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Review Article

Ultraviolet Radiation: Health Risks and Benefits

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Abstract

Recent studies have shown that the incidence of melanoma skin cancer and deaths has been increased globally, where the rate of melanoma skin cancer deaths reaches 75% among the white-skinned population. However, Ultraviolet (UV) light exposure is the only known risk factor for developing melanoma skin cancer. In this study, the main concepts about the electromagnetic spectrum are introduced. The visible light bands and wavelengths are presented. The energy classifications of ultraviolet radiation are discussed. Sources of ultraviolet radiation are discussed. The optics of the skin and the interaction mechanisms of light with human skin are discussed. The relationship between ultraviolet radiation and skin cancer is discussed. And the applications and beneficial effects of ultraviolet radiation in many desplines are summarized. However, the main objectives of this study are to gain and provide knowledge about solar radiation exposure risks, benefits, and to identify factors influencing practices that increase the risk for developing melanoma.

Keywords: Skin cancer, visible light bands, UVR sources, forensic investigations, cataracts, human health protection.

INTRODUCTION

Ultraviolet radiation (UVR) interaction with human skin is so important in a variety of desplines such as medicine, (food-cosmetic) industry, biology, physics, research and forensic investigations. However, exposure to (UVR) occurs from both natural and artificial sources. The known effects of (UVR) on man can be detrimental or beneficial depending on the safety measures that have been taken for protection. Harmful effects may involve primarily the skin and the eye. An eye overexposure to (UVR) contributes to the formation of cataracts. On skin it produce (sunburn), which if severe enough, may result in blistering and destruction of skin surface. Therefore, the main objectives of this study are to gain and provide knowledge about solar radiation exposure risks, benefits, and to identify factors influencing practices that increase the risk for developing melanoma. Understanding the effects of the solar (UVR) and artificial radiation sources is vital for human health protection.

The Electromagnetic Spectrum

The electromagnetic spectrum comprises the spectrum of energy ranging from very long radio waves to very short gamma rays. It represents the entire continuous range of electromagnetic radiation extending from radio waves to gamma rays according to wavelength, frequency and photon energies. The human eye can detect and sense only a small portion of this spectrum called visible light. Figure1 shows the bands of the electromagnetic spectrum by common names. It can be stated that there is no sharp cut between bands but the differences between bands are rather gradual [1].

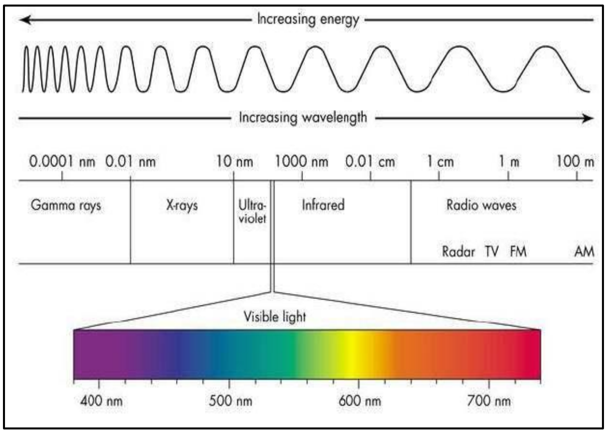

Figure 1: Bands of the electromagnetic spectrum by common names.

An electromagnetic wave consists of electric field components and magnetic field components perpendicular to each other and moving with speed of light (see Figure 2) [1].

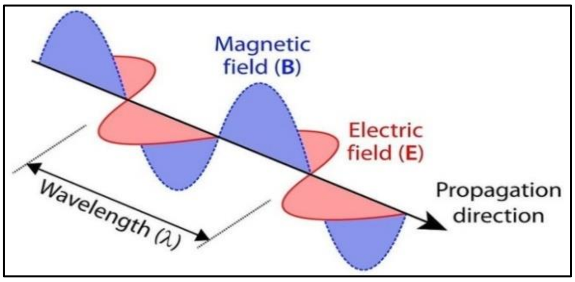

Figure 2: The electromagnetic wave and its components [2]

However, in this study, emphasis will be placed on the optical properties of visible light. Light is the small part of the electromagnetic spectrum of various wavelengths. The range of wavelengths starts from the infrared portion to the ultraviolet portion.

Visible Light Bands and Wavelengths:

Visible light occurs in the middle of those two extremes. Visible light is the small part of the electromagnetic spectrum that we can see. As shown in Figure 3, colors exist at different wavelengths from lowest energy to highest energy: red, orange, yellow, green, blue, indigo, and violet. Light waves can be refracted, reflected, absorbed, or transmitted through various materials.

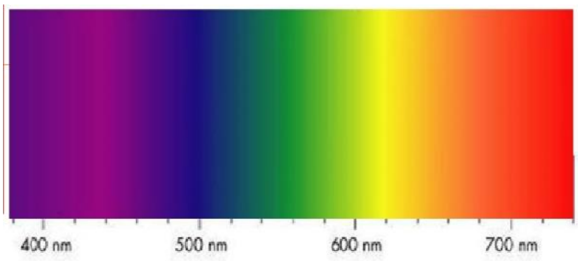

Figure 3: The visible light spectrum [3]

Ultraviolet Radiation

Exposure to ultraviolet radiation (UVR) occurs from both natural and artificial sources. However, the sun is the principal natural source. The known effects of UVR on man may be beneficial or detrimental, depending on a number of circumstances. Artificial UVR sources are widely used in industry and, because of the germicidal properties of certain portions of the UVR spectrum; they are also used in hospitals, biological laboratories, and schools. UVR is extensively used for therapeutic purposes, as in the prevention of vitamin D deficiency, the treatment of skin diseases, and for cosmetic purposes. Artificial UVR sources are available as consumer products. The migration of people between areas of different UVR exposure may give rise to unforeseen exposures [4].

UVR is classified into UV-A (320-400 nm)., UV-B (280-320 nm), and UV-C (200-280 nm) regions. Wavelengths in the UV-C region cause unpleasant, but usually not serious effects on the skin and eye. UV-C, from the sun, is virtually completely screened out by the Earth's atmosphere, and is thus a negligible source of adverse effects on the skin, eye and human health [4].

UV-B is extremely detrimental to living organisms and is responsible for erythema (sunburn) and associated with an increased risk of skin cancer. However, living organisms are usually protected from excessive solar UV-B radiation by feathers, fur, or pigments that absorb the radiation before it reaches sensitive physiological targets. On the other hand, solar UV-B is crucial in the synthesis of vitamin D, which some recent studies suggest may potentially reduce risk of colon, prostate and breast cancers [4].

The biological effects of UV-A radiation are less known. However, UV-A contributes to skin aging and has more recently been implicated, along with UV-B, in the development of skin cancers in animals and in immunosuppression in humans. It can augment the biological effects of UV-B and doses of UV-A, in the presence of certain chemical agents, results in injury to tissues (photo toxicity, photo allergy, enhancement of photo carcinogenesis). Although the sun is the main source of UV-A exposure, use of UV-A emitting lamps in sunbeds for recreational tanning has raised concern about artificial sources of human exposure [4, 5]. People can also be exposed to man-made sources of UV rays. These include:

- **Phototherapy (UV therapy):** Some skin problems (such as psoriasis) are helped by treatment with UV light. For a treatment known as PUVA, a drug called a PSORALEN (P) is given first. The drug collects in the skin and makes it temporarily more sensitive to long-wave ultra- violet light (UVA). Then the patient is treated with UVA radiation. Another treatment option is the use of UVB alone without a drug (see Figure 4) [6].

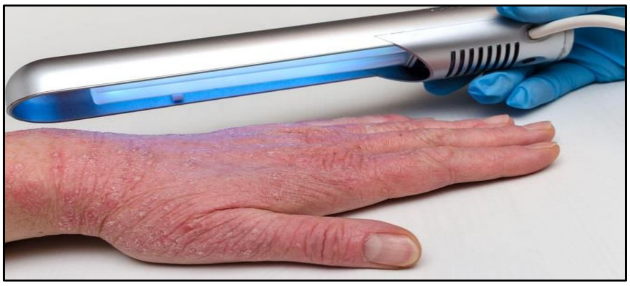

Figure 4: Phototherapy, benefits and risks

● **Black-light lamps**: These lamps use bulbs that give off UV rays (mostly UVA). The bulb also gives off some visible light, but it has a filter that blocks most of that out while letting the UV rays through. These bulbs have a purple glow and are used to view fluorescent material. Bug-zapping insect traps also use "black light" that gives off some UV rays, but the bulbs use a different filter that causes them to glow blue (see Figure 5) [6].

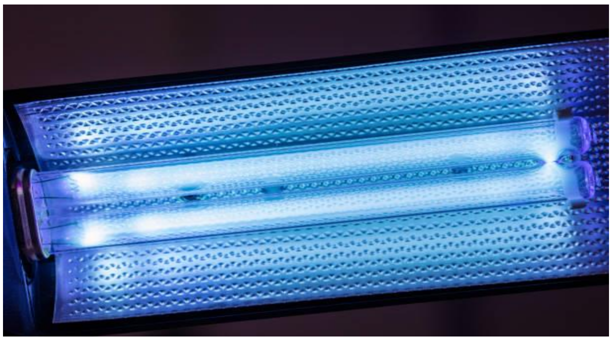

Figure 5: Black-light lamps

● **Mercury-vapor lamps**: are actually made up of 2 bulbs: an inner bulb that emits light and UV rays, and an outer bulb that filters out the UV. Mercury-vapor lamps can be used to light large public areas such as streets or gyms. They do not expose people to UV rays if they are working properly. UV exposure can only occur if the outer bulb is broken. For safety purposes some mercury-vapor lamps are designed to turn themselves off when the outer bulb breaks. The ones that don't have this feature are only supposed to be installed behind a protective layer or in areas where people wouldn't be exposed if part of the bulb breaks (see figure6) [6].

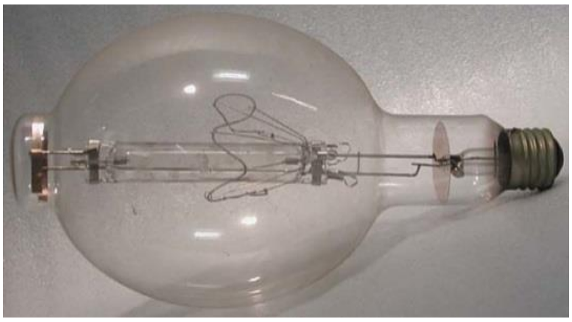

Figure 6: Mercury-vapor lamps

● **Xenon and xenon-mercury arc lamps:** are highly specialized type of gas discharge lamps that produces a bright white light to simulate sunlight. These lamps are used as sources of light and UV rays for many applications, such as using high-intensity ultraviolet light UV to cure or dry inks, coatings or adhesives coatings, disinfection, to simulate sunlight and to test solar panels. Most of these are mainly of concern in terms of workplace UV exposure (see Figure 7) [6].

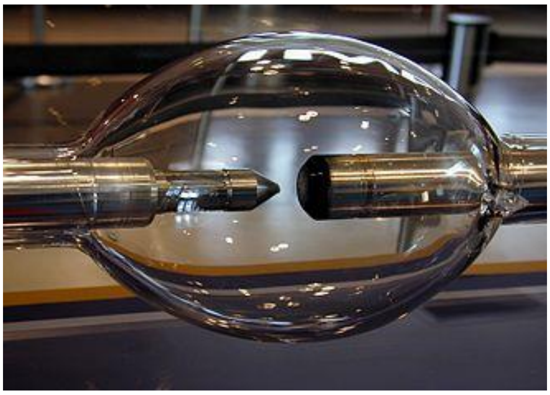

Figure 7: And xenon-mercury arc lamp

Optics of the skin

Human health can be strongly influenced by exposure to solar radiation. Interactions relevant for health take place mainly in the skin. In this context the optics of human skin is of the utmost importance. Reflection, scattering and absorption are the optical properties affecting the nature of these interactions. Skin is a multilayered and inhomogeneous organ. Figure 8 shows the biological characteristics of its main constituents, and how they affect the propagation and absorption of light [7].

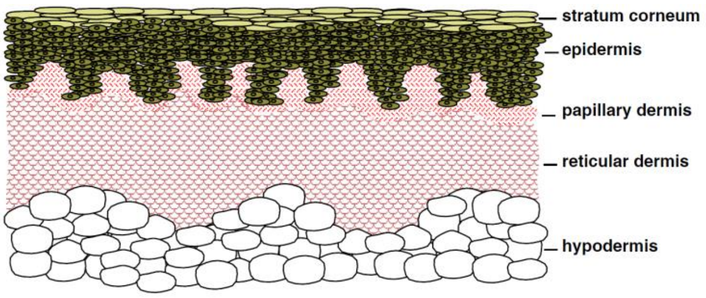

Figure 8: Schematic cross-section of human skin tissues and the subcutaneous fat tissue (hypodermis)

The first and outermost section of human skin is the stratum corneum (الطبقة القرنية), which is a stratified structure approximately 0.01-0.02 mm thick. This part is considered as a part of another tissue, namely the epidermis. The stratum corneum is composed mainly of dead cells. Light absorption is low in this tissue; with the amount of transmitted light being relatively uniform in the visible region of the light spectrum. The epidermis is a 0.027-0.15mm thick structure composed of four layers (stratum basale, stratum spinosum, stratum granulosum and stratum lucidum). The epidermis absorbs light [7].

The dermis is a 0.6-3mm thick structure and absorbs light. It is divided into two layers: the papillary dermis and the reticular dermis. These layers are primarily composed of dense, irregular connective tissue with nerves and blood vessels (smaller ones in the papillary, and larger ones in the reticular dermis) [7].

The hypodermis is a subcutaneous adipose tissue characterized by a negligible absorption of light in the visible region of the spectrum. It is usually not considered part of the skin, and its size varies considerably throughout the body. It can be up to 3cm thick in the abdomen and absent in the eye lids. The hypodermis presents significant deposits of white fat, whose cells are grouped together forming clusters. Due to the presence of these white fat deposits, most of the visible light that reaches this tissue is reflected back to the upper layers [7].

Interaction mechanisms of light with human skin:

When light propagates in human skin, there is a series of complicated interactions with in the skin. The absorption is the main event during light propagation in skin. The absorption can be considered as how the electrons (subatomic particle) bound in the atoms take up the energy of photons. From the perspective of atomic physics, the atoms and molecules that make up matter contain electrons. These electrons have energy states that can be described by an atomic orbital. Each orbital has its unique state such as energy, and these orbitals are discrete. Electrons can also be transferred from one orbital to another orbital by emitting or absorbing photons with energy matching the energy difference between electron orbitals [8].

When light with the same specific frequencies enters into medium, these electrons will absorb the energy of light and jump from ground state to excited state. Electrons at excited state are unstable and will decay back to ground state with the emission of electromagnetic energy [8]. Figure 9: summarizes the mechanisms of light interaction with human skin.

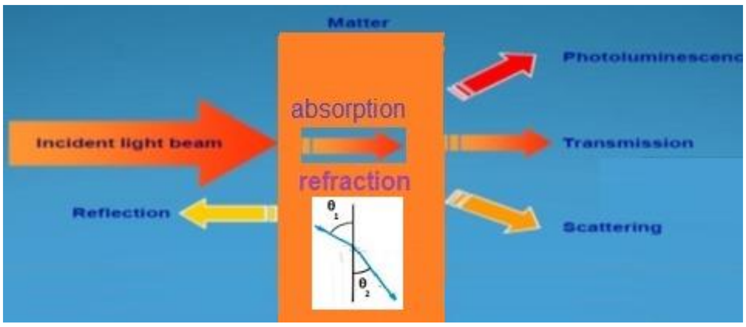

Figure 9: The mechanisms of light interaction with human skin

Absorption: When a light beam is incident on a material surface, part of the incident beam is absorbed through the material. **Transmission***:* When a light beam is impinged on a material surface, fraction portion of the incident beam is transmitted through the material. **Scattering:** Rayleigh scattering and Compton scattering (inelastic scattering). Rayleigh scattering: where a photon interacts with the electrons orbiting an atom and is scattered **w**ithout any change in photon energy (elastic scattering). Compton scattering: where a photon transfers some of its energy to the atomic electron. The transferred energy should exceed the electron binding energy. Photoluminescence: is the emission of light which is caused by the irradiation of a substance with other light. Figure3: summarizes the mechanisms of light interaction with substances. **Refraction***:* is the change in direction of the incident light at an angle to a boundary (interface) between two transparent media with different densities. **Reflection**: when light is incident on an interface between media that differ in refractive index, all of the light will be reflected back into the medium from where it travels. The Reflected light comes out at same angle as incident beam, but on other side of normal [1].

The relationship between ultraviolet radiation and skin cancer

UVR radiation is classified as a ―complete carcinogen‖because it is both a mutagen and a non-specific damaging agent and has properties of both a tumor initiator and a tumor promoter. In environmental abundance, UV is the most important modifiable risk factor for skin cancer and many other environmentally-influenced skin disorders. However, UV also benefits human health by mediating natural synthesis of vitamin D and endorphins in the skin, therefore UV has complex and mixed effects on human health [9]

Skin cancer is the most common type of cancer in many parts of the world. Skin cancers are mainly divided into melanoma, and non-melanoma skin cancers. However, Melanoma (estimated that 132,000 cases occur worldwide each year) is responsible for most of the cancer related mortalities. The non-melanoma (estimated that 2–3 million cases occur worldwide each year) can result in significant disfigurement, leading to adverse physical and psychological consequences for the affected patients [10].

Sunlight is a continuous spectrum of electromagnetic radiation that is divided into three major spectrums of wavelength: ultraviolet, visible and infrared. However, the UV range is the most significant spectrum of sunlight that causes photo aging and skin cancer. UVR is subdivided into ultraviolet [UVA (315–400 nm)], ultraviolet [UVB (280– 315 nm)] and ultraviolet [UVC (100–280 nm)]. Approximately 90–99% of the solar UVR energy that reaches the earth's surface is UVA, where only 10% is UVB. One study indicated that about 65– 90% of all melanomas are attributable to UVR exposure [10].

The damaging effects of UVR on the skin are thought to be caused by direct cellular damage and alterations in immunologic function. UVR produces DNA damage (formation of cyclobutane pyrimidine dimers), gene mutations, immunosuppression, oxidative stress and inflammatory responses, all of which have an important role in photo aging of the skin and skin cancer. In addition to this, UVR creates mutations to p53 tumor suppressor genes; these are genes which are involved in DNA repair or the apoptosis of cells that have lots of DNA damage. Therefore, if p53 genes are mutated, they will no longer be able to aid in the DNA repair process; as a result, there is ‘‘dysregulation of apoptosis, expansion of mutated keratinocytes, and initiation of skin cancer. UVA radiation has an important role in the carcinogenesis of stem cells of the skin. UVB radiation induces DNA damage, which causes inflammatory responses and tumor genesis. Figure 10 shows the penetration depth of UVR [10].

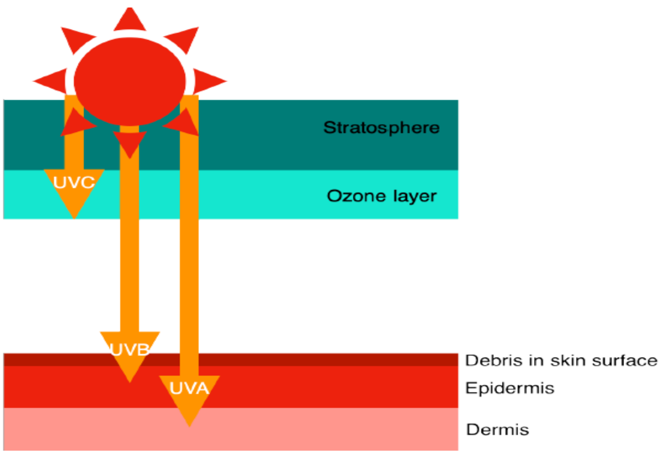

Figure 10: The damaging effects of UVR on the skin [8]

In humans UVA penetrates deeper into the skin than does UVB. Because UVA represents the majority of the UV spectrum of tanning appliances and of solar radiation reaching the Earth's surface, far more UVA than UVB reaches the basal layers of the epidermis, where skin keratinocytic stem cells and melanocytes are located. Other studies showed that radiation emitted by lamps used in tanning appliances (mainly UVA) could significantly increase the carcinogenic effect of broad-spectrum UV radiation, indicating the possibility of a complex interplay between UVA and UVB radiation in human skin. In addition, both UVA and UVB radiation can affect the immune response that may be involved in the promotion of melanoma. However, the two types of radiation seem to act differently. Results suggested that UVA may influence local immune responses different from those influenced by UVB [11].

Applications of ultraviolet radiation

In forensic investigations

Ultraviolet lights have been used in forensic laboratories and at crime scenes for years to look for blood and body fluid stains. Recently, more portable versions of these lights have been used with varying degrees of success in clinical practice with victims of violence. The first report of UV lights being used to identify semen was in 1919 by Dr. Wood. Some lights allow many substances to fluoresce including hair gel, lubricant and other innocuous substances, while other lights only make semen and sometimes saliva fluoresce. Long wavelength ultraviolet light is known as UVA radiation and is at least 320 nm to over 400 nm. This longer wavelength, particularly over 400 nm, is the recommended minimum for forensic use [12].

When body fluid stains are on surfaces such as skin or fabric they may not be visible to the naked eye. The use of fluorescent techniques such as ultraviolet lights and laser lights allows us to see stains not otherwise seen. When the ultraviolet light is directed at an area, the light is absorbed from the substance/fluid, making the area fluoresce. These two lights are known as excitation light and emission light. In medium to long ultraviolet wavelengths (about 320 nm), the excitation light is not visible to the naked eye, and only the emission light is seen, making the stain visible. When the excitation and emission light are both seen, it is difficult to differentiate the stain from surrounding tissue which also shows excitation light [12].

When both lights are visible it is known as the visible fluorescence spectrum. The only way to view the stain is by blocking out the excitation light within that fluorescent region. Barrier filters in the form of goggles or camera filters are used for this reason. The colour of the barrier filter differs with the range of light and the body fluid to be seen. As an example, if looking for semen using a 450 nm ultraviolet light, orange goggles are needed to filter out everything but the emission light from the stain and make the stain visible (see Figures 11-13) [12].

Figure 11: UV light makes the stain visible [12]

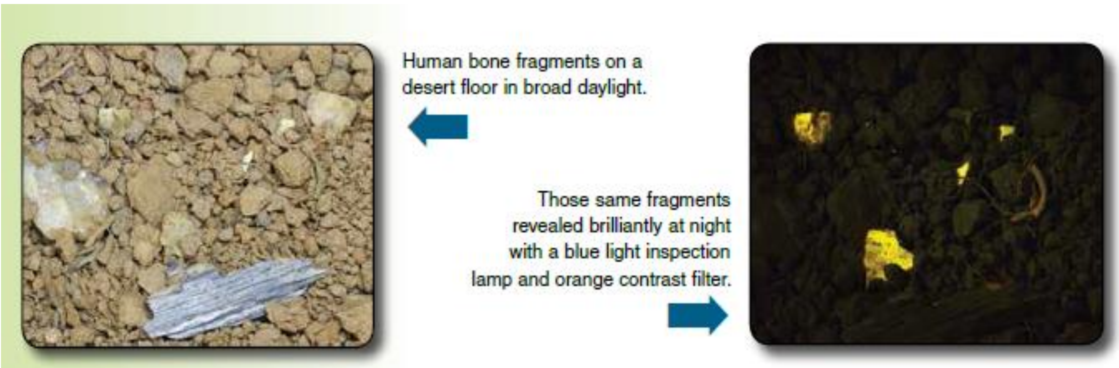

Figure 12: Application of UV light at night [12]

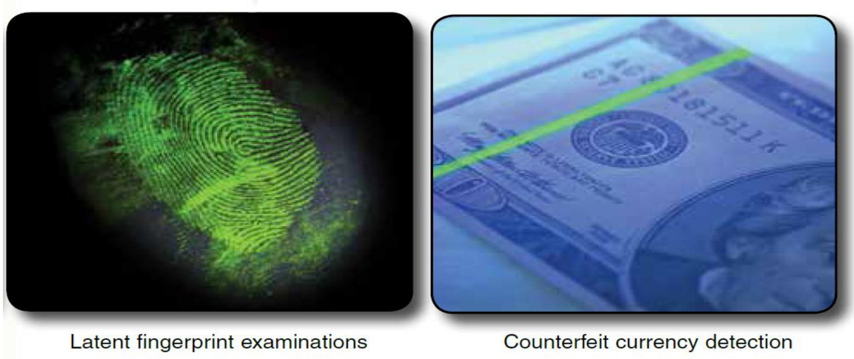

Figure 13: Other application of UV light [13].

Ultraviolet light (UV) light as Disinfection tool.

One of the earliest reports describing the germicidal effects of UV was by Downes and Blount (1877). They described the lethal effects of sunlight on a mixed microbiological population and assigned the cause of these effects to UV radiation. Early interest in the application of UV for disinfection was originally centred on potable water. Today, however, many different liquids are disinfected by UV light, including primary, secondary and tertiary filtered wastewater. UV light has proved to be a very “clean” and effective alternative to those disinfection methods which use chemical agents such as chlorine, chlorine dioxide or ozone. Unlike these methods, UV does not produce any disinfection-by-products (DBPs) [14].

In wastewater disinfection: Today, medium pressure UV lamps are used for a wide range of disinfection applications including potable water, wastewater and industrial process water. Medium-pressure lamps contain mercury gas at much higher pressure (approximately 1,000 torr). These lamps produce UV of a higher intensity and over a broader range of wavelengths (200–400 nm). UV light has proved to be a very “clean” and effective alternative to those disinfection methods which use chemical agents such as chlorine, chlorine dioxide or ozone. Unlike these methods, UV does not produce any disinfection-by-products. Laboratory and full-scale studies investigating the effects of UV lamp technology, configuration, cleaning requirements, ageing and longterm performance have demonstrated the effectiveness of UV in inactivating pathogens in wastewater and can be used for biological effects [14].

Ultraviolet light (UV) light in food industry:

Ultraviolet light (UV) light holds considerable promise in food processing as an alternative to traditional thermal processing. Its applications include pasteurization of juices, post lethality treatment for meats, treatment of food contact surfaces and to extend the shelf-life of fresh produce [15].

Ultraviolet light (UV) light in geology

In geology: Fluorescence, as the term is commonly used, refers to the emission of visible light by substances during their irradiation by ultraviolet (UV) light. Most minerals are not perceptibly fluorescent but many are. Fluorescence in minerals is observed commonly through excitation by two types of UV source: shortwave UV light, usually produced by a low-pressure mercury discharge lamp that produces a spectrum containing the Hg line at a wavelength of 254 nanometers (nm); and long wave UV light. Fluorescence can be useful to the geologist and mineralogist in many ways: as a way of recognizing minerals (sometimes of economic value), which would otherwise go undetected; providing an indication of zoning or alteration in minerals; as a means of recognizing the presence of certain metals or other elements (see Figure 14) [16].

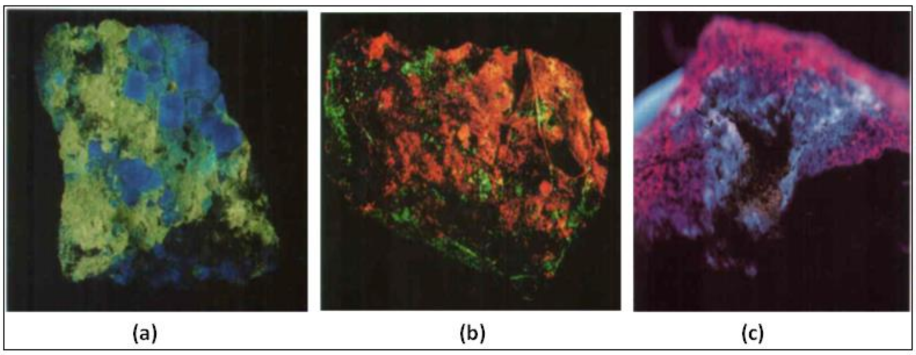

Figure 14: (a) Using (long wavelength UV) produced image of Fluorite (blue-violet) with cerussite (yellow fluoresces). (b) Using (short wave UV) produced image of Willemite fluoresces green, calcite fluoresces red. (c) Using (short wave UV) produced image of alkali feldspar (pinkish-red fluoresces) and hydrocarbon material (bluish-white fluorescence) [16]

Ultraviolet light (UV) light in medicine

Because of its ability to cause chemical reactions and excite fluorescence in materials, ultraviolet light has a huge number of useful applications in modern medicine, for diagnostic and therapeutic purposes. In medical practice, UV lamps are used for treating psoriasis and for treating jaundice in new born babies. UV radiation can also be used as phototherapy to suppress pathogenic cutaneous immune responses. UV radiation induces chemical reactions which are essential for the formation of pre-vitamin D3. The application of UV light in medicine can be summarized in Table 1 [17].

Table 1: UV applications in medicine

Wavelength	Application
230–400 nm	Optical sensors, various instrumentation
240–280 nm:	Disinfection, decontamination of surfaces and water (DNA absorption has a peak at 260 nm)
200–400 nm:	Forensic analysis, drug detection
270–360 nm:	Protein analysis, DNA sequencing, drug discovery
280–400 nm:	Medical imaging of cell
300–320 nm:	Light therapy in medicine, effective long-term treatment for many skin conditions like psoriasis, vitiligo, eczema
300–365 nm	Curing of polymers

In dental medicine Ultraviolet (UV) light finds different application: Ultraviolet light to root canal walls, as a means of complementary immediate disinfection after the use of sodium hypochlorite. Illumination of root canals with ultraviolet light may be an effective supplementary means to achieve immediate disinfection of infected root canals. In addition, upon irradiation of dental bacteria with ultraviolet light has shown significant reduction in the bacterial growth [17].

Ultraviolet light (UV) light in Research

Ultra-violet light can be used for determining the optical constants such as refractive index, absorption coefficient, extinction coefficient and the real (εr) and imaginary (εi) components of the dielectric constant for various solutions of different concentrations at different environments [18, 19].

Table 2: Optical data for distilled water under a static magnetic field (75mT), using ultraviolet filter, with maximum transparency wavelength (366 nm)

Exposure Time(min)	Refractive index	Absorption coefficient $\alpha(10^{-4})$	Extinction coefficient k(10^{-9})	Dielectric constant (ε') real part	Dielectric constant imaginary part (ε'') (10^{-9})
5	2.195734	161.21	0.469768	4.821249	2.062971
10	2.195734	161.21	0.469768	4.821249	2.062971
15	2.356048	184.24	0.536878	5.550964	2.529824
20	2.527416	207.27	0.603987	6.387831	3.053055
25	2.618034	218.79	0.637542	6.854102	3.338215
30	2.527416	207.27	0.603987	6.387831	3.053055

Occupational protection

Due to the central importance of sun avoidance in preventing melanoma skin cancer, data regarding sun avoidance, knowledge, and use of sun protection may be beneficial in future prevention goals, practices, and standards [20].

It can be stated that the golden rule implies that exposure of both the eyes and skin to UVR should be kept to a minimum. On the other hand, in order to protect persons in the vicinity of artificial UVR, the following precautions are recommended:

- Whenever possible, prevention of excessive exposure of the eyes and skin should be ensured by proper engineering design of UVR-emitting installations and suitable enclosures, so that any UVR is either adequately contained or sufficiently attenuated.
- When, for justifiable reasons, such containment is not possible, protection should be afforded by providing close-fitting goggles and/or face shields accompanied, if necessary, by suitable UVR-opaque clothing and gloves to cover the skin.
- Adequate and appropriate instruction should be given, to any person liable to be excessively exposed to UVR, concerning the hazards involved and the precautions to be observed to avoid excessive exposure.
- For artificial TJVR sources that do not emit significant visible light, a visible or audible warning signal may be required to show when the TJVR is being emitted.

- Powerful short wavelength UVR sources may generate ozone. This additional hazard should be avoided by providing either adequate ventilation or an adequate ozone removal system in the workplace [4].

CONCLUSION

Despite the fact that there are some beneficial effects of UVR, the negative effects can potentially be life threatening. It can be stated that using broad-spectrum sunscreens UVR protection with an SPF (Sun Protection Factor) is currently the best preventative measure to maintain homeostasis within the eye and the skin. Dermatologists should encourage their patients to limit time in the sun especially between 10am and 2pm. If a patient must be out in the sun, dermatologists should recommend wearing protective clothing, such as hats, long-sleeved shirts, pants, and eye protection.

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