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Short Essay on Physical Concepts, Applications and Side Effects of Radiation on the Human Tissue

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Abstract

We reported here the concepts, applications and side effects of radiotherapy on the human tissue. The properties of x and γ rays, and their applications on the tumor tissues such as radiation therapy, gamma camera and gamma Knife are presented. Further, the physics of laser and its applications such as photo-coagulation, photo-vaporization, photo-chemical ablation, laser surgery, and laser in dentistry, laser in ophthalmology and laser in hemoglobin are also mentioned. Moreover, the side effects of those radiations on the normal tissues of the human body are discussed. On the other hand, the different methods of medical imaging such as radiography, computed tomography, fluoroscopy, magnetic resonance imaging (MRI) and nuclear magnetic imaging (NMI) are presented.

Keywords: Radiotherapy; Gamma knife; Medical Imaging and Laser Surgery

1. Introduction

1.1: X and Gamma rays

X-rays is referred to Rontgen radiation who is usually credited as it's discover and named it as x-ray to signify an unknown type of radiation. Most of x-rays have a wavelength in the range of 0.01 to 10 nm (0.1-100 Å), corresponding to energies in the range of (100-1000 eV). X-rays with photon energies (5000-10000 eV) (0.10-0.15 nm) are called hard x-rays, while those with lower energy are called soft x-rays.

Due to their penetrating ability, hard x-rays are widely used to image the inside of objects in medical radiography and airport security. Since the wavelengths of hard x-rays are similar to size of atoms they are also useful for obtaining the crystal structures of materials through x-ray crystallography. By contrast, soft x-rays are easily absorbed in both air and water, and the attenuation lengths of 600 eV x-ray energy are about 2 nm and 1000 nm in air and water, respectively. The maximum energy of the produced x-ray is limited by the energy of incident electron because it is equal to the voltage on the tube times the electron charge (eV). However, x-rays are produced in an x-ray tube shown in Figure 1. The electron gun shoots electrons which hit the target material with a very high velocity (tungsten is most widely used as a target element). The tube is normally evacuated to permit the electrons to get to the target unimpeded. A cathode heated, by a filament through which an electric current is passed, supplies electrons by thermionic emission.

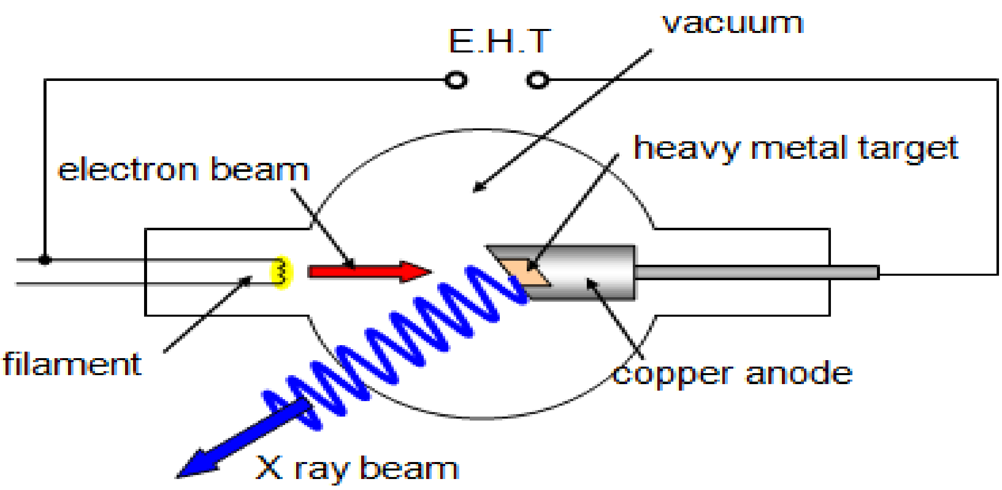

Figure 1: x-ray generation tube

The high potential difference of 35 KeV is maintained between the cathode and a molybdenum metallic target to accelerate the electrons toward the latter. The face of the target is at an angle relative to the electron beam, and the x-rays that leave the target pass through the side of the tube. When the electrons hit the target, x-rays are created by following two

When the electrons hit the target, x-rays are created by following two different atomic processes.

***I. Characteristic X-ray emission*:** If the electron has enough energy it can knock an orbital electron out of the inner electron shell of a metal atom, and as a result electrons from higher energy levels then fill up the vacancy and X-ray photons are emitted. This process produces an emission spectrum of X-rays at a few discrete frequencies, sometimes referred to as the spectral lines. The spectral lines generated depend on the target (anode) element used and thus are called characteristic lines. Usually these are transitions from upper shells into K shell (called K lines), into L shell (called L lines) and so on.

II. Bremsstrahlung: This is radiation given off by the electrons as they are scattered by the strong electric field near the high-*Z* (atomic number) nuclei. These X-rays have a continuous spectrum. The intensity of the X-rays increases linearly with decreasing frequency, from zero at the energy of the incident electrons according to the voltage on the X-ray tube.

In medical diagnostic applications, the low energy soft x-rays are un-wanted, since they are totally absorbed by the body, increasing the radiation dose without contributing to the image. Hence, a thin metal sheet, often of AL, called an x-ray filter, is usually placed over the window of the x-ray tube, absorbing the low energy part in the spectrum. This is called hardening the beam since it shifts the center of the spectrum towards higher energy (or harder) x-rays.

It is approved that no x-rays produced at a wave length shorter than a certain minimum value λ_{min} , according to the following equation ;

$$\begin{aligned} \lambda_{\min}(m) &= \frac{hc}{eV} = \frac{6.62\times10^{-34}\times3\times10^{8}}{1.6\times10^{-19}} = \frac{1.24\times10^{-6}}{V} \\ \lambda_{\min}(\overset{0}{\mathrm{A}}) &= \frac{1.24\times10^{4}}{V} \end{aligned} \qquad \textbf{(1)}$$

A nucleus that undergoes radioactive decay is left in an excited energy state. The nucleus can then undergo a second decay to a lower energy state (ground state) by emitting a high-energy photon as:

$$ {}_{Z}^{A}X^{*} \rightarrow {}_{Z}^{A}X + \gamma \qquad \textbf{(2)} $$

Where the first (X*) indicates a nucleus in an excited state. The typical half-life of an excited nuclear state is about 10^{-10} s. Such emitted photons have very high energy (MeV) relative to the energy of visible light (1eV), and x-ray (100 - 1000 eV).

Recall that the energy of photons emitted by an atom equals the difference between two nuclear energy levels. When a nucleus decays by emitting a gamma ray, the nucleus does not change its atomic mass A or atomic number Z. A nucleus may reach an excited state as a result of a violent collision with another particle. It is also very common for a nucleus to be in an excited state after undergoing α or β. The following sequence of events represents a typical situation in which gamma decay occurs:

$$ \begin{aligned} {}_{5}^{12}B &\rightarrow {}_{6}^{12}C^{*} + {}_{-1}^{0}e^{-} + \bar{\upsilon} \\ {}_{6}^{12}C^{*} &\rightarrow {}_{6}^{12}C \quad + \gamma \end{aligned} \qquad \textbf{(3)} $$

Figure (2) shows the decay scheme for ^{12}B, which undergoes β decay with a half-life of 20.4 ms to either of two levels of ^{12}C. It can either decay directly to the ground state of ^{12}C by emitting a 13.4 MeV for the electron or undergo β^- decay to an excited state of ^{12*}C, followed by γ decay to the ground state. The latter process results in the emission of a 9 MeV for the electron and a 4.4 MeV for the photon.

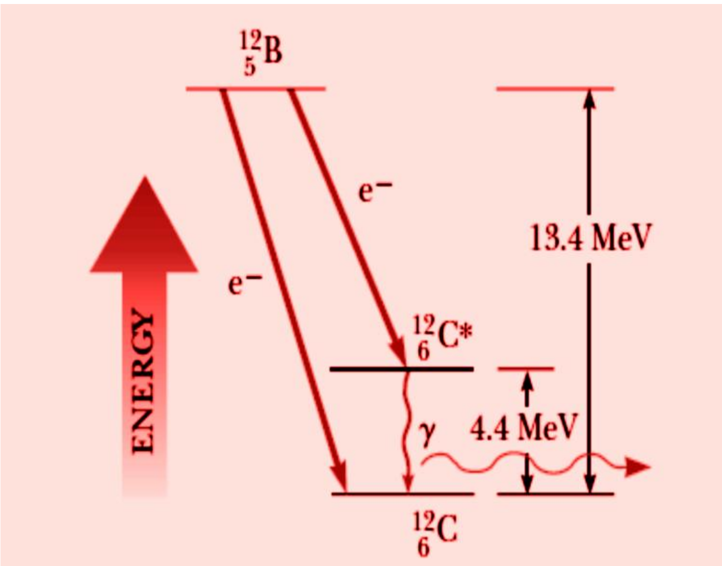

Figure (2): An energy level diagram for ^{12}B nucleus and ^{12}C

1.2: Physics of Laser

Maser has produced in 1953, and it is a device operating by amplifying microwave radiation rather than infrared or visible radiation. While a **laser** is a device that emits light through a process of optical amplification based on the stimulated emission of electromagnetic radiation. Laser is a device that emits light through a process of optical amplification based on the stimulated emission of electromagnetic radiation. The term of laser is originated by amplification of light through stimulated emission of radiation. A laser differs from the other sources of light because it emits light with spatial coherence which allows a laser to be focused to a tight spot, enabling applications like laser cutting and lithography. Spatial coherence also allows a laser beam to stay narrow over very long distances, enabling applications such as laser pointers.

Laser can also have high temporal coherence which allows them to have a very narrow spectrum; they only emit a single color of light (monochromatic wave length). Temporal coherence can be used to produce pulses of light as short as a femto-second. The beam of laser is extremely intense, more intense by far that the light from any other source. To achieve an energy density in some laser beams, a hot object would have to be at a temperature of 1030 K.

Lasers have many important applications in medicine such as laser surgery and various skin treatments. However, laser is usually generated through stimulated emission rather than spontaneous emission because stimulated emission helps for population inversion, which is necessary for optical amplification. Therefore, we can summarize the properties of laser as follows:

I- The light emitted from a laser is monochromatic, that is, it is of one color or wave length. In contrast, ordinary white light is a combination of many colors or wave lengths.

II- Lasers emit light is highly directional, that is, laser light is emitted a relatively narrow beam in a specific direction. In contrast, ordinary light such as light bulb is emitted in many directions away from the light source.

III- The light from a laser is coherent, which means that the wave lengths of the laser light are in phase in space and time. In contrast, ordinary light is mixture of many wave lengths.

These properties of laser light helps for can depositing a lot of its energy within a small area as compared to ordinary light beam. Then, it is more hazardous for the eyes and the other human surfaces.

1.2.1: Spontaneous Emission

Absorption occurs when a light pass and absorbed by the atoms which are in the ground state, and cause them to be excited to the higher energy state. The rate of absorption is proportional to the radiation intensity of the light, and also to the number of atoms currently in the ground state N_1. As a result of absorption, a spontaneous emission occurs which is the process by which a quantum system such as an atom in an excited state undergoes a transition to a state with a lower energy (ground state) and emits quanta of energy $E_2 - E_1 = h\upsilon$ as shown as in Figure (3a). Light from an atom is a fundamental process that plays an essential role in many phenomena in nature and forms the basis of many applications, such as fluorescent tubes and older television screens.

Early, laser was started by spontaneous emission, but the phase of the photon in spontaneous emission is randomly as is the direction in which the photon propagates, which is not convenient for laser. Then a stimulated emission was used instead of spontaneous emission because it is necessary for light amplifications.

1.2.2: Stimulated Emission:

It is the process by which an atomic electron (or an excited molecular state) interacting with photon of a certain frequency may drop to a lower energy level, transferring its energy to that field. A new photon created in this manner has the same phase, frequency, polarization, and direction of travel as the photons of the incident wave. This is in contrast to spontaneous emission which occurs without regard to the ambient electromagnetic field. Therefore, a transition from the higher to a lower energy state, however, produces an additional photon, and consequently tends to the process of stimulated emission.

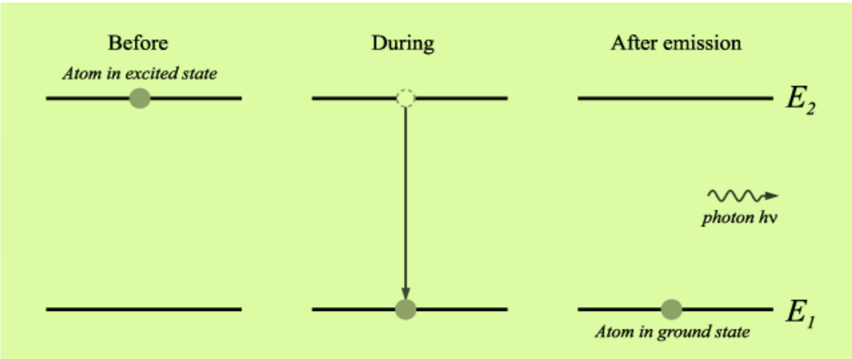

Figure (3a): Absorption and spontaneous emission by quantum system

However, the process is identical in form to atomic absorption in which the energy of an absorbed photon causes an identical but opposite atomic transition (from the lower level to a higher energy level). In normal media at thermal equilibrium, absorption exceeds stimulated emission because there are more electrons in the lower energy states than in the higher energy states. However, when a population inversion is present the rate of stimulated emission exceeds that of absorption, and a net optical amplification can be achieved as shown in Figure (3b). Such a gain medium, along with an optical resonator, is at the heart of a laser.

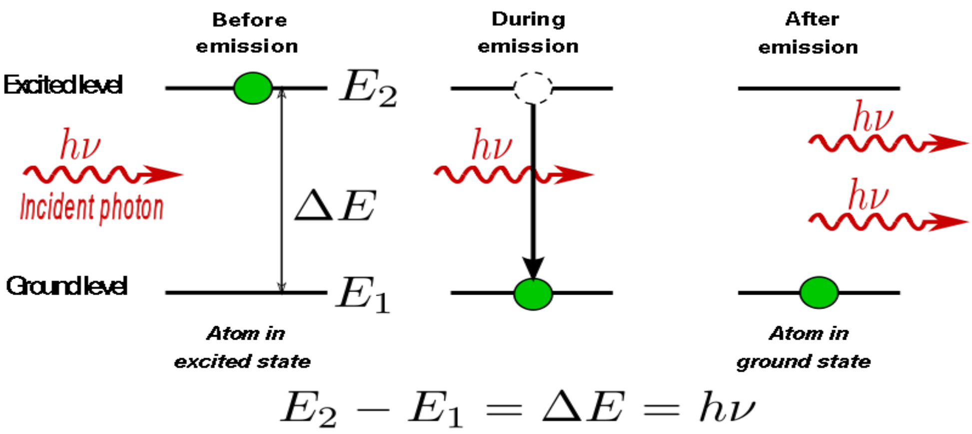

Figure (3b): Stimulated emission by quantum system

1.2.3: Population inversion

Let n_1 and n_2 be the number of active species (per unit volume) lying in the upper and lower energy levels respectively. These quantities are known as the populations of these two energy levels. As a photon of energy E_{12} can, with an identical probability, induce either the $E_1 \sim E_2$ transition or the $E_2 \sim E_1$ transition. Which of them will result depends on the energy level in which the active centre lies. If the lower level of the medium is more populated than the upper level, the absorption processes will dominate. Conversely, if the upper level is more populated than the lower, the processes of stimulated emission will prevail. Under normal conditions, specifically in thermodynamic equilibrium, the populations of energy levels decline as the level energy increases, so that normally $n_2 < n_1$, and the processes of absorption of light are dominant. Under normal conditions, specifically in thermodynamic equilibrium, the populations of energy levels decline as the level energy increases, so that normally $n_2 < n_1$, and the processes of absorption of light are dominant.

1.2.4: Active laser gain medium

The active laser medium (also called gain medium or lasing medium) is the source of optical gain within a laser. The gain results from the stimulated emission of electronic or molecular transitions to a lower energy state from a higher energy state previously populated by a pump source as shown in Figure (3.3). Examples of active laser media include certain crystals, typically doped with rare-earth ions. The most often yttrium aluminum garnet ($Y_3Al_5O_{12}$). Glasses, e.g. silicate or phosphate glasses, doped with laser-active ions. The active gain medium must be in a non thermal energy distribution known as a population inversion. The preparation of this state requires an external energy source and is known as laser pumping. Pumping may be achieved with electrical currents or with light, generated by discharge lamps. More exotic gain media can be pumped by chemical reactions, nuclear fission, or with high-energy electron beams.

1.2.5: Optical resonant cavity

The selection of some photon states and the suppression of other states can be realized by means of an optical resonator, a principal component of each laser. In its simplest version the optical resonant cavity is a pair of mirrors set on an optic axis which defines the direction of the laser beam as shown in Figure (4). The active material is placed in-between these mirrors. Solid active materials are often in the shape of a cylinder whose axis is aligned with the axis of the optic resonator, the length of the cylinder being about ten times its diameters. At least one of the mirrors of the resonant cavity is made semitransparent to serve as an output element passing the light out of the resonator.

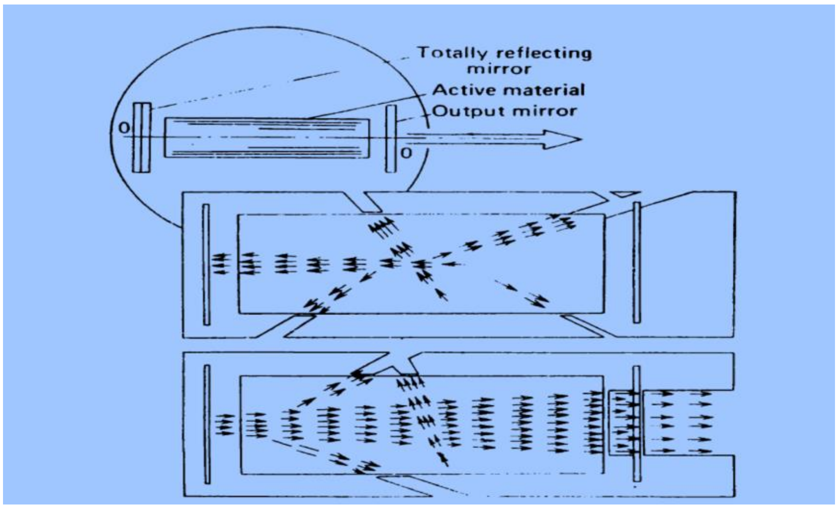

Figure (4): Optical resonator for laser direction action

1.2.6: Types of lasers

I. Gas Lasers

Following the invention of the HeNe gas laser, many other gas discharges have been found to amplify light coherently. Gas lasers using many different gases have been built and used for many purposes. The helium–neon laser (HeNe) shown in Figure (5a,5b) is able to operate at a number of different wavelengths, however the vast majority are engineered to lase at 633 nm; these relatively low cost but highly coherent lasers are extremely common in optical research and educational laboratories.

Commercial carbon dioxide (CO_2) lasers shown in Figure (6a,6b) can emit many hundreds of watts in a single spatial mode which can be concentrated into a tiny spot. This emission is in the thermal infrared at 10.6 µm; such lasers are regularly used in industry for cutting and welding. The efficiency of a CO_2 laser is unusually high: over 30%.

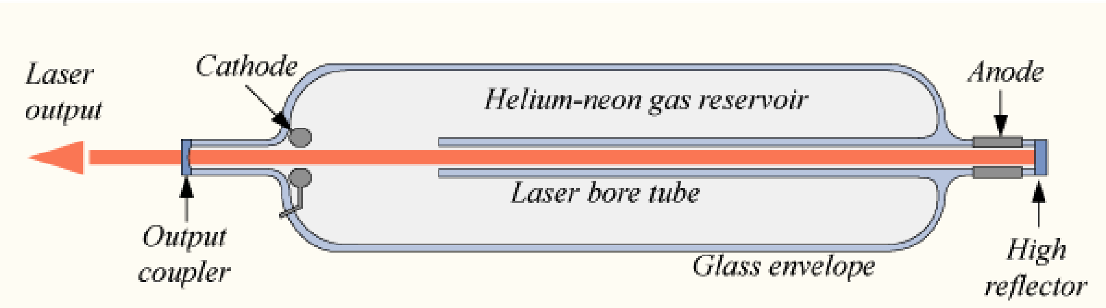

Figure (5a): The tube of helium–neon laser (HeNe)

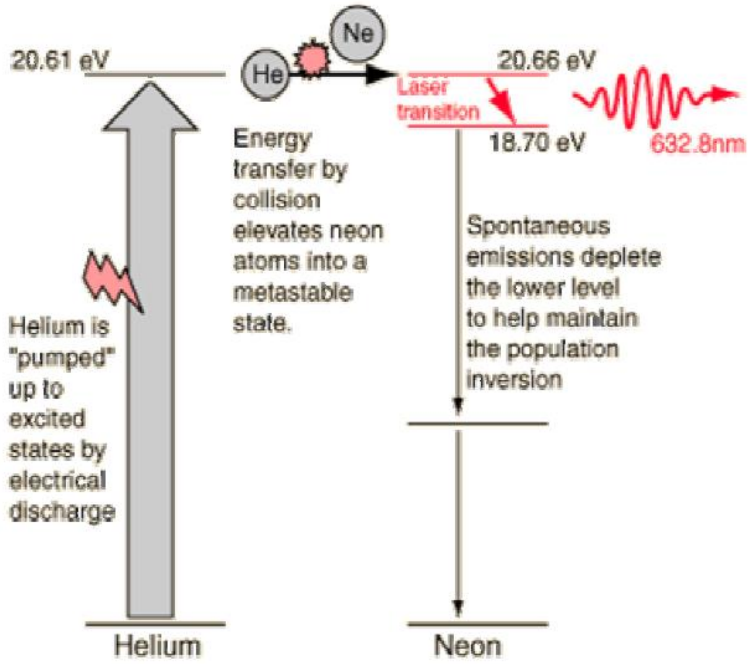

Figure (5b): The transitions of He-Ne gas laser

Argon-ion lasers can operate at a number of lasing transitions between 351 and 528.7 nm. Depending on the optical design one or more of these transitions can be lasing simultaneously; the most commonly used lines are 458 nm, 488 nm and 514.5 nm. A nitrogen transverse electrical discharge in gas at atmospheric pressure (TEA) laser is an inexpensive gas laser, often home-built by hobbyists, which produces rather incoherent UV light at 337.1 nm.

Metal ion lasers are gas lasers that generate deep ultraviolet wavelengths such as Helium-silver (HeAg) 224 nm and neon-copper (NeCu) 248 nm.

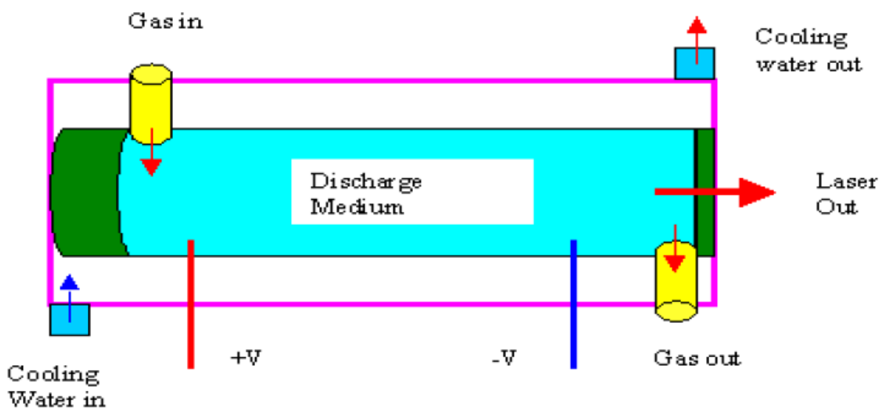

Figure (6a): The tube of Co2 gas laser

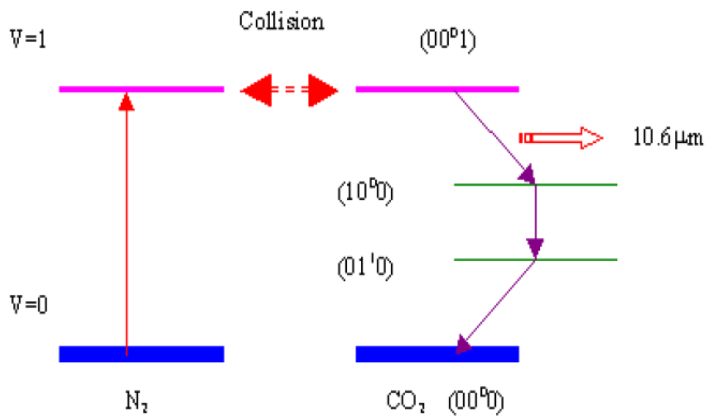

Figure (6b): The transitions of Co2 gas laser

II. Chemical Lasers

Chemical lasers are powered by a chemical reaction permitting a large amount of energy to be released quickly. Such very high power lasers are especially of interest to the military; however continuous wave chemical lasers at very high power levels, fed by streams of gasses, have been developed and have some industrial applications. As examples, in the hydrogen fluoride (HF) laser (2700–2900 nm) and the deuterium fluoride laser (3800 nm) the reaction is the combination of hydrogen or deuterium gas with combustion products of ethylene (C2H4) in nitrogen trifluoride (NF3).

III. Excimer Lasers

Excimer lasers are a special sort of gas laser powered by an electric discharge in which the lasing medium is an excimer, or more precisely an exciplex in existing designs. These are molecules which can only exist with one atom in an excited electronic state. Once the molecule transfers its excitation energy to a photon, the atoms are no longer bound to each other and the molecule disintegrates. This drastically reduces the population of the lower energy state thus greatly facilitating a population inversion. Excimers currently used noble gasses that are chemically inert.

Excimer lasers typically operate at ultraviolet wavelengths with major applications including eye surgery. Commonly used excimer molecules include ArF (emission at 193 nm), KrCl (222 nm), KrF (248 nm), XeCl (308 nm), and XeF (351 nm). The molecular fluorine laser, emitting at 157 nm in the vacuum ultraviolet is sometimes referred to as an excimer laser.

IV. Solid-State Lasers

Solid-state lasers use a crystalline or glass rod which is doped with ions that provide the required energy states. For example, the first working laser was a ruby laser shown in Figure (7), made from ruby (chromium-doped corundum). The population inversion is actually maintained in the dopant. These materials are pumped optically using a shorter wavelength than the lasing wavelength, often from a flash tube or from another laser.

V. Fiber Lasers:

Fiber lasers are guided due to the total internal reflection in a single mode optical fiber. Fibers have high surface area to volume ratio which allows efficient cooling. In addition, the fiber's wave guiding properties tend to reduce thermal distortion of the beam. Erbium and ytterbium ions are common active species in such lasers.

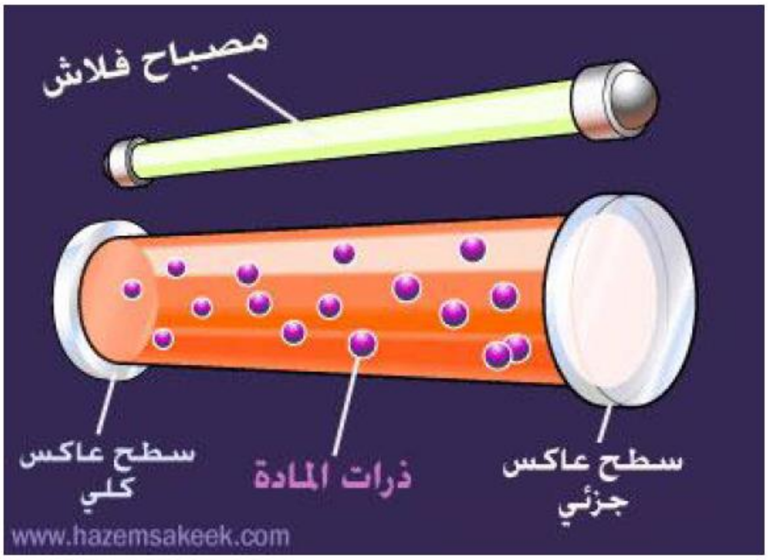

Figure (7): Ruby laser apparatus

This type of fiber consists of a fiber core, an inner cladding and an outer cladding. The index of the three concentric layers is chosen so that the fiber core acts as a single-mode fiber for the laser emission while the outer cladding acts as a highly multimode core for the pump laser. This lets the pump propagate a large amount of power into and through the active inner core region.

VI. Semiconductor Lasers

Semiconductor lasers are diodes which are electrically pumped by electrons and holes created through optical gain. Commercial laser diodes emit at wavelengths from 375 nm to 3500 nm.

Semiconductor lasers have a semiconductor active medium in a larger cavity. These devices can generate high power outputs with good beam quality, wavelength-tunable narrow- line width radiation, or ultra-short laser pulses.

VII. Free-electron Lasers:

A free-electron laser (FEL) is a type of laser whose lasing medium consists of very-high-speed electrons moving freely through a magnetic structure. FEL usually generated coherent high power radiation that is widely tunable, currently ranging in wavelength from microwaves to soft X-rays. They have the widest frequency range of any laser type. Unlike gas, liquid, or solid-state lasers, which rely on bound atomic or molecular states, FELs use a relativistic electron beam as the lasing medium.

2: Applications of Radiations

2.1: Radiation therapy:

Radiation therapy or radiotherapy is the branch of medical physics concerned with radiation treatment planning, such as methods of dose delivery, dose verification and quality control which are applied to the human body. Radiation therapy machine shown in Figure (8) usually uses high-energy radiation to shrink tumors of a certain enzyme. It might be a signal to the cell to begin endocytosis of some foreign object; this is the case for example when a while blood cell engulfs and destroys a virus particle. Sometimes receptors are also transport proteins.

If the receptor is also a transport protein, it may then pull the bound molecule through the cell membrane into the cell. Sometimes receptors signal need to transport another molecule. For example, the hormone insulin (a small protein) binds to insulin specific receptors in the cell membrane. This signals glucose transport proteins elsewhere in the membrane to allow glucose into the cell.

Figure (8): Radiation therapy machine

2.2: Methods of Radiation Therapy

2.2.1: External Therapy

In this case, the radiation may be delivered to the patient by a machine outside the body. External radiation therapy is most often delivered in the form of photon beams of x-rays or γ-rays. Many types of external-beam radiation therapy are delivered using a machine called a linear accelerator shown in Figure (9) for creating high-energy radiation that may be used to treat cancer. Patients usually receive external-beam radiation therapy in daily treatment sessions over the course of several weeks. One of the most common types of external-beam radiation therapy is called 3-dimensional conformal radiation therapy (3D-CRT).

External therapy can be also delivered by proton beams. Proton beam therapy uses a machine called cyclotron which is used to energize protons. The extracted protons from the cyclotron are directed with magnetic fields to the tumor. Protons are differs from photon beams mainly in the way they deposit energy in living tissue. Whereas photons deposit energy in small packets along their path through tissue, protons deposit much of their energy at the end of their path (Bragg peak) $2d\sin\Theta = n\lambda$ which applied on photon in the x-ray and applied on proton in the γ-ray and deposit less energy along the way.

Figure (9): Linear accelerator used in external radiotherapy

In theory, use of protons should reduce the exposure of normal tissue to radiation, possibly allowing the delivery of higher doses of radiation to a tumor. The electron beams are also used to irradiate superficial tumors, such as skin cancer or tumors near the surface of the body, but they cannot travel very far through tissue. Therefore, they cannot treat tumors deep within the body.

2.2.2: Internal Radiotherapy (Brach Therapy):

In this case, the radiation delivered from radiation sources placed inside or on the body near the cancer cells. Interstitial Brach therapy uses a radiation source placed within tumor tissue, such as within a prostate tumor. Brach therapy uses a source placed within a surgical cavity or a body cavity, such as the chest cavity, near a tumor. Brach therapy, which is used to treat melanoma inside the eye, uses a source that is attached to the eye. In Brach therapy, radioactive isotopes are sealed in tiny pellets or seeds. These seeds are placed in patients using delivery devices, such as needles, catheters or some other type of carrier. Brach therapy may be able to deliver higher doses of radiation to some cancers than external-beam radiation therapy while causing less damage to normal tissue.

2.2.3: Systemic Radiotherapy

Systemic radiation therapy uses radioactive substances that travel in the blood to kill cancer cells. In systemic radiation therapy, a patient swallows or receives an injection of a radioactive substance, such as radioactive iodine ^{131}I or a radioactive substance bound to a monoclonal antibody. Radioactive iodine ^{131}I is a type of systemic radiation therapy commonly used to help treat some types of thyroid cancer.

Radioactive liquids can be used in some situations as a liquid that can contain a radioactive substance. For example, ^{131}I is absorbed into the bloodstream and taken up by thyroid cells (both normal and cancerous). The radioactive iodine then concentrates and builds up in thyroid cells. This then destroys the thyroid cells, but has little effect on any other tissue in the body.

As indicated in Figure (10), a solution containing radioactive sodium is injected into a vein in the leg, and the time at which the radioisotope arrives at another part of the body is detected with a radiation counter. The elapsed time is a good indication of the presence or absence of constrictions in the circulatory system.

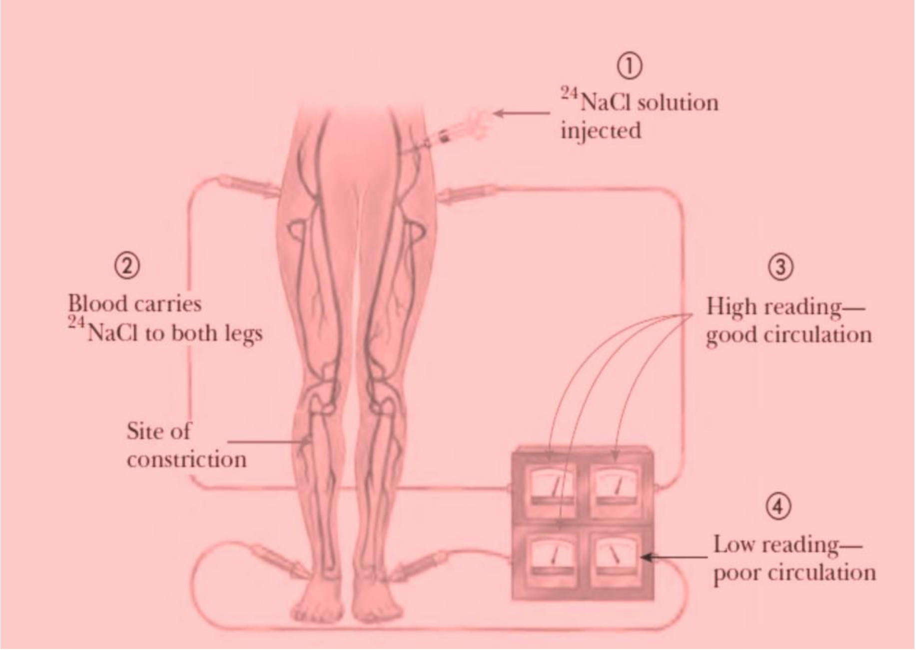

Figure (10): A tracer technique for the condition of circulating system

2.2.4: Gamma camera:

A gamma camera (a scintillation camera or Anger camera) is a device used to image gamma radiation emitting radioisotopes, a technique known as scintigraphy. The applications of scintigraphy include early drug development and nuclear medical imaging to view and analyze images of the human body or the distribution of medically injected, inhaled, or ingested radionuclides emitting gamma rays.

Figure (11): Gamma camera apparatus

A gamma camera shown in Figure (11) consists of one or more flat crystal planes (or detectors) optically coupled to an array of photomultiplier tubes in an assembly known as a “head”, mounted on a gantry. The gantry is connected to a computer system that both controls the operation of the camera as well as acquisition and storage of acquired images. The system accumulates events, or counts, of gamma photons that are absorbed by the crystal in the camera. Usually a large flat crystal of sodium iodide (Na^+) with thallium doping in a light-sealed housing is used. When a gamma photon leaves the patient, it knocks an electron loose from an iodine atom in the crystal, and a faint flash of light is produced when the dislocated electron again finds a minimal energy state.

The initial phenomenon of the excited electron is similar to the photoelectric effect and (particularly with gamma rays) the Compton effect. After the flash of light is produced, it is detected. Photomultiplier tubes (PMTs) behind the crystal detect the fluorescent flashes (events) and a computer sums the counts. The computer reconstructs and displays a two dimensional image of the relative spatial count density on a monitor. This reconstructed image reflects the distribution and relative concentration of radioactive tracer elements present in the organs and tissues imaged, as shown in Figures (12a), (12b) and (12c).

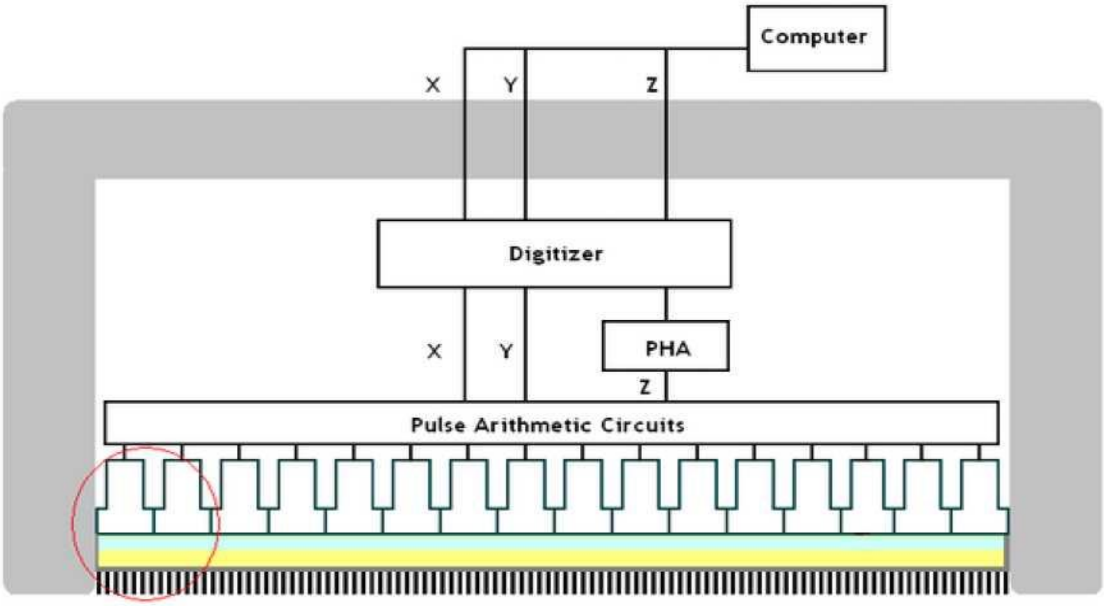

Figure (12a): Diagrammatic cross section of gamma camera detector

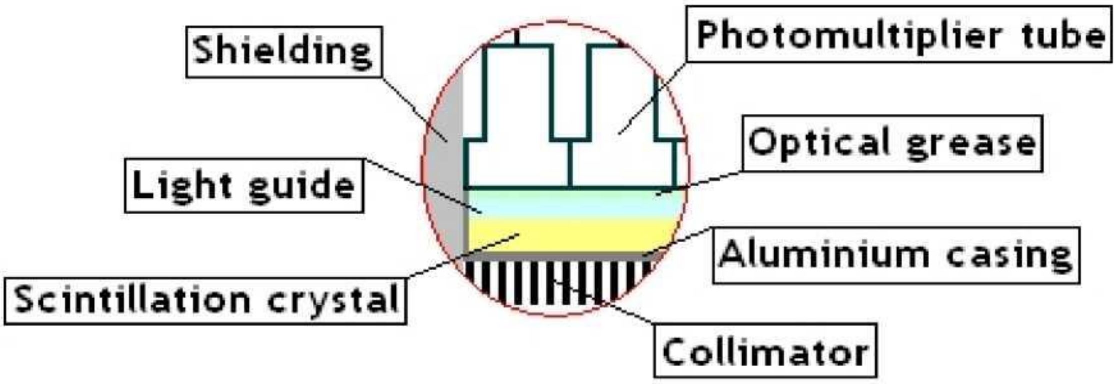

Figure (12b): details of the cross section of a gamma camera

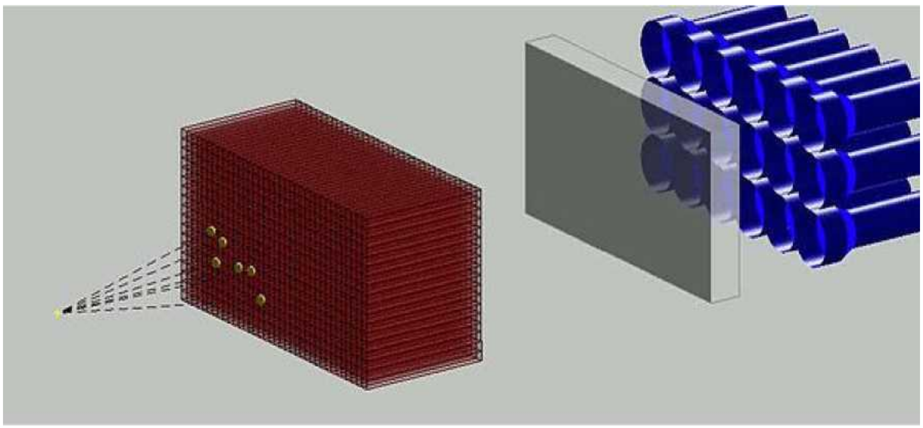

Figure (12c): Schematic diagram of gamma-camera mechanism

Scintigraphy emitted is the use of gamma cameras to capture radiation from internal radioisotopes to create two-dimensional images. SPECT (single photon emission computed tomography) imaging, as used in nuclear cardiac stress testing, is performed using gamma cameras. Usually one, two or three detectors are slowly rotated around the patient’s torso. Multi-headed gamma cameras can also be used for Positron emission tomography scanning, provided that their hardware and software can be configured to detect “coincidences”.

Gamma camera PET is markedly inferior to PET imaging with a purpose designed PET scanner, as the scintillator crystal has poor sensitivity for the high-energy annihilation photons, and the detector area is significantly smaller. However, given the low cost of a gamma camera and its additional flexibility compared to a dedicated PET scanner, this technique is useful where the expense and resource implications of a PET scanner cannot be justified.

2.2.5: Gamma Knife:

The Gamma Knife shown in Figure (13a) is used to treat brain tumors by administering high-intensity cobalt radiation therapy in a manner that concentrates the radiation over a small volume. The device was invented in 1967 in Stockholm, Sweden. A Gamma Knife typically contains 201 cobalt-^{60}Co sources of approximately 30 curies, each placed in a circular array in a heavily shielded assembly. The device aims gamma radiation through a target point in the patient's brain.

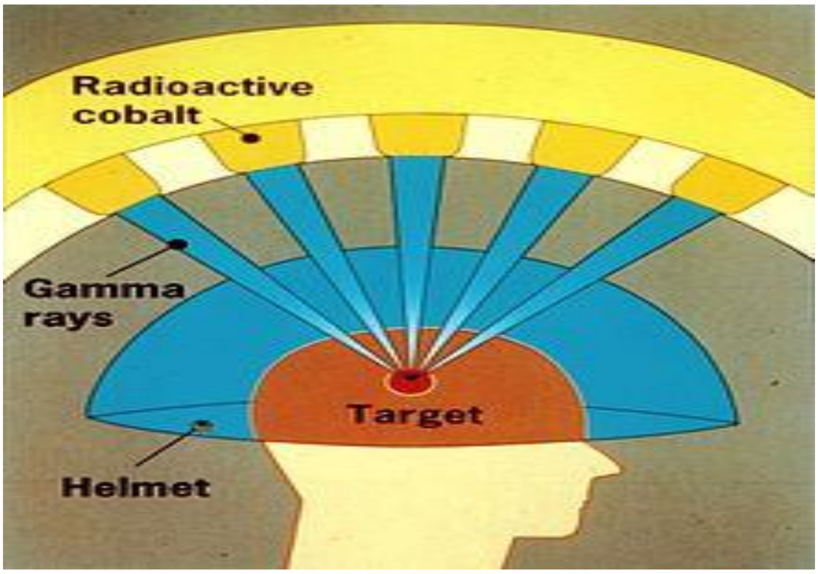

Figure (13a): Nuclear Regulatory Commission of the Gamma Knife

The patient wears a specialized helmet that is surgically fixed to the skull, so that the brain tumor remains stationary at the target point of the gamma rays. An ablative dose of radiation is thereby sent through the tumor in one treatment session, while surrounding brain tissues are relatively spared.

Gamma Knife therapy, like all radiosurgery, uses doses of radiation to kill cancer cells and shrink tumors, delivered precisely to avoid damaging healthy brain tissue. Gamma Knife radiosurgery is able to accurately focus many beams of gamma radiation to converge on one or more tumors. Each individual beam is of relatively low intensity, so the radiation has little effect on intervening brain tissue and is concentrated only at the tumor itself.

Gamma Knife radiosurgery has proven effective for patients with benign or malignant brain tumors up to 4 centimeters in size, vascular malformations such as an arteriovenous malformation (AVM), pain or other functional problems. For treatment of trigeminal neuralgia, the procedure may be used repeatedly on patients. Acute complications following gamma knife radiosurgery are rare, and complications are related to the condition being treated. Radiosurgery is surgery using radiation, that is, the destruction of precisely selected areas of tissue using ionizing radiation rather than excision with a blade. Like other forms of radiation therapy, it is usually used to treat cancer. It is usually performed by a multidisciplinary team of radiation oncologists, and medical physicists to operate and maintain highly sophisticated, highly precise and complex instruments, like medical Linacs and the Gamma Knife. The highly precise irradiation of targets within the brain and spine is planned using information from medical images that are obtained via computed tomography, magnetic resonance, and angiography, as shown Figure (13b).

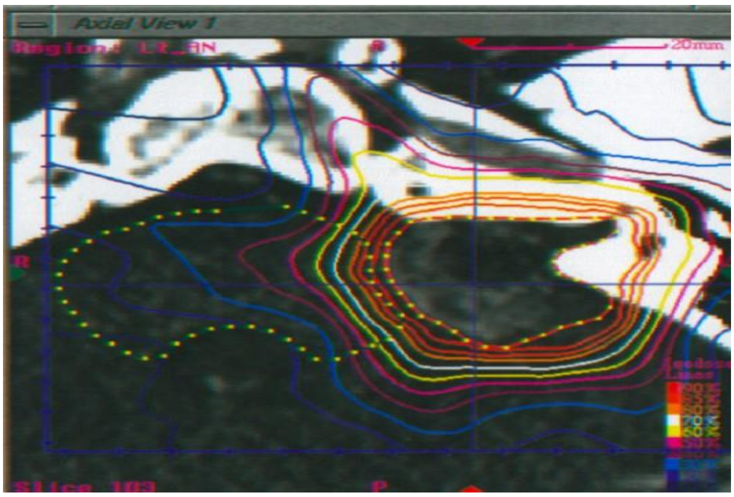

Figure (13b): Planning CT scan with IV contrast in a patient

3. Laser Applications

3.1: Photo-coagulation and Selective Absorption:

When a laser beam projected to a human tissue, five phenomena should be occurs for a laser beam such as reflection, transmission, scattering and absorption as shown in Figure (14a). Therefore, laser light transfers energy of photons to human tissue due to absorption. A slow heating of muscle and other tissues is obtained like a cooking of meat in everyday life. The heating induced the destabilization of the proteins and enzymes. Like egg whites coagulate when cooked, red meat turns gray because coagulation during cooking. Laser heating of tissues between (50 ^{o}C - 100^{o}C), induced disordering of proteins and other bio-molecules, this process is called photocoagulation.

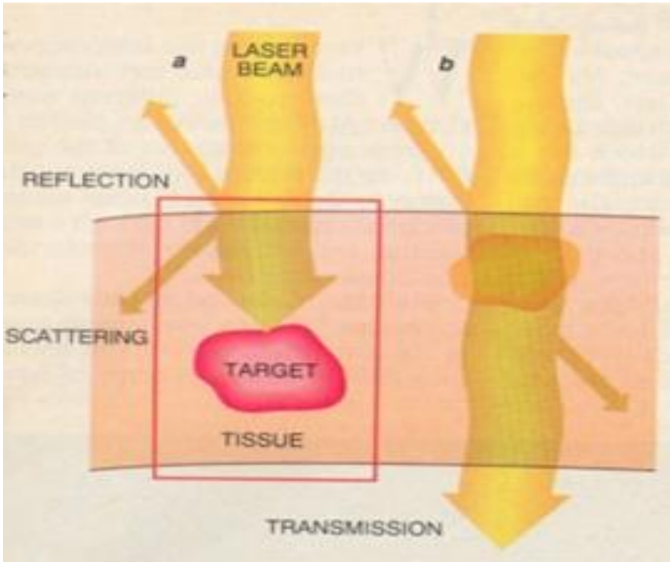

Figure (14a): Reflection, transmission and scattering of laser in tissue

Consequence of photo-coagulation tissues occurs during laser surgery as follows; the tissues become cooked because they shrink in mass because water is expelled. The heated regions change its color and lose its mechanical integrity. The cells in the photocoagulated region die and a region of dead tissue called photocoagulation burn develops which can be removed or pulls out. A blood vessel subjected to photocoagulation develops a pinched point due to shrinkage of proteins in the vessel’s wall. The coagulation restriction helps seal off the flow, while damaged cells initiate clotting. Laser photo-coagulation can be used for lot of medical application such as destroy tumors, treating various eye conditions like retinal disorders caused by diabetes and hemostatic laser surgery due to its ability to stop bleeding during surgery.

Selective absorption occurs when a given color of light is strongly absorbed by one type of tissue, while transmitted by another as shown in Figure (14b,14c). The main absorbing components of tissues are:

• Oxy-hemoglobin (in blood) due to the blood's oxygen carrying protein, absorption of UV and blue and green light.

• Melanin (a pigment in skin, hair, moles, etc) due to absorption in visible and near IR light (400nm – 1000nm).

• Water (in tissues) due to transparent to visible light but strong absorption of UV light below 300nm and IR over 1300nm.

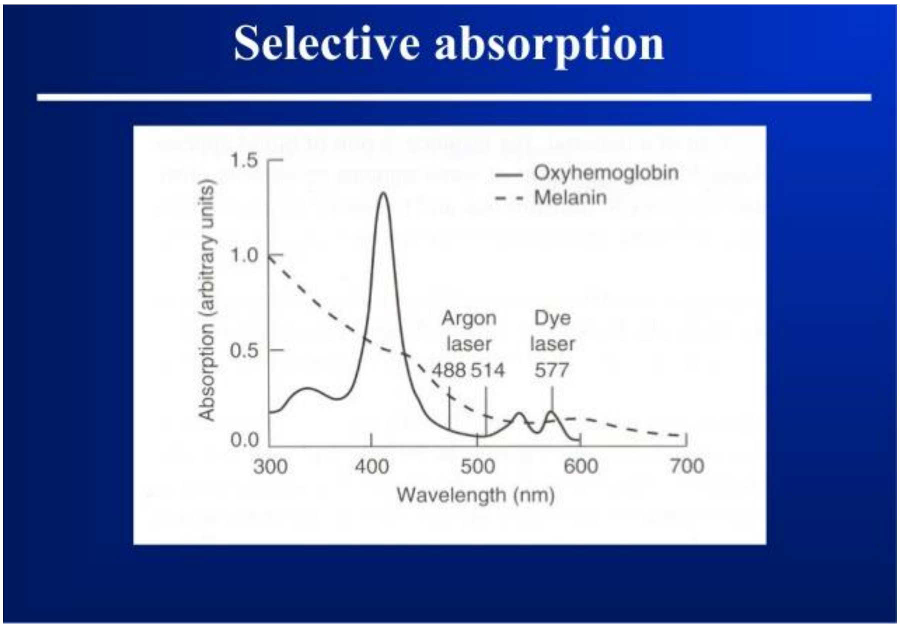

Figure (14b): Selective absorption in Oxy-hemoglobin and Melanin in tissue

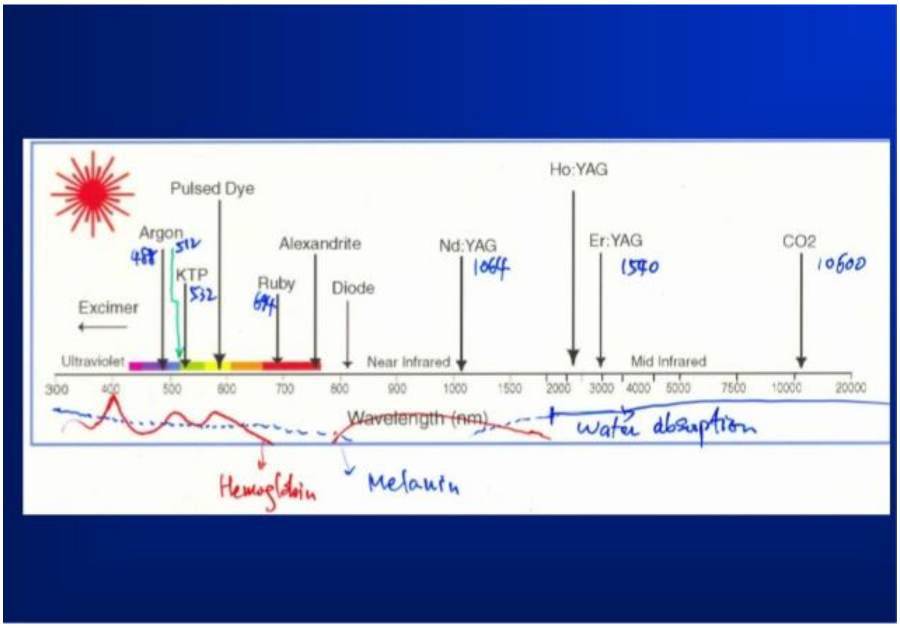

Figure (14c): Selective absorption of laser with human tissue

3.2: Photo-vaporization:

With very high power densities, instead of cooking, lasers will quickly heat the tissues to above 100 ^{o}C, water within the tissues boils and evaporates. Since 70% of the body tissue is water, the boiling change the tissue into a gas. This phenomenon is called photo-vaporization. Photo- vaporization results in complete removal of the tissue, making possible for hemostatic incision, complete removal of thin layer of tissue, and kin rejuvenation and resurfacing.

The conditions for photo-vaporization are:

• The tissue must be heated quickly to above the boiling point of the water, this require very high intensity lasers,

• A very short exposure time TE, so no time for heat to flow away while delivering enough energy, highly spatial coherence (directionality) of lasers over other light sources is responsible for providing higher intensities. Intensity requirement are for low (< 10 W/cm^2), for moderate (10 – 100 W/cm^2) and for High (>100 W/cm^2).

3.3: Photo-chemical Ablation:

When using high power lasers of ultraviolet wavelength, some chemical bonds can be broken without causing local heating; this process is called photo-chemical ablation. The photo-chemical ablation results in clean-cut incision. The thermal component is relatively small and the zone of thermal interaction is limited in the incision wall.

3.4: Laser Surgery:

Laser surgery is surgery using a laser (instead of a scalpel) to cut tissue. Examples include the use of a laser scalpel in otherwise conventional surgery, and soft-tissue laser surgery, in which the laser beam vaporizes soft tissue with high water content. Laser resurfacing is a technique in which covalent bonds of a material are dissolved by a laser, a technique invented by aesthetic plastic surgeon Thomas L Roberts, using CO_2 lasers in the 1990s. Laser surgery is commonly used on the eye. Techniques used include LASIK, which is used to correct near and far-sightedness in vision, and photorefractive keratectomy, a procedure which permanently reshapes the cornea using a laser to remove a small amount of tissue.

3.5: Laser in Dentistry:

Lasers have been used in dentistry since 1994 to treat a number of dental problems. These lasers are different from the cold lasers used in phototherapy for the relief of headaches, pain, and inflammation, as shown in Figure (15).

Still, some dentists are using lasers to treat the following:

•***Tooth decay*** in which lasers are used to remove decay within a tooth and prepare the surrounding enamel for receipt of the filling.

• ***Gum disease*** in which lasers are used to reshape gums and remove bacteria during root canal procedures.

• ***Biopsy or lesion removal*** in which lasers can be used to remove a small piece of tissue (called a biopsy) so that it can be examined for cancer. Lasers are also used to remove lesions in the mouth and relieve the pain of canker sores.

• ***Teeth whitening*** in which lasers are used to speed up in-office teeth whitening procedures. A peroxide bleaching solution, applied to the tooth surface, is "activated" by laser energy, which speeds up of the whitening process.

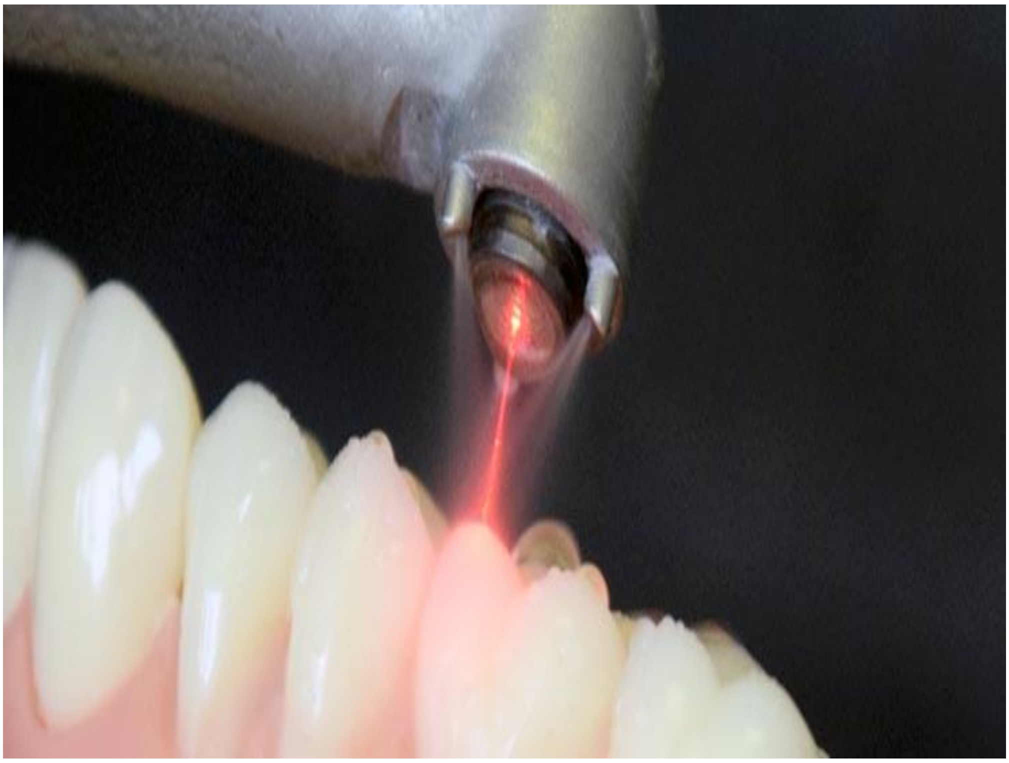

Figure (15): Application of laser in dentistry.

3.6: Lasers in Ophthalmology:

For retina operation, visible laser can be used. Visible light is transparent to the cornea and crystalline lens, and can be focused with eye’s lens on the retina. The most popular visible laser is the green argon laser, and usually used.

3.7: Laser and Hemoglobin:

Yellow laser removal of port-wine stain by the presence of hemoglobin in the blood vessels as shown in Figure (16). Laser skin rejuvenation in which IR lasers are used to remove extremely thin layer of skin (< 0.1 mm). In the absence of pigment in general, they take advantage of the presence of water in the skin to provide an ability to remove skin and body tissue.

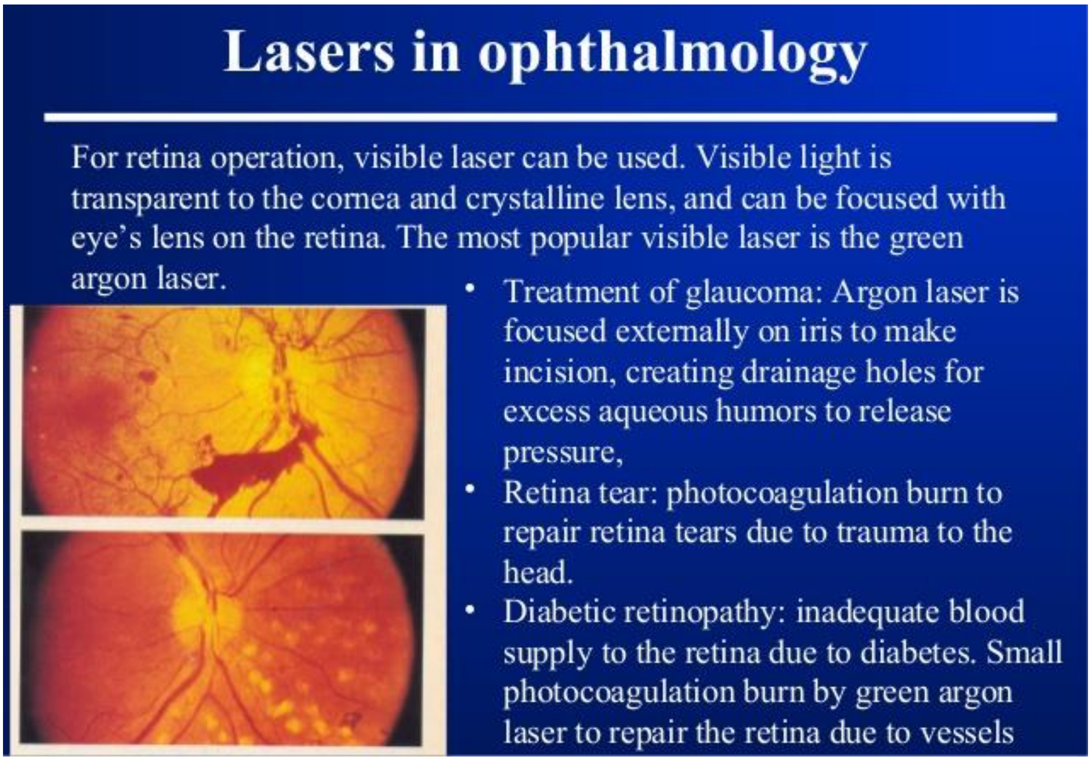

Figure (16): Laser in ophthalmology

3.8: Laser and Hemoglobin:

Laser removal of port-wine stain in which yellow laser is absorbed by the presence of hemoglobin in blood vessels as shown in Figure (17). Laser skin rejuvenation in which IR lasers are used to remove extremely thin layer of skin (< 0.1 mm). In the absence of pigment in general, they take advantage of the presence of water in the skin to provide an ability to remove skin and body tissue as shown in Figure (17).

Figure (17): Laser in ophthalmology

4. Side Effects of Radiotherapy:

Radiotherapy aims to kill or damage cancer cells, but inevitably some normal cells will be damaged, which can lead to some side effects. Normal cells are usually able to recover better than cancer cells and side-effects are often temporary (although some are permanent). Also, even with the same treatment schedule, different people can react differently and some people develop more severe side-effects than others. The most common side-effect that people experience after radiotherapy is tiredness.

This can even start after your radiotherapy has been completed. As mentioned, some people develop a local skin reaction days or weeks after having external radiotherapy. Your skin can become red, sore or itchy, and sometimes painful.

The possible side-effects depend on the area of the body being treated. For example: radiotherapy to a tumour in the the neck may cause a sore mouth; radiotherapy to the tummy (abdomen) may cause diarrhoea; etc. It is beyond the scope of this leaflet to discuss all the possible side-effects which may occur from radiotherapy to every part of the body. Your specialist will normally discuss with you the possible side-effects that may occur following radiotherapy to the particular area of your body being treated.

Radiation therapy can cause both early (acute) and late (chronic) side effects. Acute side effects occur during treatment, and chronic side effects occur months or even years after treatment ends. The side effects that develop depend on the area of the body being treated, the dose given per day, the total dose given, the patient's general medical condition, and other treatments given at the same time. Acute radiation side effects are caused by damage to rapidly dividing normal cells in the area being treated.

These effects include skin irritation or damage at regions exposed to the radiation beams. Examples include damage to the salivary glands or hair loss when the head or neck area is treated, or urinary problems when the lower abdomen is treated. Late side effects of radiation therapy may or may not occur. Depending on the area of the body treated, late side effects can include Fibrosis (the replacement of normal tissue with scar tissue, leading to restricted movement of the affected area); Damage to the bowels, causing diarrhea and bleeding; Memory loss; Infertility (inability to have a child); Rarely, a second cancer caused by radiation exposure.

To avoid the side effects, the use of carbon ion beams in radiation therapy is being investigated by researchers, but, at this time, the use of these beams remains experimental.

Carbon ion beams are available at only a few medical centers around the world. Researchers hope that carbon ion beams may be effective in treating some tumors that are resistant to traditional radiation therapy.

5. Medical Imaging:

5.1: Radiography Imaging:

Radiography is concerning imaging using x-rays coming from outside the body. A radiograph is an x-ray image obtained by placing a part of the patient in the front of an x-ray detector and then illuminating it with a short x-ray pulse of 0.5 sec time duration as shown in Figure (18).

Figure (18): Radiography machine

A large fraction of x-rays interacts in the patient, and some of the x-rays pass through the patient and reach the detector, where a radiographic image is formed. It is approved that bones in the patient contain much calcium, which due to its relatively high atomic number absorbs x-rays efficiency. This reduces the amount of x-rays reaching the detector in the shadow of the bones, making them clearly visible on the radiograph as shown in Figure (19a), which shows the x-ray radiography of a chest female and demonstrating a hiatus hernia.

Some notable examples are the very common chest x-ray, which can be used to identify lung diseases such as pneumonia, lung cancer, gallstones or kidney stones which are often visible. Radiographs are useful in the detection of pathology of the skeletal system as well as for detecting some disease processes in soft tissue, see figure (19b), which shows an arm radiograph, demonstrating broken ulna and radius with implanted internal fixation.

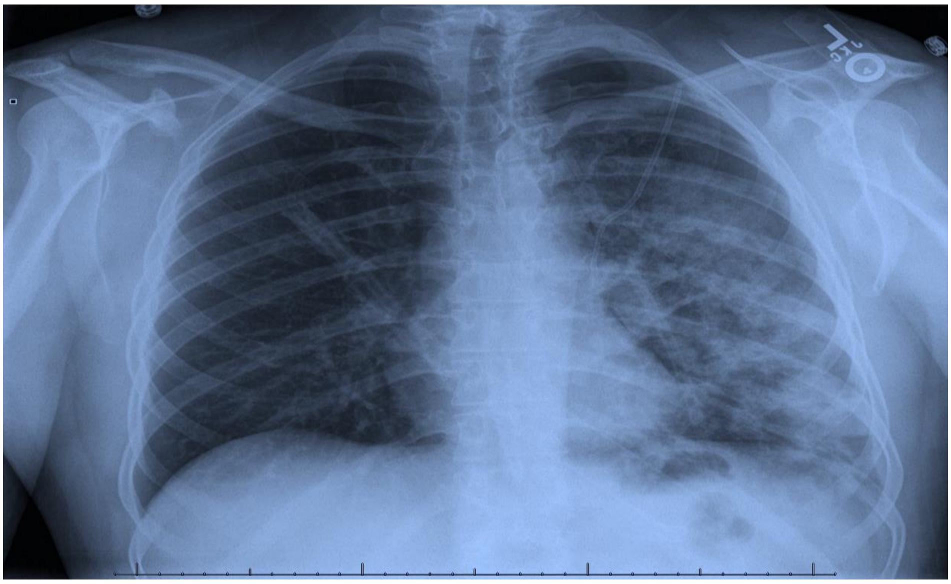

Figure (19a): A chest x-ray radiography of a female demonstrating a hiatus hernia

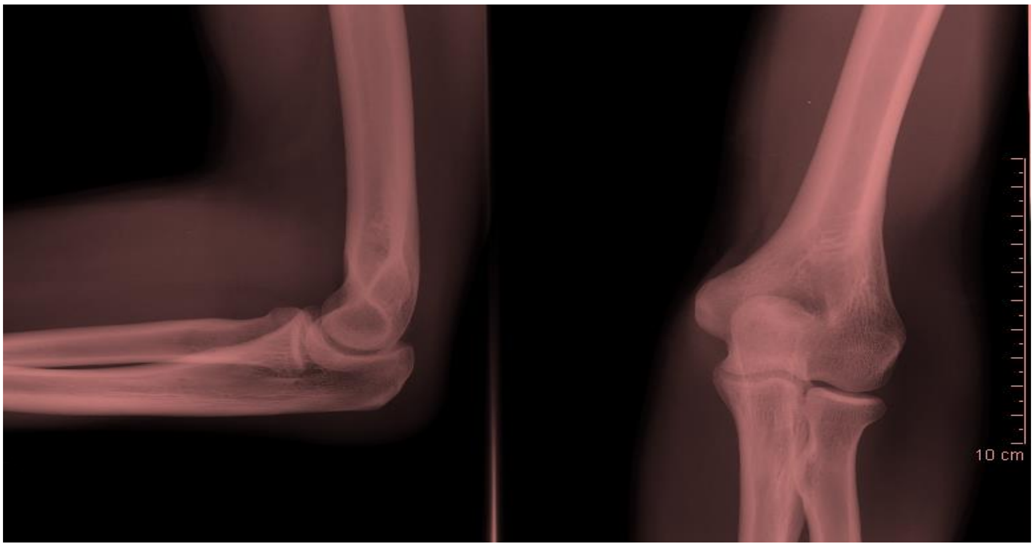

Figure (19b): An arm radiograph, demonstrating broken ulna and radius with implanted internal fixation

5.2: Computed Tomography (CT) Imaging:

CT: is a transmission technique that results in images of individual slabs of tissue. CT is usually done by passing x-rays through the patient at a large number of angles by rotating the x-rays tube around the body. One or more linear detector arrays, opposite to the x-ray source, collect the transmission projection data. The numerous data points collected in this way are synthesized by a computer into a tomography image of the patient as shown is Figure (20a).

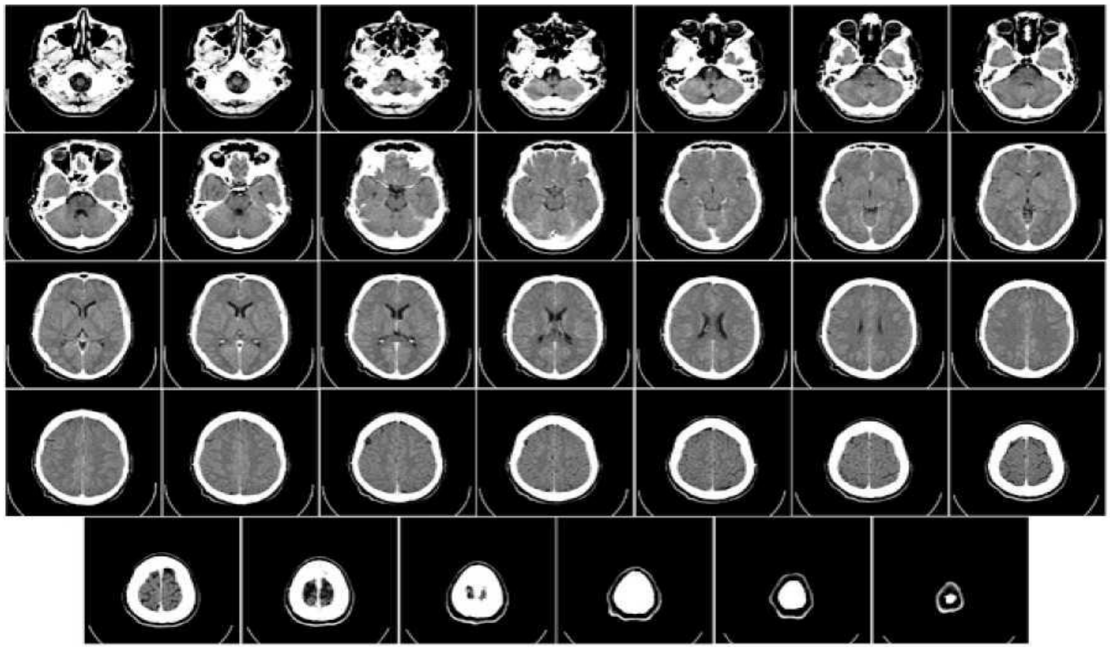

Figure (20a) :Head CT Scan tomography

CT scans are often used in treatment planning for radiation therapy. During CT scanning, pictures of the inside of the patient are created by a computer linked to an x-ray machine. CT scans are often used in treatment planning for radiation therapy. During simulation and daily treatments, it is necessary to ensure that the patient will be exactly at the same position every day relative to the machine delivering the treatment or doing the imaging. After simulation, the radiation oncologist then determines the exact area that will be treated, the total radiation dose that will be delivered to the tumor, how much dose will be allowed for the normal tissues around the tumor, and the safest angles (paths) for radiation delivery. Topographic image is able to display the anatomy in a slab of tissue in the absence of the overlying or underlying structures:

I- It reduced the need of exploratory surgery.

II- It can obtain 5mm - thick tomographic images along 30 cm length of the patient (60 images in 10 seconds). Head- to- toe imaging in as little as 30 sec.

III- It provides high-contrast sensitivity for soft tissue, bone and air interfaces without superimposition of anatomy.

IV- It reveals the presence of cancer, ruptured discs, etc as shown in Figure (20b).

Figure (20b): CT scan showing bilateral renal cell carcinoma

5.3: Fluoroscopy Imaging:

Fluoroscopy is an imaging technique commonly used by physicians or radiation therapists to obtain real-time moving images of the internal structures of a patient through the use of a fluoroscope. In its simplest form, a fluoroscope consists of an x-ray source and fluorescent screen between which a patient is placed. However, modern fluoroscopes couple the screen to an x-ray image intensifier and CCD video camera allowing the images to be recorded and played on a monitor as shown in Figure (21a).

Figure (21a): Mechanism of fluoroscopy machine

Fluoroscopy produces real-time images of internal structures of the body in a similar fashion to radiography, but employs a constant input of x-rays, at a lower dose rate. Contrast media, such as barium, iodine, and air are used to visualize internal organs as they work.

Fluoroscopy is also used in image-guided procedures when constant feedback during a procedure is required. An image receptor is required to convert the radiation into an image after it has passed through the area of interest, as shown in Figure (21b). Because fluoroscopy involves the use of x-rays, a form of ionizing radiation, fluoroscopic procedures pose a potential for increasing the patient's risk of radiation-induced cancer. Radiation doses to the patient depend greatly on the size of the patient as well as length of the procedure.

Exposure times vary depending on the procedure being performed, but procedure times up to 75 minutes have been documented. Because of the long length of procedures, in addition to the cancer risk and other stochastic radiation effects, deterministic radiation effects have also been observed ranging from mild erythema, equivalent of a sun burn, to more serious burns, as shown in Figure (21c).

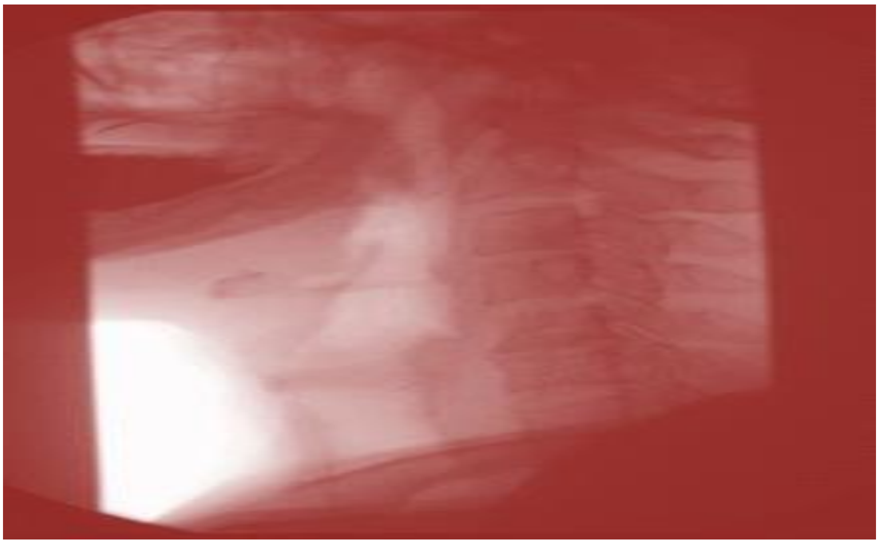

Figure (21b): A barium swallow exam taken via fluoroscopy

Figure (21c): Fluoroscopy burn from long exposure

5.4: Magnetic Resonance imaging (MRI):

A magnetic resonance imaging (MRI) uses powerful magnets, magnetic fields are about 10000 to 6000 times stronger than the earth`s magnetic field, to polarize and excite hydrogen nuclei (single proton) in water molecules of the human tissue, producing a detectable signal which is spatially encoded, resulting in images of the body. Usually $1mm^3$ of tissue contains about 10^{18} protons.

The proton has a magnetic moment (tendency to align with a magnetic field J/T), and when placed in a magnetic field of 1.5 T, the proton will preferentially absorb radio wave energy at the resonance frequency of 63 MHz. In MRI, the patient is placed in the magnetic field, and a pulse of radio waves is generated by antennas (coils) positioned around the patient as shown Figure (22a).

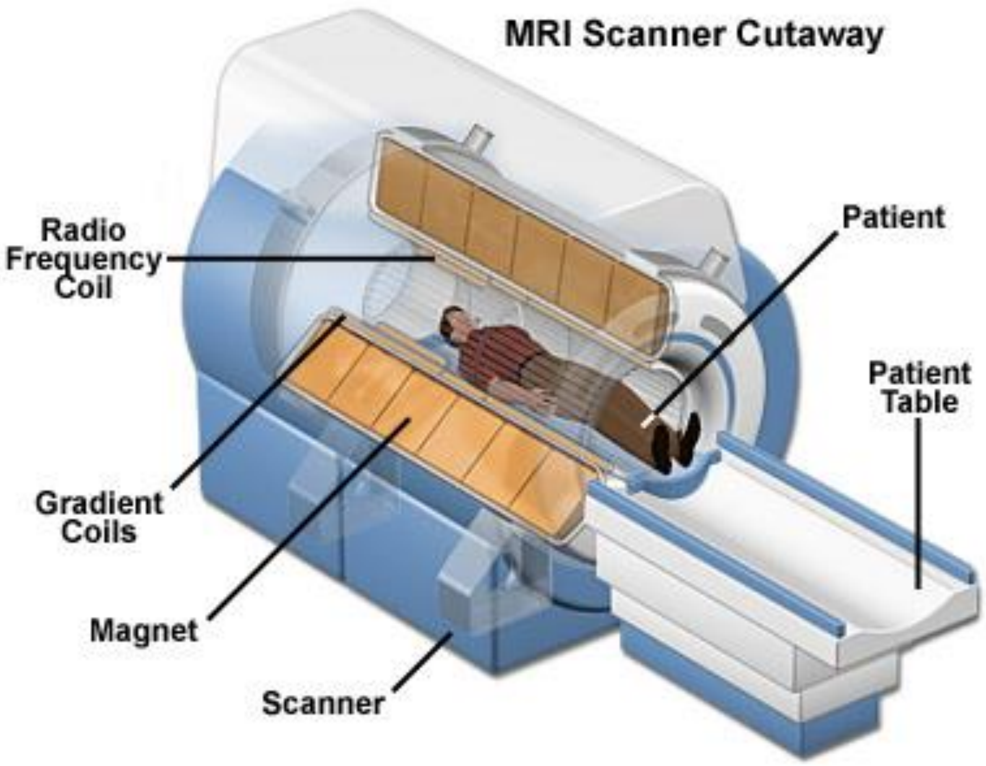

Figure (22a): Mechanism of MRI

The protons in the patient absorb the radio waves, and subsequently reemit this radio wave energy after a period of time that depends on the variation of localized magnetic field of the surrounding tissue. The particular frequency of resonance is called the Lamoure frequency and it is based on based on the particular tissue being imaged and the strength of the main magnetic field. MRI produces a set of tomographic slices through the patient, where each point in the image depends on the micro magnetic properties of the corresponding tissue at that point.

Because different types of tissue such as far, while, and gray matter in the brain, cerebral spinal fluid, and cancer all have different local magnetic properties, images made using MRI demonstrate high sensitivity to anatomic variation sand therefore are high in contrast. MRI has demonstrated exceptional utility in neurological imaging (head and spine) as shown in Figure (22b), and for musculoskeletal applications such as imaging the knee after athletic injury.

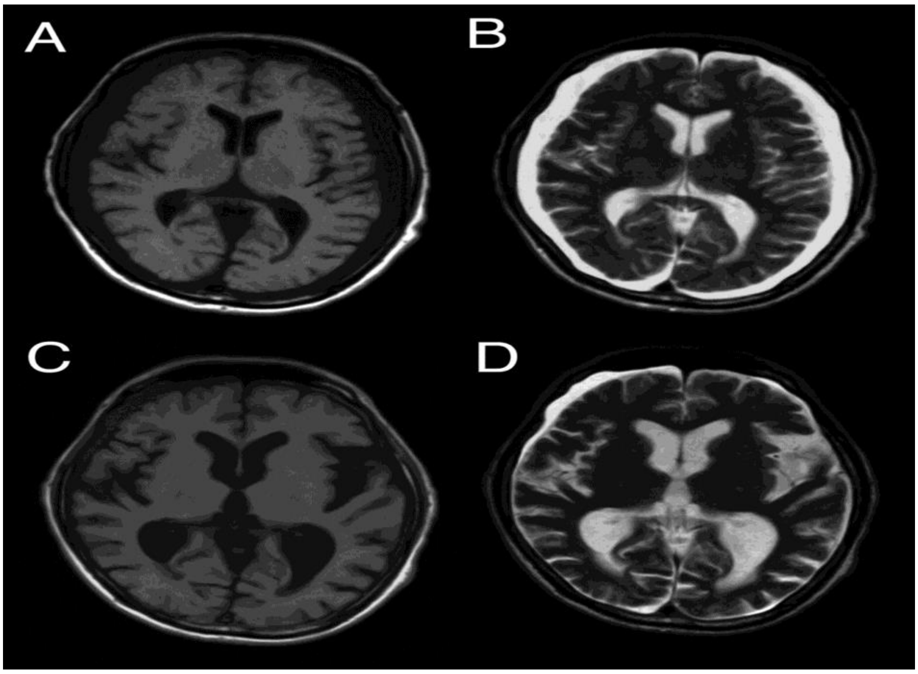

Figure (22b): MRI for the brain of the human body

5.5: Nuclear Magnetic Imaging (NMI):

NMI is a type of Systemic that Refers to the branch of radiology in which a chemical or compound containing a radioactive isotope is given to the patient orally, by injection, or by inhalation. The radioactive compound distributes its self-according to the physiologic status of the patient.

A radiation detector is used to make projection images from the x-ray or gamma ray emitted during radioactive decay of the agent. Nuclear medicine produces emission images (opposite to transmission images), because the radioisotopes emit their energy from the inside of the patient. Nuclear medicine imaging is a functional image; it gives information not only about the anatomy of patient, but also about a physiologic condition in the patient. The examples of NMI are:

Thallium tends to concentrate in normal heart muscle but does not concentrate in areas that are infracted (an area of tissue that is dying or dead as a result of obstruction of local blood supply) or ischemic (A decrease in the blood supply to a bodily organ, tissue, or part caused by constriction or obstruction of the blood vessels). These areas appear as cold spots on a nuclear medicine image and are indicative to the functional status of the heart as shown in Figure (23.a).

Thyroid tissue has a great affinity to Iodine, by administration of radioactive Iodine, the thyroid can be imaged. If thyroid cancer has metastasized in the patient, then hot spots indicating their location will appear in nuclear medicine images as shown in Figure (23.b).

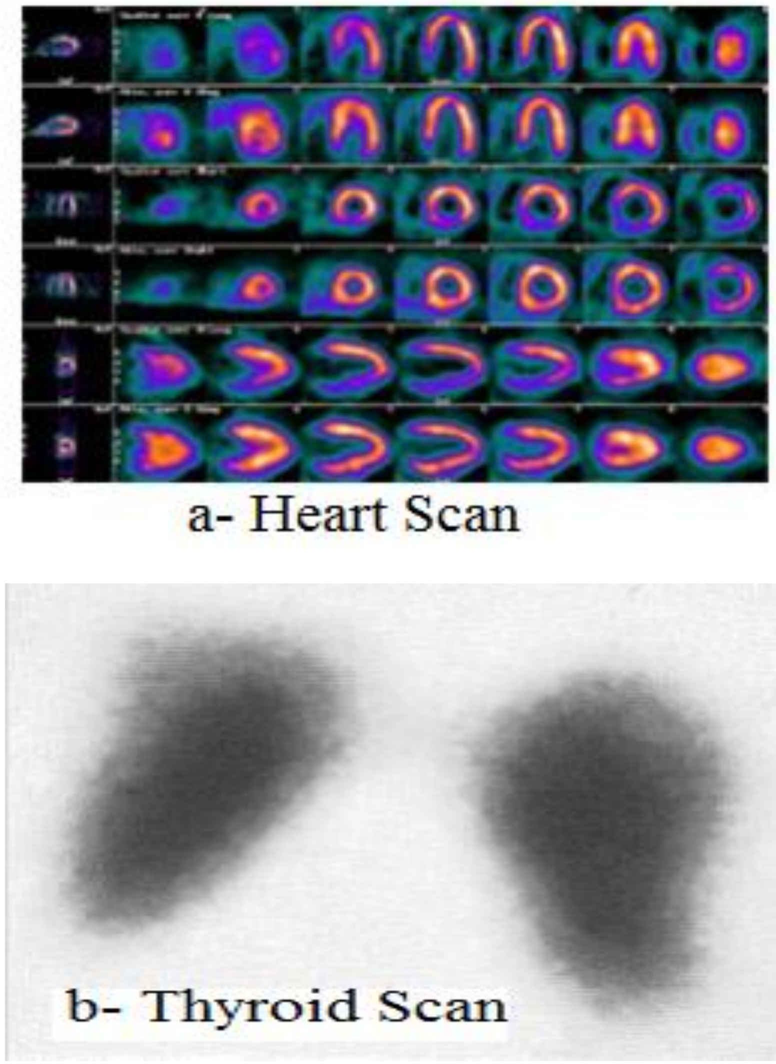

Figure (23): NMI for the heart and thyroid of the human body

Conclusion

The physical concepts, applications and side effects of radiotherapy such as x rays, γ rays and laser on the human tissue are reported. Furthermore, the side effects of those radiations on the normal tissues of the human body are presented. On the other hand, the different methods of medical imaging are also recorded.

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