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Review Article

Ionizing Radiation in Medicine

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Abstract

Longer wave length, lower frequency waves (heat and radio) has less energy than shorter wave length, higher frequency waves (X and gamma rays). Not all electromagnetic (EM) radiation is ionizing. Only the high frequency portion of the electromagnetic spectrum which includes X rays and gamma rays is ionizing. Ionizing (or ionising) radiation is radiation that carries enough energy to liberate electrons from atoms or molecules, thereby ionizing them. Ionizing radiation comprises subatomic particles, ions or atoms moving at relativistic speeds, and electromagnetic waves on the short wavelength end of the electromagnetic spectrum. Gamma rays, X-rays, and the upper vacuum ultraviolet part of the ultraviolet spectrum are ionizing, whereas the lower ultraviolet, visible light (including laser light), infrared, microwaves, and radio waves are considered non-ionizing radiation. The boundary is not sharply defined, since different molecules and atoms ionize at different energies. Typical particles include alpha particles, beta particles and neutrons, as well as mesons that constitute cosmic rays. It is applied in a wide variety of fields such as medicine, research, manufacturing, construction, and many other areas, but presents a health hazard if proper measures against undesired exposure aren't followed. Exposure to ionizing radiation causes damage to living tissue, and can result in mutation, radiation sickness, cancer, and death.

INTRODUCTION

Most people have had one or more medical tests that use ionizing radiation. Doctors use these tests to help diagnose disease and injury. Examples include: X-rays (including dental x-rays, chest x-rays, spine x-rays), CT or CAT (computed tomography) scans ,PET (positron emission tomography) scans , Fluoroscopy and Magnetic resonance imaging (MRI) and ultrasound are two other commonly used diagnostic tests. MRI and ultrasound do not involve exposure to ionizing radiation. When gamma radiation breaks DNA molecules, a cell may be able to repair the damaged genetic material, within limits. However, a study of Rothkamm and Lobrich has shown that this repair process works well after high-dose exposure but is much slower than in the case of a low-dose exposure [1-3].

Types of radiation used to treat cancer

Radiation used for cancer treatment is called ionizing radiation because it forms ions (electrically charged particles) in the cells of the tissues it passes through. It creates ions by removing electrons from atoms and molecules. This can kill cells or change genes so the cells stop growing.

Other forms of radiation such as radio waves, microwaves, and light waves are called non-ionizing. They don't have as much energy and are not able to form ions.

Ionizing radiation can be sorted into 2 major types:

- Photons (x-rays and gamma rays), which are most widely used in cancer treatment
- Particle radiation (such as electrons, protons, neutrons, carbon ions, alpha particles, and beta particles)

Some types of ionizing radiation have more energy than others. The higher the energy, the more deeply the radiation can penetrate (get into) the tissues. The way a certain type of radiation behaves is important in planning radiation treatments. The radiation oncologist (a doctor specially trained to treat cancer patients with radiation) selects the type and energy of radiation that is most suitable for each patient's cancer and location (Figure 1).

Photon radiation

By far the most common form of radiation used for cancer treatment is a high-energy photon beam. This comes from radioactive sources such as cobalt, cesium, or a machine called a linear accelerator (or linac, for short). Photon beams of energy affect the cells along their path as they go through the body to get to the cancer, pass through the cancer, and exit the body.

Particle radiation

Electron beams or particle beams are also produced by a linear accelerator. Electrons are negatively charged parts of atoms. They have a low energy level and don't penetrate deeply

Figure 1 www. redlandshospital. org) (Linear Accelerator attached with 80 lead Multileaf Collimator for 3D Conformal Radiation therapy at a cancer institute.

into the body, so this type of radiation is used most often to treat the skin, tumors, and lymph nodes that are close to the surface of the body.

Proton beams are a form of particle beam radiation. Protons are positively charged parts of atoms. They cause less damage to tissues they pass through but are very good at killing cells at the end of their path. Because of this, proton beams are thought to be able to deliver more radiation to the cancer while causing fewer side effects to normal tissues. Protons are used routinely for certain types of cancer, but still need more study in treating others.

Some of the techniques used in proton treatment can also expose the patient to neutrons (see below). Proton beam radiation therapy requires highly specialized equipment and is not widely available.

Neutron beams are used for some cancers of the head, neck, and prostate and for certain inoperable tumors. A neutron is a particle in many atoms that has no charge. Neutron beam radiation can sometimes help when other forms of radiation therapy don't work. Few facilities in the United States offer it, and use has declined partly because of problems getting the beams on target. Because neutrons can damage DNA more than photons, effects on normal tissue can be more severe. Beams must be aimed carefully and normal tissue protected. Still, neutron beams show great promise with salivary gland cancers that can't be cured with surgery.

Carbon ion radiation is also called heavy ion radiation because it uses a particle that is heavier than a proton or neutron. The particle is part of the carbon atom, which itself contains protons, neutrons, and electrons. Because it's so heavy, it can do more damage to the target cell than other types of radiation. As with protons, the beam of carbon ions can be adjusted to do the most damage to the cancer cells at the end of its path. But the effects on nearby normal tissue can be more severe. This type of radiation is only available in a few centers in the world. It can be helpful in treating cancers that don't usually respond well to radiation (called radio resistant).

Alpha and beta particles are mainly produced by special radioactive substances that may be injected, swallowed, or put into the body of a person with cancer. They're most often used in imaging tests, but can be helpful in treating cancer. You can read more about these in the section called "Radiopharmaceuticals". [4]

Medical X-ray Imaging

Medical imaging has led to improvements in the diagnosis and treatment of numerous medical conditions in children and adults. There are many types - or modalities - of medical imaging procedures, each of which uses different technologies and techniques. Computed tomography (CT), fluoroscopy, and radiography ("conventional X-ray" including mammography) all use ionizing radiation to generate images of the body. Ionizing radiation is a form of radiation that has enough energy to potentially cause damage to DNA and may elevate a person's lifetime risk of developing cancer.

CT, radiography, and fluoroscopy all work on the same basic principle: an X-ray beam is passed through the body where a portion of the X-rays are either absorbed or scattered by the internal structures, and the remaining X-ray pattern is transmitted to a detector (e. g. , film or a computer screen) for recording or further processing by a computer. These exams differ in their purpose:

Radiography - a single image is recorded for later evaluation. Mammography is a special type of radiography to image the internal structures of breasts.

Fluoroscopy - a continuous X-ray image is displayed on a monitor, allowing for real-time monitoring of a procedure or passage of a contrast agent ("dye") through the body. Fluoroscopy can result in relatively high radiation doses, especially for complex interventional procedures (such as placing stents or other devices inside the body) which require fluoroscopy be administered for a long period of time.

CT - many X-ray images are recorded as the detector moves around the patient's body. A computer reconstructs all the individual images into cross-sectional images or "slices" of internal organs and tissues. A CT exam involves a higher radiation dose than conventional radiography because the CT image is reconstructed from many individual X-ray projections [5,6] (Figure 2).

Radiation as therapy

Doctors known as radiation oncologists oversee radiation therapy, which usually consists of a specific number of treatments given over a set period of time. The goal of this treatment is to destroy cancer cells without harming nearby healthy tissue. Radiation therapy may be used as the main treatment or as an adjuvant therapy (treatment given after the main treatment to target any potential remaining cancer cells). Radiation therapy can also be used to shrink tumors and reduce pressure, pain, and other symptoms of cancer (called palliative radiation therapy) when it is not possible to completely eliminate the disease.

More than half of all people with cancer receive some type of radiation therapy. For some cancers, radiation therapy alone is an effective treatment; however, other types of cancer respond

Figure 2 (www. biomedicalequipment. in) (X-ray Machine).

best to combination treatment approaches that may include radiation plus surgery, chemotherapy, or immunotherapy.

Types of radiation therapy

External-beam radiation therapy: This is the most common type of radiation treatment, and it involves giving radiation from a machine located outside the body. It can treat large areas of the body, if necessary. The machine typically used to create the radiation beam is called a linear accelerator or linac. Computers with special software are used to adjust the size and shape of the beam and to direct it to target the tumor while avoiding the healthy tissue that surrounds the cancer cells. External-beam radiation therapy does not make you radioactive.

Types of external-beam radiation therapy include: Three-dimensional conformal radiation therapy (3D-CRT): As part of this treatment, special computers create detailed three-dimensional pictures of the cancer. This allows the treatment team to aim the radiation more precisely, which means they can use higher doses of radiation while reducing the risk of damaging healthy tissue. Studies have shown that 3D-CRT can lower the risk of complications and side effects, such as damage to the salivary glands (which can cause dry mouth), when people with head and neck cancer are treated with radiation therapy.

Intensity modulated radiation therapy (IMRT): This treatment better directs the radiation dose at the tumor than 3D-CRT by precisely modulating (varying) the intensity of the beam under strict computer guidance. (The positioning of the beam occurs during a specialized planning process.) Because of the modulation of the beam intensity and the special planning computers, IMRT protects healthy tissues from radiation better than 3D-CRT.

Proton beam therapy: This treatment uses protons, rather than x-rays, to treat some cancers. Protons are parts of atoms that at high energy can destroy cancer cells. Researchers have found that directing protons at a tumor decreases the amount of radiation delivered to surrounding healthy tissue, reducing the damage to that tissue. Because this therapy is relatively new and requires highly specialized equipment, it is not available at every medical center. The potential benefits of proton therapy compared to IMRT have not been established for some cancers, such as prostate cancer. Learn more about proton therapy.

Stereotactic radiation therapy: This treatment delivers a large, precise radiation dose to a small tumor area. Because of the precision involved in this type of treatment, the patient must remain extremely still. Head frames or individual body molds may be used to limit movement. Although stereotactic radiation therapy is often performed as a single treatment, some patients may need several radiation treatments, sometimes as many as five.

Internal radiation therapy: This type of radiation treatment, also known as brachytherapy, involves placing radioactive material into the cancer itself or into the tissue surrounding it. These radioactive implants may be permanent or temporary and may require a hospital stay. Permanent implants are tiny steel seeds (capsules) about the size of a grain of rice that contain radioactive material and are placed inside the body at the tumor site. The seeds deliver most of the radiation around the area of the implant; however, some radiation can be emitted (released) from the patient's body. This means the patient needs to take special precautions to protect others from radiation exposure while the seeds are still active. Over time, the implant loses its radioactivity, but the inactive seeds remain in the body.

For temporary implants, the radiation is delivered through needles, catheters (tubes that carry fluid in or out of the body), or specialized applicators and kept in the body for a specific amount of time, from a few minutes to a few days. Most temporary implant procedures deliver radiation for just a few minutes. If temporary implants are used for more time, the patient remains in a private room while the implants are in place to limit others' exposure to the radiation.

External beam radiotherapy

External beam radiotherapy is one of the kind of radiation therapy used for destroying cancer cells. In this therapy the external beam is directed towards the affected part of the patient's body. This beam comprising of high energy particles destroys the cancer cells. The energy of X-rays and Gamma rays produced by these beams are expressed in terms of KV or MV, in this case the voltage is the maximum electric potential used by the LINAC to produce the photon beam. External beam radiotherapy is also called as teletherapy.

Ionizing radiation for cancer treatment

When you are given radiation therapy—also called irradiation, radiotherapy or x-ray therapy—physicians attempt to protect the good cells by shielding them. They also limit dosage and spread out the treatments. About half of all cancer patients receive some type of radiation therapy, which uses ionizing radiation to kill cancer cells and shrink tumors. This therapy can be delivered from machines outside your body or from radioactive material inserted into your body. External radiation is the most common type used in this therapy. Internal radiation uses sealed implants in or near the tumor. Systemic radiation therapy employs unsealed radioactive materials that circulate throughout the body. In some cases more than one type of radiation is prescribed. External radiation uses a machine that directs high-energy rays into the tumor. Most external radiation is given over many weeks during outpatient visits.

Internal radiation (also called brachytherapy) uses radioactive metal pellets, seeds, ribbons, wires, needles, capsules or tubes that are implanted. In some cases, patients may have to be admitted to a hospital for this procedure. Implants may be left in the patient temporarily or permanently. Radioactive drugs are used in systemic radiation. These drugs can be given by mouth or injection. Systemic radiation often requires a brief hospital stay. Radiation therapy may be used to treat almost every type of solid tumor and cancers of the blood (leukemia) and lymphatic system (lymphoma). The type of radiation used depends upon many circumstances, such as the type of cancer and its location. Radiation therapy also can be used to reduce pain from cancer. This is called palliative radiation therapy. External radiation therapy will not make you radioactive. If you undergo internal radiation therapy, your body may give off a small amount of radiation briefly. If the radiation is in a temporary implant, you will be asked to stay in the hospital and may have to limit visitors during treatment. Permanent implants give off small doses of radiation over weeks. The radiation usually is confined to the treatment area; the risk of exposure to others is small. Sometimes doctors recommend that you protect the people around you if you have systemic radiation. With this type of therapy, radioactive materials can get into your body fluids. In most cases, safety precautions must be followed only the first few days after treatment. Over time the radiation becomes weaker and your body gets rid of it [7].

FAQs about Radiation Therapy for Prostate Cancer

Radiation may be delivered to the prostate by an external source of ionizing radiation (external beam radiotherapy) or by inserting radioactive seeds directly into the prostate gland (brachytherapy). There are advantages and disadvantages to both internal radiation therapy (brachytherapy) and external beam radiation therapy. The recommendation by Smilow Center radiation oncologists will depend both on the patient's concerns about the duration and side effects of treatment, as well as the stage and aggressiveness of the cancer. Some studies have shown that brachytherapy is superior at preserving erectile function, although these studies have not been conclusive. In addition, brachytherapy may not be appropriate for men with severe lower urinary tract symptoms such as frequency and urgency, since the symptoms may be aggravated, and acute urinary retention may develop. In external beam radiation therapy, X-rays are generated by a machine and focused on the prostate. Treatment usually takes place daily for several weeks, for a total of 40–45 treatment sessions. Over the past 5 to 10 years, the computer software controlling the beam delivery has advanced, allowing more precise focusing of the radiation beam and less damage to surrounding structures. The better precision of the beam results in fewer radiation-induced side effects. The primary external radiation therapy technique used at NYU is a daily intensity-modulated radiation therapy with image guidance via cone-beam CT scan (IMRT/IGRT).

In intensity-modulated radiation therapy (IMRT), radiation is delivered from many different angles by a machine rotating around the patient. The intensity of the radiation is altered depending on its path, helping to minimize damage to surrounding healthy tissues.

In image-guided radiation therapy (IGRT), each daily radiation treatment session is preceded by a CT scan to determine the exact location of the prostate and adjacent structures. A CT scan is a series of X-ray 'slices' of the body that, when reconstructed by a computer, produces a three-dimensional view of the internal organs. The IGRT takes into account that the prostate configuration nay be altered by the radiation treatment. MRI is also being studied at NYU Langone as a method of imaging prior to and after radiation delivery to assess response to treatment. The technique of seed implantation (brachytherapy) for localized prostate cancer involves implanting radioactive pellets in the prostate. These pellets slowly release a high dose of radiation directly into the prostate. Because the type of radiation used in brachytherapy does not travel far, it destroys the cancer but minimizes damage to the surrounding healthy tissues. Smilow radiation oncologists and urologic oncologists working in collaboration regularly perform permanent seed implants. This procedure can be completed in one day. Medical research has demonstrated the effectiveness of this treatment for low-risk disease over the course of 10–12 years.

Brachytherapy may be used as a single mode of treatment in patients with low-risk prostate cancer (Gleason score <6, PSA <10, and only a small nodule of prostate cancer on digital rectal exam) or in combination with external beam radiation therapy for patients with intermediate-risk disease (Gleason score of 7, or PSA of 10–20).

Brachytherapy may not be appropriate for men with a large prostate (more than 50–60 grams) or for men who have significant lower urinary tract symptoms such as urinary urgency or frequency. In addition, brachytherapy should not be used alone for cancers with adverse clinical or pathologic features.

The CyberKnife is a frameless robotic radiosurgery system. It produces radiation using a small linear particle accelerator and has a robotic arm that allows the energy to be directed at any part of the body from any direction. By increasing the accuracy of the delivery of radiation, there is a potential for dose escalation, resulting in an increase in effectiveness.

The CyberKnife system has been approved by the US Food and Drug Administration to treat any solid tumor, including tumors of the prostate. Studies of the CyberKnife have not shown any general survival benefit over conventional treatment methods. Studies to date have been limited in scope, and more extensive research will be needed to show any effects on survival.

Proton beam therapy is a type of external beam radiotherapy that works by aiming energetic ionizing particles (in this case, protons accelerated with a particle accelerator) onto the target tumor. Because protons are relatively large, they do not spread or "scatter" significantly in tissue. Therefore, the beam stays focused on the tumor, with less radiation delivered to surrounding structures. It is possible to focus the proton beam at the precise depth in the tissue where the tumor is situated. Proton therapy has been used for numerous tumors throughout the body, including the prostate. Some studies in prostate cancer show a reduction in long-term rectal and genitiourinary side effects when compared with conventional X-ray therapy. However, other studies show that the difference is small and limited to a small subset of cases where the prostate is particularly close to certain anatomical structures [8].

There is an abundance of clinical information demonstrating that preoperative (neoadjuvant) and postoperative (adjuvant) hormonal therapy improves survival outcomes for men with high-risk, clinically localized prostate cancer. For this reason, hormonal therapy is almost always offered in conjunction with radiotherapy for men with high-risk disease. The duration of hormonal therapy remains controversial. Because of the side efforts and unproven benefit, hormonal therapy is not offered in conjunction with radiotherapy for low-risk disease. The typical short-term side effects associated with radiation therapy include fatigue and urinary and rectal symptoms. Urinary symptoms may include frequency, urgency, urge incontinence, nocturia and diminished urinary stream. Rectal symptoms may include diarrhea, fecal incontinence, rectal bleeding and rectal urgency. In most cases, the urinary and rectal symptoms are transient. In addition, erectile dysfunction often develops months or years after radiation therapy.

Long-term complications are rare and include rectal or urinary fistulas, urinary strictures, hemorrhagic cystitis and proctitis (chronic bleeding from the rectum and bladder) and dysfunctional bladder or rectum due to scarring. There is increasing evidence than men undergoing pelvic radiation are at significantly greater risk of developing bladder and colon cancer. Medications prescribed for men with lower urinary tract symptoms due to other conditions like BPH and overactive bladder are often administered to men who develop these bothersome symptoms during and after radiation therapy. These medications include alpha-blockers or anticholinergic agents. These drugs are not offered as preventative measures but rather if symptoms become bothersome. The PSA level often takes up to two years after the completion of radiation therapy to reach a nadir level. Androgen deprivation therapy offered before and after radiation therapy will lower the PSA level. Therefore, the effect of radiation therapy cannot be determined while there are any ongoing, residual effects on PSA due to androgen deprivation therapy. Just as after radical prostatectomy, the PSA is the best measure of disease control after radiation therapy. The PSA typically is undetectable after radical prostatectomy, since the entire prostate is removed. Low levels of PSA are often detectable after radiation therapy because it is not feasible to totally eradicate the prostate with radiation without destroying adjacent structures. Therefore, a measureable PSA after radiation therapy does not necessarily indicate residual prostate cancer. Recurrence after radiation therapy is typically defined as a PSA level 2. 5 ng/dl above the nadir (lowest) PSA level measured after treatment. It should be noted that a biochemical recurrence after radical prostatectomy and biochemical recurrence after radiation have very different clinical connotations: a biochemical recurrence after radical prostatectomy simply implies the presence of some residual disease, whereas a biochemical recurrence after radiation therapy portends a poor prognosis [9] (Figure 3).

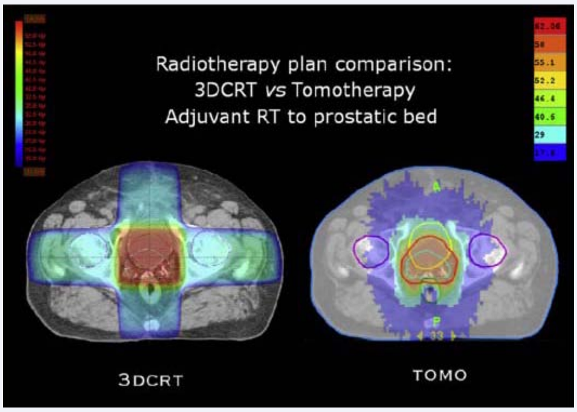

Figure 3 (www. europeanurology. com) (three-dimensional conformal radiation therapy (RT) and tomotherapy plan for radiation of the prostate bed.)

Ionizing radiation colon cancer

Strong evidence has been recorded of a possible connection between colon cancer and some evidence of rectal cancer has been found in studies of exposure to ionizing radiation. This evidence is based upon studies of nuclear workers and others exposed to ionizing radiation. These findings are consistent with the National Research Council's determination that tissues of the colon and rectum may be sensitive to ionizing radiation. Colon cancer, but not rectal cancer is designated as a "specified" cancer under the Energy Employees Occupational Illness Compensation Program Act. the colon and rectum form a long, muscular tube called the large intestine (also called the large bowel). Cancer that begins in the colon is called colon cancer, and cancer that begins in the rectum is called rectal cancer. Cancers affecting either of these organs may also be called colorectal cancer. (National Cancer Institute) In considering the cancer risk from exposure to ionizing radiation at work, it is important to understand other risk factors. The following is a list of other possible risk factors for these factors may add to any risk due to workplace exposure to ionizing radiation. Those who have had family members with colorectal cancer are at higher risk. Studies among other groups of people who were not nuclear workers can also be significant as evidence of possible increases in colorectal cancer among those who have been exposed to ionizing radiation. Most other research has been conducted of people exposed to atomic bombs. According to the National Research Council's BEIR V committee, "the risks of cancer of the colon and cancer of the rectum can be increased by intensive irradiation in humans. The National Research Council advises the U. S. government on scientific matters. Their Committee on Biological Effects of Exposure to Ionizing Radiations (BEIR) V reviewed sensitivity of parts of the body to radiation. Their findings are based mostly on studies of cancer among atomic bomb survivors, as well as on some of the available information on the biology of the body, animal studies, and other evidence. The greatest risk is at high exposure levels.

Risk factors for breast cancer is ionizing radiation

Everyone is exposed to ionizing radiation from natural and medical sources. In fact, ionizing radiation may be the most studied cancer causing agent in humans with scientific committees on radiation continuously reviewing and evaluating adverse health outcomes for over 70 years. The female breast is known to be highly susceptible to the cancer-causing effects of radiation when exposure occurs before menopause. This fact sheet will discuss what is known about radiation induced breast cancer and what factors influence or modify the effects of exposure. Most people are not exposed to the high levels of radiation that are known to cause breast cancer, and accordingly, radiation is not considered a major cause of breast cancer. Although unnecessary exposures should be avoided, diagnostic or therapeutic procedures should not be refused because of possible radiation risk. Radiation is the emission of energy in the form of waves or particles. Radiation that is so powerful that it can remove electrons from atoms is called ionizing. Examples of types of ionizing radiation are x-rays from medical machines and gamma rays from radioactive substances. We live in a sea of low-level radiation from natural sources. These natural sources include radioactive radon gas that we breathe, radioactive elements such as potassium-40 that is found in many foods (including salt), uranium and thorium which are found in soils and building materials, and cosmic rays that continually bombard us from outer space. However, there are other sources of manmade ionizing radiation. These sources include medical x-rays which are used to both diagnose disease and to treat cancer; occupational radiation which is experienced during employment in certain industries and professions; radioactive fallout from nuclear weapons testing or reactor accidents; and radioactive emissions from the normal operation of nuclear facilities such as those used to produce electrical power.

In terms of exposure to the entire population, natural sources contribute by far the largest radiation dose to people, with medical radiation contributing the next largest amount. For individual women the amount of radiation experienced throughout life is influenced by her access to medical care, illnesses requiring diagnosis or treatment, residence that is related to levels of background radiation, and occupation in a profession with possible radiation exposure. Studies of groups of people exposed to ionizing radiation have conclusively found that sufficiently large radiation doses can cause breast cancer. These groups include: 1) the female survivors of the atomic bombings in Japan during World War II; 2) women given radiation therapy to treat Hodgkin's disease and both malignant and benign breast disease; 3) girls treated as infants or children for several non-malignant conditions such as enlarged thymus glands; and 4) young adolescents and women who received large numbers of diagnostic x-ray examinations to monitor tuberculosis treatments or to monitor the curvature of the spine during treatment for severe scoliosis. In fact, more is probably known about the patterns of breast cancer following radiation exposure than of any other cancer, including leukemia. These studies have revealed a number of things about radiation-induced breast cancer. First, female breast tissue is highly susceptible to radiation effects. Second, it takes a minimum of about 5-10 years for a radiation-induced breast cancer to develop. Third, greater levels of radiation exposure lead to greater risk of breast cancer, i. e. , there is a direct dose and effect relationship. Finally, women's age at the time of exposure is also very important. First, the breast tissue of young women is one of the most sensitive tissues to the carcinogenic action of ionizing radiation. Only the bone marrow (where exposure can result in leukemia) and the infant thyroid gland are more sensitive to the cancer-causing effects of radiation.

Second, it takes a minimum of about 5-10 years after exposure before a radiation-induced breast cancer would develop, and usually many more years. In fact, the time between radiation exposure and breast cancer development is longest in young women and shortest for older women; young children do not show a detectable elevation in breast cancer occurrence for some 35 to 40 years after exposure. Radiation-induced breast cancers appear to occur later in life during the same ages when breast cancer rates, in general, begin to increase. It appears that a single exposure of sufficient dose during early life can increase breast cancer risk even 50 years later. Third, the relationship between radiation dose and breast cancer risk [11].

Nuclear scans

Other names include nuclear imaging, radionuclide imaging, and nuclear medicine scans.

Nuclear scans make pictures based on the body's chemistry rather than on physical shapes and forms (as is the case with other imaging tests). These scans use substances called radionuclides (also called tracers or radiopharmaceuticals) that release low levels of radiation.

Body tissues affected by certain diseases, such as cancer, may absorb more or less of the tracer than normal tissues. Special cameras pick up the pattern of radioactivity to create pictures that show where the material travels and where it collects. These scans can show some internal organ and tissue problems better than standard x-ray images.

If cancer is present, the tumor may show up on the picture as a "hot spot" – an area of increased tracer uptake. Depending on the type of scan done, the tumor might instead be a "cold spot" – a site of decreased uptake.

Nuclear scans are used to find tumors. They are also used to study a cancer's stage (the extent of its spread) and to decide if treatment is working.

Nuclear scans may not find very small tumors, and cannot always tell the difference between benign (not cancer) and malignant (cancer) tumors. They are often used along with other imaging tests to give a more complete picture of what's going on. For example, bone scans that show hot spots on the skeleton are usually followed by x-rays of the affected bones, which are better at showing details of the bone structure (Figure 4).

Nuclear scans have different names, depending on the organ involved. Some of the more commonly used nuclear scans (described in more detail further on) are:

Bone scans

Gallium scans

PET scans

Thyroid scans

MUGA scans

Some nuclear scans are also used to measure heart function.

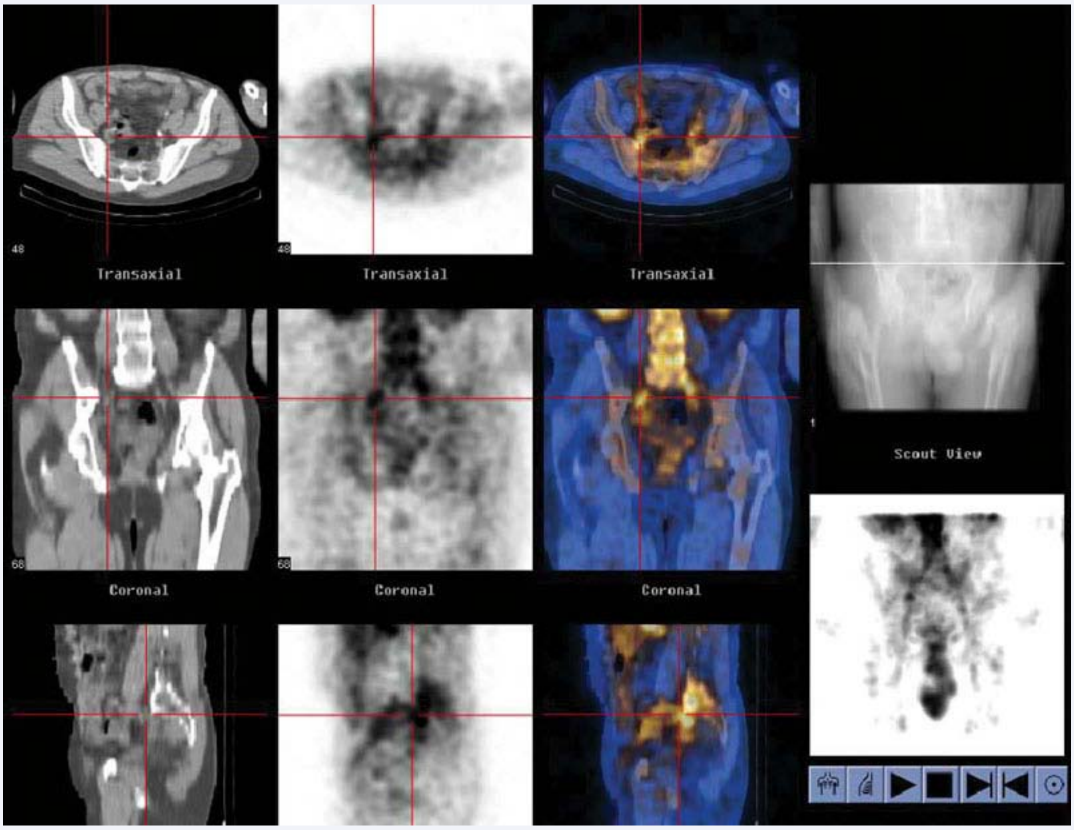

Figure 4 (www. gehealthcare. com) (View LargerA nuclear medicine (NM) scan is sometimes called scintigraphy or a scintigraphic study. Nuclear medicine scans can provide important information .)

The type of scan done depends on what organ or tissue the doctor wants to study. In most cases you are given a substance that sends out small doses of radiation. Some are swallowed while others are given into a vein or inhaled as a gas.

Radionuclide scans: Because they look at more than just the shape of a tumor, radionuclide scans are used for more than just creating pictures. Here are some of the more common radionuclides now in use:

Gallium-67 is used to look for cancer in certain organs. It can also be used for a whole body scan. This may be called a gallium scan.

Technetium-99 is used in whole body scans, especially in bone scans. Bone scans look for cancers that may have spread (metastasized) from other places to the bones. Technetium-99 is also used in heart scans, including the MUGA scan which looks at heart function.

Thallium-201 scans are most often used in cardiology to study heart disease. They are sometimes used to look at how well treatment is working for certain kinds of tumors and may be used to find some types of cancer.

Radioactive iodine (iodine-123 or iodine-131) can be used to find and treat thyroid cancers.

Radionuclides send out gamma rays which are picked up by a special camera (known as a gamma camera, rectilinear scanner, or scintiscan). The signals are processed by a computer, which turns them into 2- or 3-dimensional (3-D) pictures, sometimes with color added for extra clarity. A radiologist or a doctor who specializes in nuclear medicine interprets the pictures and sends a report to your doctor.

Positron emission tomography scans: Positron emission tomography (PET) is a scan that uses a form of radioactive sugar. Body cells take in different amounts of the radioactive sugar, depending on how fast they are growing. Cancer cells, which grow quickly, are more likely to take up larger amounts of the sugar than normal cells. The radioactive sugar gives off tiny atomic particles called positrons, which run into electrons in the body, giving off gamma rays. A special camera picks up these rays as they leave the body and turns them into pictures.

PET scans are used to find cancer and to see if it's responding to treatment. The chemical changes they show can also help doctors look at the effects of cancer treatment. Because PET scans look at body function, they may show changes that suggest disease before the changes can be seen on other imaging tests.

PET/CT scans: Some machines combine a PET scan with a CT scan. PET/CT scanners give more detailed information on any increased cell activity, helping doctors pinpoint tumors. But they also expose the patient to more radiation.

Use of monoclonal antibodies in nuclear scans: A special type of antibody produced in the lab, called a monoclonal antibody, can be designed to stick to substances found only on the surface of cancer cells. A radioactive substance can be attached to the monoclonal antibody, which is then given into a vein. It travels in the bloodstream until it gets to the tumor and sticks to it. This causes the tumor to "light up" when seen through a special scanner. Some examples of monoclonal antibody scanning used to look at cancers are the ProstaScint® scan for prostate cancer, the OncoScint® scan for ovarian cancer, and the CEA-Scan® for colon cancer.

The steps needed to prepare for a nuclear scan depend on the type of test and the tissue that will be studied. Some scans require that you don't eat or drink for 2 to 12 hours before the test. For others, you may be asked to take a laxative or use an enema. Be sure your doctor or nurse knows everything you take, even over-the-counter drugs, vitamins, and herbs. You may need to avoid some medicines (prescription and over-the-counter) before the test. Your health care team will give you instructions.

The radioactive material can be given by mouth, put into a vein (IV), or even inhaled as a gas (though this is rare for cancer-related imaging tests). You may get it anywhere from a few minutes to many hours before the test. For example, in a bone scan, the tracer is put into a vein in your arm about 2 hours before the test begins. For gallium scans, the tracer is given a few days before the test.

In most cases, a nuclear scan done is done as an outpatient procedure. Because of the special materials and equipment needed, these scans are usually done in the radiology or nuclear medicine department of a hospital. You might be able to wear your own clothing or you might be given a gown to wear during the test. You will need to remove all jewelry or metal items that could interfere with the scans.

The scanner has a hole in the middle and looks like a large doughnut. You lie on a padded table which fits through the hole and the scanner moves back and forth. The technician may ask you to change positions to allow different views to be taken. The test is not painful. But you may get uncomfortable after lying on the table for a while.

A nuclear scan takes about 30 to 60 minutes, plus the waiting time after the radioactive material is given. For bone scans, the material takes 2 to 3 hours to be absorbed, and the scan itself takes another hour or so. Gallium scans take several days between the injection and the actual scan. Results of nuclear scans are usually available within a few days.

For the most part, nuclear scans are safe tests. The doses of radiation are very small, and the radionuclides have a low risk of being toxic or causing an allergic reaction. Some people may have pain or swelling at the site where the material is injected into a vein. Rarely, some people will develop a fever or allergic reaction when given a monoclonal antibody.

The radiation exposure from a nuclear scan comes from the radionuclides used – the scanner itself does not put out radiation. The radioactive material in your body will naturally decay and lose its radioactivity over time. It may also leave your body through your urine or stool within a few hours or a few days. Talk to your health care team about having sex, or being close to children or pregnant women after these tests.

You will be asked to drink a lot of water to flush out the radioactive material.

To reduce the risk of being exposed to radioactive material in your urine after a scan, you should flush the toilet as soon as you use it.

Nuclear scans are rarely recommended for pregnant women, so let your doctor know if you are or might be pregnant.

If you are breastfeeding, be sure to tell the doctor ahead of time. You may need to pump breast milk and discard it until the radionuclide is gone from your system [4].

RESULT AND DISCUSSION

Radiation therapy is responsible for extending the life of many people, and the application of radiation and radiopharmaceuticals has led to greatly improved medical diagnoses and subsequent treatment of injuries and diseases. More indirectly, applications of radiation and radionuclides in industry have led to economic benefits that have improved living standards and, consequently, better health. But the question was posed often is referring to small doses of radiation and the direct effects on the individuals exposed. Here, the story is much more complicated. All living organisms have evolved and exist in the presence of ionizing radiation. Consequently, it is logical to expect that organisms have "learnt" or "adapted" to cope with the damaging effects of ionizing radiation and, indeed, biological processes have been found that do repair damage to cellular constituents like that caused by overexposure to potentially toxic agents like ionizing radiation. One can press this idea further and ask whether the stimulation of such repair processes results in the organism being able to cope better with other subsequent potentially toxic agents. This can include further radiation exposure, or other completely different agents including heat, metals, and chemicals. This type of effect has actually been observed in many studies with micro-organisms, plants and animals. One could even ask whether such stimulation has become an essential feature of life and that without it, organisms will not be as healthy and, further, that a little more ionizing radiation might have a beneficial effect on the life of an organism – in other words, a "hermetic" effect (from "hormesis" – a well-known effect where low doses of common toxins, like arsenic, are good for you but high doses aren't). There is certainly evidence for all these effects from particular radiation experiments with animals. The question is to what extent they may be generally applicable to humans [12].

The damaging effects of high doses of radiation on health are well documented. Indeed the effectiveness of radiation therapy relies on killing cancer cells. Doses of ionizing radiation lower than those used in therapy, but still hundreds of times higher than occupational and environmental levels, are known to increase the likelihood that some kinds of cancer will occur sometime (years) after the exposure. This was recognized, more than 50 years ago in the increased incidence of leukemia in various groups that had been exposed to high doses of radiation: children after they had been exposed to X-rays for various medical reasons during infancy or prenatal care, radiologists, and the Japanese survivors of the Hiroshima atomic bomb. Therefore, scientists concluded at the time (in 1958) that the most conservative approach for protection was to assume that the incidence of leukemia would be proportional to the accumulated radiation dose, although there could be a dose below which there would be no negative effect. At high doses (about 100 chest X-rays all at once or about 100 mSv) data generally support the idea that the increased incidence of some cancers is proportional to the accumulated radiation dose. It has been possible to estimate the relationship between radiation dose and increased incidence of cancers (the "risk coefficient") that do appear to be induced by high doses of radiation. The Japanese survivors of the atomic bombs in Hiroshima and Nagasaki have provided most information for this.

For very low doses, like we are exposed to every day from nature, or from dental X-rays, airplane flights, or working near radiation like nuclear medicine and nuclear power stations (i. e. doses below 100 mSv), it is not possible to determine from A-bomb survivor data what the relationships are between radiation dose and cancer. However, just to be safe, the approach for protection purposes assumes all radiation can be detrimental and should be avoided or kept to levels "as low as reasonably achievable" (ALARA) [12].

In other words, the cancer risk is assumed to be proportional to radiation dose, all the way from zero to doses where effects have actually been observed. This is the "linear non-threshold" model (LNT) that is the basis for regulations on radiation around the world. It is generally assumed that this model is "reasonably conservative" – that is, it errs on the safe side without going overboard. It has the practical advantage that protection against radiation can be considered on its own, without knowledge of previous radiation dose (e. g. from a medical examination, or from radon at home).

There is dissent on the appropriateness of the LNT model, however, in both directions, and advocates of the conflicting positions can point to experimental data in support of their claims. The suggestion that the LNT model under-estimates the actual risk is based on some selected data from population studies (childhood leukemia from nuclear test fallout) and on experimental observations that some animal cells that are close to a cell that has been hit by radiation appear to be genetically affected even though they have not been hit. (This is called the "bystander" effect.) However, this suggestion is generally regarded by radiobiologists and epidemiologists as having no sound scientific basis. There is the view that there is a threshold below which radiation doses have no harmful effect. There is also the view that some increases in radiation exposure have a beneficial effect on health. Even with the much more extensive data now available than was the case when the LNT model was first adopted, it is still not possible to determine unequivocally whether there is or there is not an increased risk of cancer at a doses of a few tens of mSv.

However, everyday our understanding of genetics, biochemistry, and processes involved in cancer formation become stronger, and scientists will continue to collect information that will increase our knowledge about low-dose effects. Currently, there is strong evidence that shows that not all radiation may be detrimental. For example, the risk of cancer following consumption of radioactive paint used historically for making watches glow in the dark (radium dial painters) showed that low doses did not cause bone cancer. In the case of the Japanese atomic bomb survivors, the incidence of leukemia at low doses was not significantly raised. Some scientists have interpreted the leukemia data as indicating a reduced incidence in the low dose range but, in reality, the statistical variation weakens this interpretation. There have been other studies, such as of human populations that live in regions with high natural background radiation (tens or hundreds of mSv per year), or of animals in the region around the Chernobyl nuclear power plant, where the absence of effects or of beneficial effects have been claimed, but none of these studies have overcome statistical limitations and practical difficulties. Evidence for beneficial effects on human health from radiation exposures continues to be much sought after but, so far, it remains elusive.

REFERENCES

1. Gayle W. Environmental, Safety, and Health Engineering. US: John Wiley & Sons. 1997; 476.
2. Stallcup JG. OSHA: Stallcup's High-voltage Telecommunications Regulations Simplified. US: Jones & Bartlett Learning. 2006; 133.
3. Rothkamm K, Löbrich M. Evidence for a lack of DNA double-strand break repair in human cells exposed to very low x-ray doses. Proc Natl Acad Sci U S A. 2003; 100: 5057-5062.
4. American Cancer Societies.
5. Diagnostic Reference Levels in Medical Imaging: Review and Additional Advice - International Commission on Radiological Protection (ICRP, 2002). ICRP Publication 105 (2007), Section 10 ("Diagnostic Reference Levels"), summarizes pertinent sections of the previous ICRP Publications 60, 73, and Supporting Guidance 2, and it contains much of the same information as in the 2002 document.
6. Diagnostic Reference Levels and Achievable Doses, and Reference Levels in Medical and Dental Imaging: Recommendations for Applications in the United States - U. S. National Council on Radiation Protection and Measurements (NCRP) Report No. 172.
7. Livescience Trending
8. Slater JD, Rossi CJ Jr, Yonemoto LT, Bush DA, Jabola BR, Levy RP, et al. Proton therapy for prostate cancer: the initial Loma Linda University experience. Int J Radiat Oncol Biol Phys. 2004; 59: 348-352.
9. Advances in Prostate Imaging and Ablative Treatment of Prostate Cancer.
10. Breast Cancer Fund. Help us expose and eliminate the environmental causes of breast cancer. Together we can stop this disease before it starts.
11. Act for change.
12. Canadian Nuclear FAQ. Section D: Safety and Liability.

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