who carry the genes. For this reason genetic mutations may not become manifest until several generations later.

Not all mutations are undesirable. If mutations had not occurred, we can speculate that evolution would not have culminated in the development of man.

Life might have remained stationary in a virus stage. But desirable mutations are rare, hence, the general effect of an increased mutation rate would most likely be undesirable. The evaluation of mutagenic damage in humans has only been started and we undoubtedly will have to wait many years to know the final answer. Strong selection pressures are necessary to improve a biological type by mutation. These factors are not readily apparent in human populations. On the basis of genetic theory most mutations are expected to be recessive, therefore, it is unlikely that we would observe noticeable effects in the first generation.

Kaplan (11) has made a study of the genetic effects in children born to women who were treated for sterility by radiation. He estimates the range of exposure of the pelvis to be in the range of 50 to 90 roentgens in his series. His study is summarized briefly as follows: 351 of the women that were radiated gave birth to 566 children. There were 8 still births; 3 due to hydrocephalus, 4 to cord strangulation and one due to maldevelopment due to a large uterine fibroid. There were 12 deaths of children, 2 from congenital abnormalities and 3 following premature births. The other deaths could have no possible relation to the genetic influence--accidents, infections, etc.

Three children are alive with abnormalities. There are 543 normal, healthy children; 260 boys and 283 girls.

The meaning of normal was not defined but since only gross abnormalities were described in the study, it is possible that some of the more subtle effects such as slight to moderately impaired mental development, decreased fertility, etc., may have been present but unnoticed. Since most mutations are recessive, statistically significant evidence for damage or lack of it would not likely be seen for several generations. The presence of "normal" children may give a false sense of security to the clinician who lacks an understanding of radiation genetics. No other area of radiation biology has as much experimental evidence as the field of genetics, but much of this evidence is from studies on rodents and insects.

The abnormalities in the living children which may suggest genetic abnormality consist of one case of mental retardation, one child with 6 digits on one hand, and one child with but one finger on one hand and one toe on one foot.

For easy reference the statistical summary of the study is as follows:

	Normal %	This series %
Sex ratio of infants	50--50	50.2--49.8
Miscarriage Rate	10.	17.7
Fetal Death Rate	16.6	20.6
Stillbirths	4.	1.4
Known Abnormalities	4.2--7	1.

Kaplan points out that the high miscarriage rate and fetal death rate may be partially accounted for by the fact that these women were referred for sterility problems and have some ovarian dysfunction and undeveloped uteri and are prone to miscarriage. Only 64 had had regular menstrual periods. He also reports that there are 46 normal grandchildren of the originally irradiated women with only one death due to maternal eclamptic toxemia.

This limited statistical study probably proves nothing. Women can be exposed to radiation and still have "normal healthy" children, since most of the damage is recessive and only gross abnormalities, if any, would not likely be seen in the first generation. The genetic heritage of future generations may be observed only after the genetic pool contains enough widely scattered mutant genes that combinations may occur to give expression to some defect. By then, caution is too late. Obviously there are no genetic hazards after the reproductive age is passed.

Webster (12) gives an interesting point of view in comparison of the effects of wearing a radium-dial watch. He estimates that it would take 100 chest or skull examinations if the testes are protected from direct exposure to equal the genetic hazard of wearing an average radium-dial wrist watch for one year! He also makes an interesting comparison of the mutagenic effect of increased gonodal temperature due to wearing trousers and gonadal irradiation. On the assumption that man responds the same as the fruit fly, then it is estimated that the temperature dependent spontaneous mutation rate due to the increase in gonadal temperature is equivalent to an exposure of about 40 r. This amount of gonadal exposure at an estimated gonadal dose of 0.00016 r per 14 x 17 chest film would require some 250,000 examinations. In an upper gastrointestinal series the gonadal exposure is about 0.008 r, hence, the theoretical mutagenic effect equal to that of wearing trousers would not be reached until 5,000 such examinations were done! Webster does not make these comparisons to discount the possible ill effects of radiation but rather to show that there are other activities our society accepts with equanimity which may be as deserving of searching investigation as we are now giving diagnostic radiology.

The Somatic Tissues

Somatic tissues in contrast to reproductive tissues show different characteristics of response to ionizing radiation. Somatic tissue is sensitive to the rate of exposure as well as to the total dose. As was stated earlier, an acute exposure of about 450 r (total body) will probably result in death, yet by giving whole body radiation to mice over an extended length of time Lorenz (13) has shown that mugh higher dosages can be tolerated. The effects of summation are not complete since there is varying degrees of recovery. The tissues also show a wide variability of response, mature bone being very resistant while morphologic change can be seen within an hour in heavily irradiated lymph nodes. In the dosages encountered in routine diagnostic roentgenology permanent injury to somatic tissue is exceedingly rare if it exists at all.

Life Expectancy

From time to time there have been reports of decreased life expectancy (3) (14). A search of the literature fails to show any valid evidence of decreased life span. Failla (14) estimates that the effect of each roentgen of whole body dose would shorten the life span by 1 to 15 days. This estimate is based in part on extrapolation of data from the study of animals. It has been established with reasonable certainty that acute, heavy, whole body radiation will shorten the life span of mice. But there is no evidence that the levels of exposure such as are delivered by diagnostic procedures has any effect on the life span. Lorenz (13) studied the effect of chronic whole body irradiation using mice, guinea pigs and rabbits and demonstrated a marked species difference. In mice the decrease in expected life span among those given higher accumulated dose levels was partly due to increased tumor incidence. There was no terminal anemia or leukopenia in the mice used in his experiments. Radiation death in the guinea pigs was due to pancytopenia which is a function of dose rate rather than total dose. Rabbits tend to develop uterine tumors at dose levels above 1.1 r but in the 3 rabbits exposed to 0.11 r no tumors were observed. The hematopoietic system of rabbits is not very radiosensitive. This species difference of response to irradiation adds weight to the argument that it is doubtful if such data derived from the study of animals can be applied to humans. Nevertheless, it is not unusual to read estimates of decreased life expectancy based on such information. These "guesstimates" serve best to cause concern among the uninitiated and uncritical readers such as was seen following the report of Dr. Curtis as reported in Time and previously referred to (3).

As an example, to show the fallacy of applying the data without consideration of all pertinent factors; let us use the data presented by Lorenz (13) which is often quoted as a basis for estimates of decreased life expectancy. Using 59 mice as controls, he found the mean survival time to be 703 days. 45 mice were exposed to chronic radiation, gamma radiation from radium totalling 1.1 r and given over a period of 8 hours per day. (A fluoroscopic examination of the chest gives about the same exposure to a limited area of the body.) For the group exposed to this amount of radiation he found the mean survival time to be 761 days! This is an increase of life expectancy of 58 days over the control group and expressed as a percent is slightly over 8%. Now if we apply this to humans with a normal life expectancy of about 65 years, an 8% increase would add 6 years to boost the life expectancy to 71 years. This is quite a contrast to an expected loss of from 1 to 15 days of life. The fallacies of such reasoning in support of increased life expectancy are many and obvious; the pessimistic view of decrease of life span is quite as invalid. The data available on man is so inadequate that a quantitative estimate is at best only an ill advised and foolish guess. Kallmann (15) was unable to demonstrate significant shortening of life by exposure limited to the chest of female mice even though the exposures were as high as 700 r.

Embryo

Exposure of the developing embryo to ionizing irradiation is a well recognized hazard. The decision to use x-ray pelvimetry is one which calls for competent professional judgment because it involves exposure to reproductive tissue of both mother and fetus. The evidence of the effects of fetal irradiation in humans is incomplete and there are many contradictory reports in the literature, however, the implications of the experimental studies in animals are probably more valid in regard to the influence of low levels here than as extrapolated and applied to life span. Experimental studies have consistently produced radiation injuries in every class of vertebrates and in a large number of invertebrates; it is hard to believe that man would prove to be the only exception.

Using animals exposed at various time intervals after conception and comparing to the human gestational cycle, it appears that the most critical time in humans is from the second to the sixth week post conception--the organogenic period. Irradiation at later stages may also induce abnormalities but they are not likely to be so extreme. Russell (16) refers to an interesting case in which the embryo was known to have been exposed to irradiation in the fourth or fifth week of gestation and was born with an abnormality of the arm. Similar abnormalities according to the Russells can be induced by exposure of mice at the corresponding stage of development. This is strong presumptive evidence supporting the validity of animal studies which are applied to humans in this area.

The Russells also state that definite effects can be demonstrated in mice with as little as 25 r which falls well within the range used in diagnostic fluoroscopy. Case reports of human abnormalities include: mongolism, microcephaly, hydrocephaly, mental deficiency, general physical subnormality and others.

The obvious practical use of the critical concept period is the avoidance of irradiation in early pregnancy. If there is clinical indication for pelvimetry with diagnosis of pregnancy in doubt, it should be timed during the first two weeks following the menstrual period. The critical time to avoid fetal irradiation is from the second to sixth weeks and it is at this time that pregnancy is most difficult to diagnose. In case a known pregnancy exists, exposures, if indicated, should be delayed as long as possible since it appears that abnormalities are not so severe or frequent with increasing fetal age.

<u>Malignancy</u>

Ionizing radiation has been implicated in the production of human malignancies such as bone tumors, thyroid carcinoma, and leukemia. There is no known evidence that bone tumors have ever followed diagnostic procedures, most reported damage following excessive therapeutic use and will not be discussed in this paper.

From time to time there have appeared articles which suggest a relationship between thyroid carcinoma and radiation therapy to the head, neck or chest. Rooney (17) states that approximately one third of all children who have the diagnosis of thyroid cancer have had previous radiation therapy and lists 121 reported cases. He discounts the possibility that the increasing incidence of recent years is due to better diagnosis and sees a positive correlation between the increasing incidence of thyroid carcinoma and previous radiation. It should be pointed out that retrospective studies are often heavily biased and are apt to be statistically inconclusive.

Snergireff (18) has conducted a carefully controlled prospective study of 148 persons who received radiation therapy for enlarged thymus, 23 patients with untreated thymic enlargement and 162 patients as control without detectable enlarged thymus. 75 of the treated 148 have been followed over a period of 20 years and no malignancy has developed. Exposure varied from 100 r to 1800 r with 87.83% receiving 400 r. He states, "The previously reported high incidence of primary cancer of the thyroid and of leukemia following irradiation for thymic enlargement is not borne out in our samples."

The most extensive data with respect to radiation induced malignancies has to do with leukemia. Lewis (19) states that there has been a steady increase in the incidence of leukemia from 18 cases per million persons in 1942 to 26 cases per million people in 1954 in the 25-34 age group. This may be due to better diagnosis. It may likewise be related to the increased exposure of the population to ionizing radiation.

Stewart (20) conducted a study in children exposed to maternal irradiation and found that cancer, except leukemia, increased approximately the same as the increase in leukemia. In adults a significant increase has not been observed in cancer cases where it has been observed in leukemia. The normal cancer incidence in adults is about forty times that of leukemia, hence, a significant increase in leukemia is easier to detect. It may also be that since the bone marrow and blood are very sensitive to x-radiation that the latent period is less and leukemia would be seen earlier than other forms of cancer even though the incidence of both may finally be shown to be the same.

Studies on the survivors of Hiroshima and Nagasaki by Brown and Doll as reported by Lewis (19) show that the probability of leukemia per individual per rad per year is nearly constant over a wide range of doses. He also states that the incidence of leukemia in radiologists (chronic rate estimated at 0.1 rad per day or less) is of the same magnitude of Japanese survivors. This suggests that there may be no threshold dose. He estimates the probability of an individual developing leukemia to be in the range of 0.7×10^{-6} to 6×10^{-6} per rad per year.

Even though we do have considerable quantitative data on leukemogenic effects of total massive body irradiation, we still lack quantitative information on the effect of small doses delivered to small parts of the body. Any statement to the effect that small doses delivered to a small part of the body will or will not increase the risk of leukemia must rest on highly presumptive evidence almost totally lacking in proof.

Natural background radiation gives a total of about 0.1 rem per year while medical and dental sources account for about 1.5 to 3.0 rems per year. Nothing can be done to substantially decrease the background dosage but in light of the evidence, medical and dental sources probably can be reduced. The employment of diagnostic radiation should be used only in the presence of sound clinical reasons by those qualified to keep exposure to a minimum with an appreciation of the potential hazards in the absence of gross damage.

Practical Implications of Diagnostic Exposure

Roentgenology

Everyone is exposed to ionizing radiation. The medical and dental exposure estimates of radiation dosage include radiation therapy as well as diagnostic procedures. No data is available on the proportion of the estimates accumulating from diagnostic procedures.

The principal sources of radiation are as follows: (8)

	Dose per year in rems
Cosmic rays	0.03
Earth, housing	0.05
Atmosphere	0.002
Internal	0.025
Total Natural Background	0.107
Medical and Dental	0.15 to 0.30
Occupational	0.005
Plant environs	0.005
Fall-out	0.007 to 0.015
Total exposure	0.274 to 0.015

In medical roentgenology the problem of exposure becomes important only when the gonads are in direct beam or receive large doses of scatter radiation. X-ray examinations of skull and extremities in an adult involves such trivial gonadal doses that discussion is unwarranted. Where the testes are not in the direct beam, the dosage is so small that it is impossible to make an ionization chamber small enough and at the same time sensitive enough to measure the dose accurately.

Dosage depends on many factors such as

kilovoltage, filtration, type of grid, field area, target-skin distance and film speed. The gonads of an infant are closer to the primary beam than those of a tall adult. The problem of exposure in infants and children is particularly important.

The best estimate of gonadal dosage according to Hodges (21) who reports on measurements done on adults at the University of Chicago in the Department of Radiology during 1957 is as follows:

	Kv.	Al.Fil. mm.	Ovary mr.	Testes mr.
Chest film (14 X 17)	90	2.0	0.5	0.05
	72	0.5	1.2	0.12
Microfilm (Refractor lens)	80	2.0	4.7	0.47

Even if we were to take the greatest exposure from this measurement and have one film per year at this rate, the dose would be about 1/200 r compared to about 1/10 r for natural background exposure. In other words, natural background radiation would give us 20 times more exposure.

Stanford and Vance (22) have compiled an estimate of exposure to reproductive organs during routine x-ray examinations. Their estimate of gonadal dose is calculated on the basis of skin doses measured on exposed patients and then calculated by using a conversion factor obtained from the study of cadavers to determine the ratio of skin dose to gonadal dose under different types of examinations. Their findings are as follows:

Examination	Exposure Kv.	mA.	Dose per film in mr. Male	Female
Skull	65	100	0.2	0.05
Teeth:				
Whole mouth	65	10	0.34	0.06
Chest				
14 X 17	68	300	0.36	0.06
Shoulder, A.P.	58	100	0.22	0.03
Spines:				
Cervical, A.P.	58	100	0.27	0.06
Dorsal, A.P.	62	100	8.	11.
Lumbar	68	100	24.	227.
Pelvis, A.P.	65	200	1100.	210.
Abdomen, A.P.	72	200	69.	200.
I.V.P., renal	72	200	69.	200.
I.V.P., bladder	72	200	93.	230.
Gall-bladder, P.A.	70	200	0.6	5.2
Elbow, Wrist, Hand	58	100	0.13	0.026
Knee, Tibia, Fibia	67	100	3.	0.55
Foot and ankle	62	100	0.62	0.012
Barium meal	70	2	20.	9.
Barium enema	70	2	40.	20.

This data at best is only an estimate but it is believed that the error does not exceed plus or minus 50%.

Fluoroscopy

The fluoroscope finds its greatest usefulness as a supplement to radiography. Simple fluoroscopy is most useful for the direct observation of dynamic body processes such as descent of the diaphragm, cardiac pulsations, nature of inflation of the lungs, etc. For several reasons it is an inferior diagnostic tool when compared to an x-ray film. If it is used as the only diagnostic technique, exposure is inevitably prolonged resulting in increased radiation to the patient. Small lesions can be very easily missed by the fluoroscopic procedure. The radiographic film, besides providing much more information also provides a permanent record which can be studied with deliberation.

Insofar as diagnostic procedures are concerned, the fluoroscope delivers the greatest amount of radiation to the individual relative to the information gained. In radiography patient exposure is limited by the acceptable density of the film but no such technical limitation is present to prevent excessive exposure on the fluoroscope. The output of fluoroscopes is extremely variable between machines; the operators vary even more in the manner of use.

The only practical way to reduce the exposure due to the operator factor is by education. The examiner who is aware of the output of his machine, the limitations of this type examination and the physical limitation of his own visual apparatus will probably restrict examinations to where they are necessary rather than just desirable or convenient. Since fluoroscopic vision itself at best is much less acute than normal daylight vision, the operator must depend on dark-adaption to increase his acuity rather than the questionable expediency of increasing the intensity of the x-ray beam.

In a survey conducted by Gorson and others (23) on 81 fluoroscopes in Philadelphia and vicinity, when the operators were asked about the radiation output of their fluoroscopes, "a great majority did not know and declined to guess." They estimate that only 6 out of 81 machines inspected would meet minimal requirements as set up by the National Committee on Radiation Protection and the National Bureau of Standards, however, 50% of the machines were not considered unduly hazardous and 90% could be made acceptable by filtration and accessory shielding to reduce scatter radiation.

Because of the many variables, the estimates of total exposure per examination by various authors are extremely variable. Kirsh (24) claims an average of only 13.7 r for an entire gastrointestinal series on an average patient. This includes 6 spot films and 5 ordinary films. If we allow 0.55 r per film, this allows 5.55 r for the fluoroscopic part of the examination or a rate of 2.775 r per minute if we accept Kirsh's estimate of 2 minutes per average examination. In the survey by Gordon (23) reported in 1959 it was found that the average radiation exposure rates were about 8.9 r per minute with a h.v.l. of 2.9 mm. of aluminum among radiologists and 16.3 r per minute with a h.v.l. of 1.9 mm. of aluminum among non radiologists.

If adequate examination is weighed against the total exposure, the first figure is more ideal but seems rather low. Any exposure is excessive if the examination is inadequate. The latter figures seem more realistic.

Radioisotopes

During the past decade there has been a tremendous increase in the clinical use of radioisotopes both diagnostically and therapeutically. Increased production, reduced expense and rapid transportation have made this new diagnostic tool available to most physicians. The technical details are left to the specialist by the referring physician, but in order to receive the maximum benefit from their use, the referring physician must have some general idea of what they have to offer, their limitations, and their risks. It would not be unreasonable, it seems, to anticipate that the use of isotopes for diagnosis and treatment may be a part of the office procedures for many general physicians as well as specialists.

Before 1946 radioisotopes were available only as a research tool. Today it is estimated that at least 500,000 people receive diagnostic and therapeutic benefit yearly (25).

The responsibility of weighing the risk involved against clinical indications rests on the physician using isotopes. The effects of long-lived isotopes which may be deposited in the tissues of the body in small amounts are not known. Osteogenic sarcoma has been found repeatedly in animals after the administration of various radioactive substances such as radium or radioactive phosphorous (P^{32}). In rats polonium (Po^{210}) causes tumors of the kidney and adrenal glands, yttrium (Y^{91}) leads to adenocarcinoma of the colon. P^{32} has been found to cause leukemia in mice; radiogold (Au^{198}) has caused liver adenomas. (26) These facts should keep the potential dangers fresh in our minds.

Many substances such as radium, plutonium, strontium, uranium, cercium, yttrium, polonium are selectively deposited in bones. The hazards of radioactive poisoning from internal radiation was first recognized in the luminous dial industry where results such as radiation necrosis, progressive anemia, leukopenia, osteogenic sarcoma, and pathologic fractures resulted from the exceedingly small total body content of ingested radium ranging from 2 to 180 micrograms.

Some of the diagnostic applications of isotopes are concerned with: anemia, tumor localization, blood volume determination, circulation measurements, and the most common use, thyroid disease.

The dosage used in diagnosis of thyrotoxicosis is relatively low, ranging from 25 to 50 microcuries of I^{131}. This is estimated to give a gonadal dose of 0.1 rad or less. There is no evidence that diagnostic dosages in these amounts have ever caused any harm to any patient.

Dental X-rays

More x-ray units are owned and operated by dentists than any other profession. It is estimated that about 50% of the 128,000 roentgen ray machines in the United States are owned by dentists. (27)

The NCRPM makes no recommendations on exposure for medical purposes but they have established 100 mr. per week as the maximum permissible average weekly dose to the total body for occupational exposure. (28) If we use this criteria, then most dentists are operating under acceptable standards of exposure. Garber (29) investigated 94 film badge readings in Missouri and found an average of 63 mr. per week with 6 over

300 mr. per week. Gorson (30) surveyed 140 film badges in Philadelphia in 1956 and found an average exposure of 45 mr. per week. Of the 140 surveyed, 11 were over 100 mr. per week and 2 exceeded 300 mr. per week.

The exposure to the patient should be kept to a minimum by considering the indications for each examination. "The number of exposures to children should be restricted to an absolute minimum from both somatic and genetic considerations." (31) The common practice of routine x-raying of deciduous teeth in children is to be deplored. Indiscriminate exposure of children must especially be avoided.

In Gorson's study (30) the exposure to the patient for one periapical adult molar roentgenogram ranged from 15.8 r maximum to 0.4 r minimum as measured in air at the cone tip; the mean was 4.6 r.

Patient exposure can be kept to a minimum by exposing only where there is sound clinical need, use of fast films, increased filtration and focal-skin distance. Since the patient dose decreases with increasing h.v.l. Gorson suggests that with the tube potentials used that the h.v.l. in aluminum of the primary beam should be at least 1.8 mm. and preferably above 2.0 mm.

What about Image Intensification?

Summary and Conclusions

There has been a steady growth in the use of x-rays since their discovery by Professor Rontgen in 1895. The possibilities of medical application of x-rays were recognized earlier than the possible dangers, which range from no observable effect to death. With recognition of the hazards appropriate safety measures have been found and applied so that with competent application for diagnostic purposes, gross danger does not exist.

We are guided in our safety consciousness by theoretical potential dangers rather than any proven hazard. Since radiation is in such widespread use today, a high percentage of the population will receive some exposure. Exposure to genes is cumulative even over several generations and no recovery from exposure occurs; the genetic hazard is recognized as the limiting factor on which the recommendations for maximum permissible doses are arbitrarily established. This hazard concerns only those in the reproductive age or under.

The data concerning genetic hazards in humans is extremely limited and most information has been extrapolated from animal and insect studies. In light of the suggestive evidence from these experiments, if we are to protect the genetic heritage of future generations, then now is the time for caution for by the time that combinations of mutant genes occurs and some defect is manifest, caution will be too late.

In somatic tissue some recovery takes place after exposure. There is wide variability of response between tissues as well as marked species differences. The supposed life shortening effect of radiation is at best an ill considered and foolish guess. The evidence for malignancy developing after exposure at diagnostic levels is only suggestive, being insufficient and inconclusive at this time.

There is general agreement that exposure within the diagnostic range can cause damage to the developing embryo. Experimental evidence has consistently produced injuries in fetal irradiation in every class of vertebrates as well as invertebrates. Russell reported a case of human abnormality following irradiation at a fetal age of about two weeks. The more subtle abnormalities such as reduced mental efficiency and general physical subnormality are difficult to evaluate. The practical implication here is simply to avoid pelvic irradiation during pregnancy or to delay it as long as possible, if indicated, since abnormalities seem to decrease in severity with increasing fetal age.

The evidence for malignancy developing after exposure at diagnostic levels is insufficient and inconclusive.

Everyone is exposed to ionizing irradiation. Background irradiation accounts for 20 times more exposure than one 14 x 17 chest film on a yearly basis.

Fluoroscopy is a supplement to radiography. It is an inferior diagnostic tool, a film supplies more information, provides a permanent record, and may be studied with deliberation. Exposure in fluoroscopy is not self limited and it delivers the largest amount of exposure to the patient relative to the information gained of any of the diagnostic techniques.

Radioisotopes are finding increasing uses in diagnostic procedures. There is no evidence that dosages at the diagnostic levels have ever caused any harm to any patient.

Most dentists are operating under acceptable standards of exposure. Since indiscriminate exposure of children must be especially avoided, routine x-raying of deciduous teeth would seem to present an unnecessary exposure.

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