frontiers FOR YOUNG MINDS

HUMAN HEALTH
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WHY IS SKIN CANCER RISK ELEVATED AT HIGHER ALTITUDES?

Ilana D. Breen[1*] *and Jillian M. Richmond*[2]

[1] *Mayo Clinic Alix School of Medicine, Mayo Clinic, Scottsdale, AZ, United States*

[2] *Department of Dermatology, University of Massachusetts Chan Medical School, Worcester, MA, United States*

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One of the strongest risk factors for skin cancer is direct exposure to the sun. Sunlight emits ultraviolet (UV) radiation, which can damage the DNA of the cells in our bodies. UV exposure causes mutations in DNA, and these accumulated mutations can lead to skin cancer. Melanin is a pigment present in the skin that gives skin its color. Melanin also helps protect skin against UV radiation and sun damage. In addition to protective effects of the skin, most of the damaging ultraviolet radiation from the sun is filtered out by the Earth's atmosphere. However, at higher altitudes, there is less atmospheric filtering of UV radiation. Therefore, ultraviolet radiation exposure is increased at high altitudes, which explains the higher risk of skin cancer in regions with high elevation.

HIGH ALTITUDES AND SKIN CANCER RISK

Leadville, Colorado is the highest United States city, with an elevation of 10,152 feet (3,094 m). The city is not only high in altitude, but also

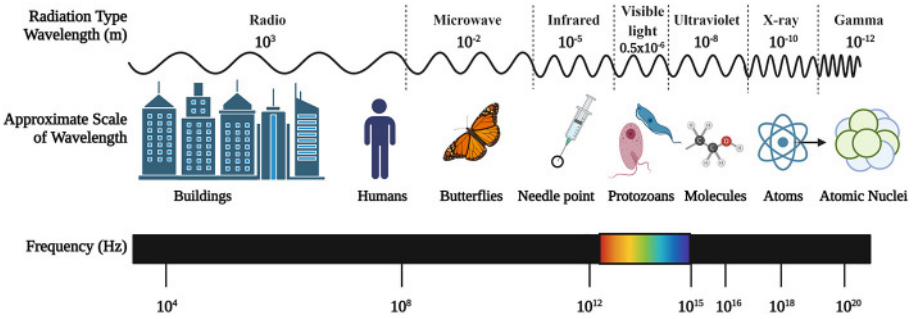

Figure 1

The properties of the electromagnetic spectrum. The top red squiggle in this diagram shows the approximate wavelength and frequency of different types of energy waves, spanning from radio waves to gamma rays. The approximate scale of the wavelengths are shown below, with radio waves being as big as buildings, and gamma rays being the size of atomic nuclei. At the bottom, the frequency in Hertz (Hz) using scientific notation is provided. Notice that visible light is shown in color from red to purple. Infrared waves are longer than red visible light, and ultraviolet waves are shorter than purple visible light (Figure created with Biorender.com; based off of Image [1]).

RADIATION

The release of energy either as particles or waves.

ATMOSPHERE

The air and gases surrounding the earth or other planet.

ELECTROMAGNETIC SPECTRUM

The range of wavelengths and frequencies over which radiation can exist.

WAVELENGTH

Wavelength is the distance between successive crests of a wave.

FREQUENCY

Frequency refers to the number of waves that pass a fixed point in unit time.

has high rates of skin cancer. To find out why, we need to take a closer look...or rather, a "farther look," starting as far away as the sun.

Ninety-two million miles away from Earth, the sun emits **radiation**, which is basically energy. The earth's **atmosphere** helps shield us from this radiation. But being at a higher altitude means there is less atmosphere between your skin and the sun, leaving it more vulnerable to radiation damage and ultimately skin cancer. To understand more about this process, we will explain in more detail principles of radiation, the skin, and skin cancer.

ENERGY—THE ELECTROMAGNETIC SPECTRUM

To understand the radiation from the sun, we will begin with an overview of all possible forms of radiation. These different forms are classified into a system called the **electromagnetic spectrum** (Figure 1) [2]. Light and radiation behave very differently than the objects we interact with in everyday life. For example, you can not hold light in your hand in the same way that you can hold an apple. This is because light can behave like a wave. But believe it or not, light can *also* behave like a particle (like a very, very small apple!) and these particles of light are called photons. This means that electromagnetic radiation can behave like a particle *or* it can behave like a wave. Albert Einstein helped develop the theory of particle-wave duality [2].

Electromagnetic radiation can be described in terms of two main features: **wavelength** and **frequency**. Wavelength is the distance between successive crests of a wave. Frequency refers to the number of waves that pass a fixed point in unit time. In the electromagnetic spectrum, different forms of radiation are distinguished by their wavelengths, which range from extremely long (radio wavelengths are as long as skyscrapers) to very short (gamma ray wavelengths are the same length as a single atomic nucleus). In Figure 1, you will notice that the frequency is inversely related to wavelength. This means that as wavelength increases frequency decreases, and vice versa. Higher frequencies (and therefore, shorter wavelengths) correspond to higher

energy. In general, higher energy radiation is more damaging to the human body [1].

ULTRAVIOLET (UV) RADIATION

Let us get back to sunlight. The sun emits mostly visible, ultraviolet, and infrared light [2]. We will focus on ultraviolet light because it is primarily responsible for the sun's effects on human health. There are three main types of ultraviolet light. UV-A has the longest wavelength and lowest energy, UV-B has a medium wavelength and energy, and UV-C has the shortest wavelength and highest energy.

UV-A composes 95% of the ultraviolet radiation that reaches the Earth, but it only has a small contribution to tanning and skin cancer development [3]. UV-B leads to tanning and is the major culprit of sunburn and skin cancer [3]. UV-C *could* cause the most detrimental health effects, but it is entirely filtered by the Earth's atmosphere and does not reach the Earth's surface.

What does it mean that the atmosphere "filters" the UV-C light? The ozone layer is a shield-like region around the Earth that absorbs most of the sun's ultraviolet radiation. This prevents the high-energy, dangerous UV-C waves from reaching the Earth. This protective process is called **atmospheric shielding**. As an analogy, glass windows in your house absorb almost all UV-B light. This explains why you do not get sunburned when you hang out in a sunny spot in your living room. You can not see the filtration of light through the glass window but it is happening, just as the ozone layer is filtering out UV-C light! While the ozone layer is responsible for much of the atmospheric shielding, the *entire* atmosphere (from the Earth's surface to the stratosphere) provides shielding effects [4].

ATMOSPHERIC SHIELDING

Absorption of cosmic radiation by Earth's atmosphere.

Therefore, the higher the elevation above sea level, the less atmospheric shielding, and the more UV exposure.

UNDERSTANDING THE SKIN

To understand how UV exposure causes skin cancer, we must understand the skin as well. The skin is composed of three main layers [3]. The epidermis is the outermost, waterproof layer. The dermis lies underneath the epidermis and contains connective tissue, hair follicles, and sweat glands. Finally, the subcutaneous tissue, also called the hypodermis, contains adipose tissue (fat) and more connective tissue (Figure 2).

MELANIN

A dark brown pigment located in the outer layer of skin, which is responsible for skin coloration and tanning; it also protects against UV light.

The epidermis contains **melanin**, a pigment that determines skin complexion. Melanin is efficient at absorbing UV radiation [5]. In fact, melanin protects the body from 99.9% of UV-B light—so we can

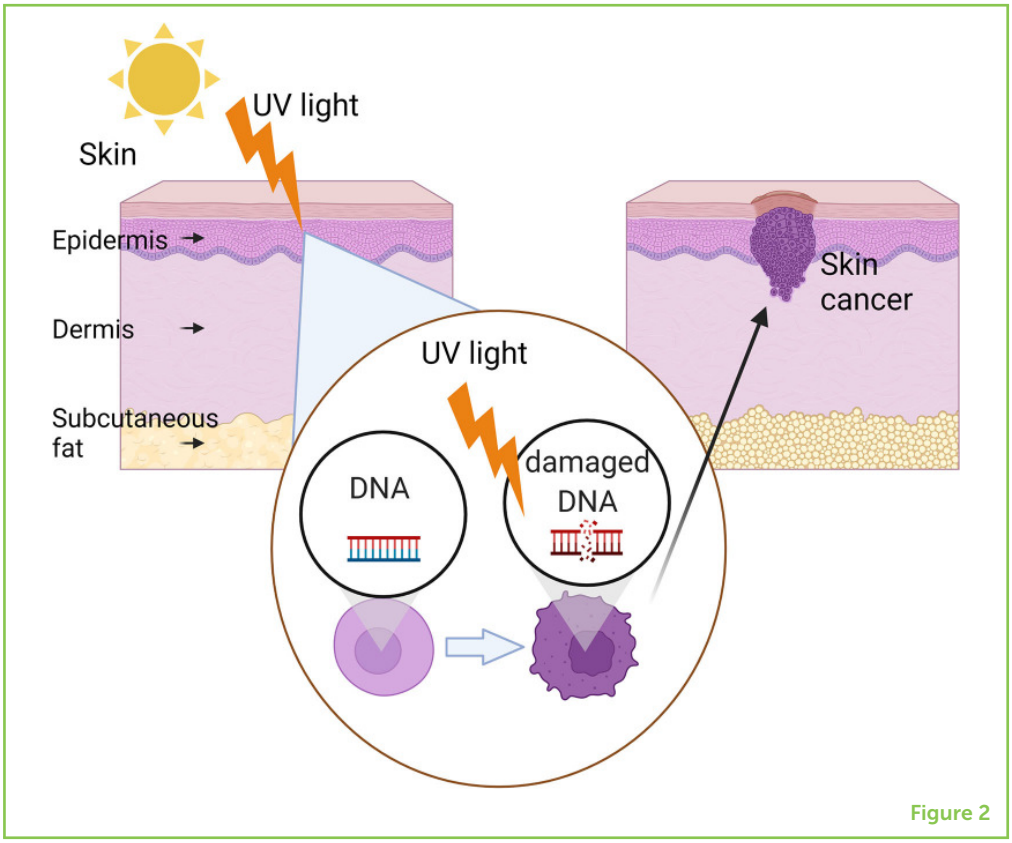

Figure 2

How sun exposure leads to skin cancer. The skin is comprised of 3 main layers: the epidermis, dermis and subcutaneous fat. UV light from the sun can penetrate the skin and damage DNA in the nucleus of skin cells. If the cells are not able to repair this damage, or repair it improperly, it can lead to uncontrolled cell growth and formation of a tumor. A tumor is considered cancerous when it is able to metastasize, or grow outside of its normal tissue. Developing skin cancer is more likely to happen with more or more frequent sun exposure, sunburns, or with age, as the cells lose their ability to repair DNA because there is too much or too repeated damage. Wearing sunscreen can help shield your skin cells from UV light and can help prevent skin cancer (Figure created with Biorender.com).

say melanin is **photoprotective** [3]. Usually, UV light stimulates the production of melanin [5]. This explains why sunbathing may lead to tanning in most individuals. However, some individuals never tan and only sunburn. The greater the number of sunburns a person gets, the higher the risk of skin cancer. This is because sunburns often indicate a high level of UV exposure, capable of causing DNA damage [3].

PHOTOPROTECTIVE

Able to prevent damage from sunlight.

MUTATIONS

Changes in the DNA sequence.

THE LINK BETWEEN UV LIGHT AND SKIN CANCER

When melanin absorbs UV light, the energy in the light is not absorbed by the DNA. If UV light energy is absorbed by DNA, this can cause **mutations**. DNA mutations can be dangerous changes to the DNA that can lead to the development of skin cancers (Figure 2). These mutations can occur in genes that promote cell growth (oncogenes, get turned on) or in genes that prevent cell division (tumor suppressors, get turned off). Skin cancers usually occur as one of three types: squamous cell carcinoma, basal cell carcinoma, and melanoma. UV-induced DNA damage can cause any of these cancers.

It is important to recognize that sunlight is not *all* bad. There are several health benefits of sunlight, including vitamin D production, positive effects on mood, healing properties for some diseases, and prevention of some cancers [4]. However, despite these benefits, excessive sun exposure is strongly linked to the development of skin cancers. In

high-altitude locations, like Leadville, Colorado at 10,152 feet, people have higher risks for skin cancer. At this altitude, there is decreased atmospheric shielding from UV radiation, which leads to 50% more UV exposure than at sea level. So, the next time you go skiing in the mountains, make sure to wear your sunscreen!

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YOUNG REVIEWERS

ANISHA, AGE: 14

I have always been interested in the fields of science and math and so when I grow up I wish to be a biomedical engineer. In school, my favorite subjects are math and all the sciences. In my freetime, I enjoy playing the piano as well as reading. Some of my favorite books include The Wonderful Wizard of Oz and the Harry Potter series. I also enjoy trying new experiences and foods.

KATHERINE, AGE: 15

Hi my name is Katherine and I am 15 years old. I enjoy reading, listening to music, and taking walks with my dog. My favorite subjects are math and physics. I play tennis and badminton for my school.

AUTHORS

ILANA D. BREEN

Ilana is a fourth-year medical student at Mayo Clinic Alix School of Medicine and an aspiring dermatologist. She studied chemistry at New York University and later served as assistant research scientist in the Turner Laser Lab. She hopes to apply her laser background to skin disease research. She has a particular interest in the role of lasers to treat burn patients and light therapies to treat skin conditions spending time with family, playing piano, and flying (pictured in a glider to the right), which sparked her interest in the risk of skin cancer at high elevations. *ilanabreen7@gmail.com

JILLIAN M. RICHMOND

Jillian is an assistant professor of dermatology at the University of Massachusetts Medical School. She earned her B.S., in molecular & cellular biology from Johns Hopkins University and her Ph.D., in immunology and pathology from Boston University School of Medicine. Her laboratory studies the role of the immune system in skin diseases. Jillian is passionate about teaching and mentoring students in the classroom and the laboratory and discovering new treatments for patients through her research. She enjoys spending time with her kids, baking, and gardening.