THE ULTIMATE GUIDE TO

RED LIGHT THERAPY

How Does Red and Near-Infrared (NIR) Light Therapy Work?

ARI WHITTEN

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By Ari Whitten

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The next important question to answer is "how the heck does red and near-infrared light actually cause these effects?"

We know how UV light affects us, for example – it works primarily by interacting with our skin and stimulating the production of vitamin D. We also know how blue light enters our eyes and feeds back into the circadian clock in our brain (in the suprachiasmatic nucleus) to regulate our 24-hour biological rhythm, including the complex array of hormones and neurotransmitters that are regulated by this circadian clock in our brain.

These mechanisms are well understood by science. But what about red/NIR light?

There are numerous different physiological and biochemical mechanisms that researchers have identified as being affected by red and near-infrared light, but for our purposes here (since this is not a book meant for academics, but for regular people wanting to benefit from red and near-infrared light), I don't want to get too bogged down in the details of dozens of different molecular signaling pathways at the cellular level. Instead, I want to keep things as simple and easily understandable as possible.

First, it's important to understand that there isn't just one mechanism. For example, this isn't a drug that acts on one particular enzyme, compound or receptor (e.g. serotonin, cholesterol, etc). There are literally **dozens of mechanisms** at the biochemical and cellular level.

It also can affect different cells differently – for example, affecting damaged and dysfunctional cells differently than healthy cells. It even has the capacity to irradiate the blood (and affect things like inflammatory mediators and immune cells), thus affecting the entire body through the changes in blood cells/compounds, not just the area the light was shined on. Here's Hamblin et al. summarizing this in their 2018 textbook:

> "Light irradiation using a low power density has been reported as a noninvasive, noncarcinogenic, nontraumatic procedure that can provide a therapeutic benefit to many diseases and medical conditions, and that has been reported to have few (if any) side effects. In addition, PBM (photobiomodulation – the changing of biology with light) is used to improve human wellness with aesthetic and cosmetic applications, improvements in sports performance, and has diverse veterinary applications. The biomodulation achieved by PBM allows it to be applied in situations that can be apparently paradoxical because it can sometimes be used to stimulate cells and tissues, and in other situations it can inhibit the same biological effect. For this reason, PBM is referred to by many researchers as a regulator or modulator because it restores the organism to homeostasis. Moreover, there is considerable evidence of the systemic effects of PBM, which means that application to one site of the body can produce an improvement of a condition in another distant body part that did not receive light. Systemic effects can be explained by local effects of light that can be transferred to other sites through the circulating blood, via the lymphatic system, or via the nervous system."[28]

To go into the details and nuances of all the mechanisms and pathways known to be affected by near-infrared and red light could easily fill a textbook. Again, that's not the goal of this book. I'd like to simplify the mechanisms here as much as possible and not turn this into a biochemistry textbook, so let me first give a very brief overview of many of the molecular, cellular, and tissue mechanisms of action of how red/NIR light works, according to what is currently confirmed by research.

Please note that even here, I am only going to list them out and give brief descriptions of the more notable factors. If you'd like to see a complete medical textbook-level in-depth discussion of *all* of the

factors, I suggest getting Hamblin et al.'s new 2018 textbook *Low-Level Light Therapy: Photobiomodulation*. If you're wondering why I am simplifying here, I'll give you a brief example of the type of writing you'll find in that textbook, and after reading it, hopefully you'll have a greater appreciation for my attempts to make things easily understandable for even those without any science background:

> *"**ERK/FOXM1:** Fork-head box protein M1 (FOXM1) is a protein involved in the regulation of the transition from the G1 to the S phase of the cell cycle and the progression to mitotic division. Ling et al. investigated the protective effect of LLLT using red light at 632.8 nm against senescence caused by UV light, and reported an activation of the ERK/FOXM1 pathway that caused a reduction in the expression of the p21 protein and G1 phase arrest. Senescence was attenuated by over-expression of FOXM1c with or without LLLT, and if FOXM1 was inhibited by shRNA, the effect of LLLT in reducing cell senescence was abrogated. LLLT promoted the nuclear translocation of extracellular signal-regulated kinase (ERK), increasing FOXM1 accumulation in the nucleus, and the transactivation of c-Myc and p21 expression."*[29]

Now, how many people without a strong background in physiology and biochemistry do you think can understand just that single paragraph, let alone hundreds of pages of that kind of writing?

Hopefully you now have more of a sense of appreciation for how much I've simplified things. And if you thought what I've been explaining is unnecessarily complex, perhaps you now have a new reference for comparison! So hopefully you love me a little bit more right now for making things relatively easy to understand.

Again, my goal here is not to make this into a textbook for researchers, but to make it accessible for regular people. With that said, here is a summarized, simplified, and greatly shortened version of the mechanisms known to science about how red/NIR light works (broken down by molecular, cellular, and tissue-level mechanisms), as discussed in the latest 2018 textbook[30] from several of the world's top authorities on this topic. (Note: If you don't care about all the details of the mechanisms and specific molecules at the cellular level, you can skip the next couple pages of the bullet-point lists to the part right after "Two Key Mechanisms of Red/NIR Light Therapy." In that next section, I explain the details of the two most important mechanisms red/NIR light works in our body.)

Red/NIR light has been shown in research to affect all of the following compounds and pathways:

Molecular Mechanisms:

- **Cytochrome c oxidase:** This is a photoreceptor located on mitochondria in our cells that "accepts" light photons and then triggers events in the mitochondria. (More detail on this below).
- **Retrograde mitochondrial signaling**: This is a key factor where mitochondria in the cells communicate with the nucleus of the cell about what is going on, thus affecting what genes get expressed in the DNA-containing nucleus of our cells.
- **Light-sensitive ion channels:** There are channels in our cells which control the flow of various ions (e.g. calcium, potassium, sodium, etc.). Some of these are affected by light, and then are involved with triggering further events in the cell or between cells.
- **Adenosine triphosphate (ATP):** This is cellular energy produced by mitochondria. One of the more notable findings from many studies is that exposure to red/NIR light increases levels of ATP production.
- **Cyclic AMP:** This is involved with opposing inflammatory pathways, among other functions in the cell.
- **Reactive oxygen species (ROS):** These are also commonly called "free radicals." While commonly associated with bad things (e.g. cell damage, oxidation, etc.), they also play vital roles in our bodies as signaling molecules. For example, ROS are produced from physical exercise and signal many of the positive adaptations that our body makes to exercise.

- **Calcium:** Red/NIR light can affect calcium levels in the cell, which in turn act as a signal for numerous cellular processes.
- **Nitric oxide (NO):** It is known that NO levels rise after red/NIR light exposure. NO is well known by most people for its role in blood vessel dilation, but it also acts in many other signaling pathways. (More on this below.)
- **Nuclear factor kappa B:** This is a signaling compound that regulates many genes involved in inflammation and cell survival to stressors.
- **RANKL:** A protein involved in bone regeneration/remodeling.
- **Hypoxia-inducible factor:** A protein involved in cellular adaptation to low oxygen levels.
- **Akt/GSK3b/b-catenin pathway:** This pathway relates to cell survival and apoptosis (programmed cell death)
- **Akt/mTOR/CyclinD1 pathway:** Involved in cell growth signaling.
- **ERK/FOXM1:** Involved in regulating cell division.
- **PPARy:** Involved in the inflammatory response.
- **RUNX2:** Involved in bone cell differentiation.
- **Transforming growth factor:** Stimulator of collagen production (e.g. in the skin).
- **Pro- and anti-inflammatory cytokines:** Many pro- and anti-inflammatory cytokines and mediators have been shown to have their levels altered by red and near-infrared light exposure.
- **Vascular endothelial growth factor:** Involved in angiogenesis – the formation of new blood vessels.
- **Hepatocyte growth factor:** Involved in liver cell health.
- **Basic fibroblast growth factor and keratinocyte growth factor:** Involved in the wound healing process.
- **Heat-shock proteins:** Involved in inflammation, wound healing, and cellular survival against many types of stressors (e.g. exercise, sauna/heat stress, etc.).
- **Melatonin:** Interestingly, red/NIR light therapy has been shown to increase "extra-pineal" production of melatonin outside of the pineal gland. Melatonin is much more than just a sleep inducing hormone as most people know it – melatonin has critical roles in protecting the mitochondria from damage and supporting glutathione levels, which is one of our body's most powerful and important antioxidants and detoxifying compounds. Some researchers have suggested that this increased melatonin may be a significant factor in the effects of red/NIR light.[31]
- **Brain-derived neurotrophic factor:** Involved in neuron/brain cell growth and regeneration.

Cellular Mechanisms:

- **Inflammation:** One of the most important cellular mechanisms that red/NIR light have is their effect on inflammation pathways. It appears to do this through inhibition of inflammatory prostaglandin PGE2 production and expression of COX-1 and COX-2, as well as inhibition of the NF-kB pathway. The net effect: Reduced inflammation.
- **Cytoprotection:** Various studies have shown that red/NIR light can help protect cells from dying after being exposed to various toxins (e.g. methanol, cyanide, etc.). It appears to have cell-protective effect in some instances.
- **Proliferation:** Some types of cells (e.g. skin cells, bone cells, cells that line blood vessels, etc.) have been shown to grow and replicate faster with exposure to red/NIR light.
- **Migration:** Some types of cells (e.g. tenocytes in tendons or melanocytes in skin) need to actually move to get to the location they're needed. Some research has shown that red/NIR light can stimulate this.
- **Protein Synthesis:** Red/NIR light can also stimulate cells (e.g. skin cells, bone cells, etc.) to produce more proteins (e.g. collagen).

- **Stem Cells:** Stem cells are apparently even more sensitive to red/NIR light. Red/NIR light has been shown to positively affect growth, movement, and viability of stem cells. This may be relevant to both stem cells already present in our body, as well as in the context of stem cell therapy.

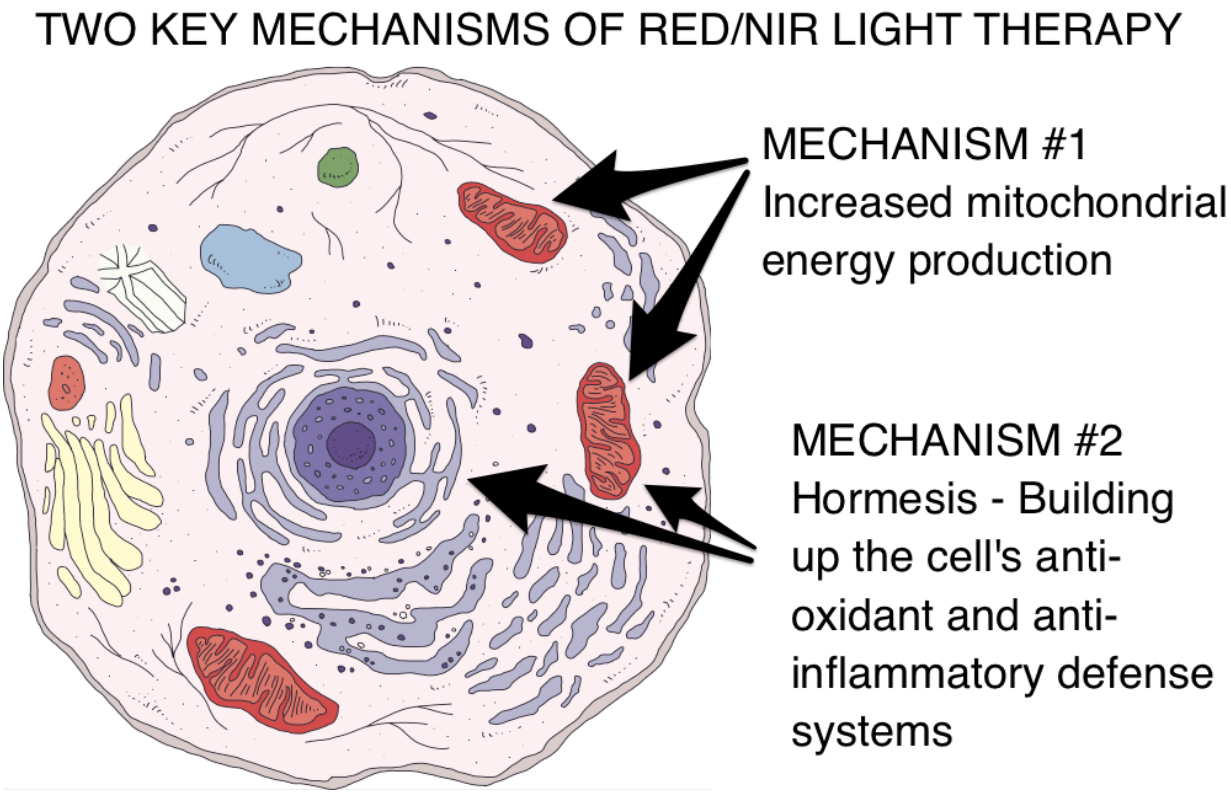
Tissue Mechanisms:

- **Muscles:** Numerous studies have shown that red/NIR light affect muscle performance, recovery from exercise, and adaptations (i.e. enhanced strength, endurance, muscle growth, fat loss) to exercise. (These studies are discussed in this book in later sections.)
- **Brain:** Red/NIR light has been shown to benefit brain function as well. Studies have shown improvements in cognitive performance and memory, improved functioning after traumatic brain injury, improved mood, as well as improvements in certain neurological diseases (e.g. Alzheimer's disease). The improvements in mitochondrial function, reduction in inflammation, and increased Brain-Derived Neurotropic Factor (BDNF) likely all play a role in enhancing neuron health.
- **Nerves (Pain):** Some studies have shown that red/NIR light can dull pain due to blocking conduction at nerve fibers. Anti-inflammatory actions, as well as blocking of substance P, likely play a role in this effect.
- **Healing (Bones, Tendons, and Wounds):** Numerous studies have shown that red/NIR light can stimulate and accelerate healing of numerous types of injuries – from tendon/muscle/ligament tears to bone fractures, and skin wounds. This is likely by affecting local growth factors involved in cellular repair, as well as effects on the inflammatory processes.
- **Hair:** Red/NIR light is also used in the context of hair re-growth, and numerous studies have shown it to be effective for this purpose. This is likely due to local blood vessel dilation and anti-inflammatory effects.
- **Skin:** Numerous beneficial effects on skin wrinkling and laxity, cellulite, collagen production and other aspects of skin health have been found. Anti-aging of the skin is one of the most common uses for red/NIR light.
- **Fat:** The exact mechanisms of how this happens are still debated among researchers, but numerous studies have shown that red/NIR light can stimulate the release of fatty contents from fat cells, and ultimately, lead to body fat loss.

Two Key Mechanisms of Red/NIR Light Therapy

Having gone through this more complete list of factors and mechanisms, now I want to simplify and condense the science. I generally think of red/NIR light as having two central mechanisms in how it benefits cellular function and overall health:

1. Stimulating ATP production in the mitochondria through interacting with a photoreceptor called cytochrome c oxidase.
2. Creating a temporary, low-dose metabolic stress (known as hormesis, which is also a primary mechanism of why exercise works) that ultimately builds up the anti-inflammatory, anti-oxidant and cell defense systems of the cell.



Let's talk about each of these mechanisms in more detail:

Mechanism #1: Stimulating Mitochondrial Energy Production

Researchers have found that one specific mechanism of near-infrared and red light therapy is that these wavelengths of light are able to penetrate into cells and activate the mitochondria, directly leading to increased cellular energy production. Many lines of research indicate that the mitochondria are the key player when it comes to the mechanism of how red and near-infrared light affect our cells. According to Hamblin, M. and Carroll, J. et al.,

> *"Several pieces of evidence suggest that mitochondria are responsible for the cellular response to red visible and near-infrared light. The effects of (red and near-infrared light) on mitochondria isolated from rat liver, have included increased proton electrochemical potential, more ATP synthesis, increased RNA and protein synthesis and increases in oxygen consumption, membrane potential, and enhanced synthesis of NADH and ATP."*[32]

This point deserves special attention, because a huge amount of research in the last decade points to the mitochondria as being critical to health, disease prevention, energy levels, and longevity. So let's go into some detail about why mitochondria are so important.

The mitochondria are the life-yielding, energy yielding engines within the cells of all living things. Our mitochondria produce cellular energy in the form of ATP (adenosine tri-phosphate). All living things thrive because of the production of ATP. ATP is our life force, period. Our bodies are constantly producing and using massive amounts of ATP in every cell in order to fuel every function in the body, from breathing to thinking to lifting a dumbbell. Every time you breathe, digest food, your heart beats, or you perform a bicep curl, your cells are using ATP energy.

Our heart and liver are packed with mitochondria, because they work constantly to pump blood, give life, filter toxins, and protect us from toxic damage. The brain is also packed with mitochondria. So are all our organs, tissues, skin, and especially muscles, which power us through movement.

The mitochondria are the batteries that fuel all the processes of our organs; thus, **things which enhance the mitochondria translate into more cellular energy inside the cell, which allows the cell or organ (e.g. brain, heart, liver, skin, muscles, etc.) to work optimally**.

However, since we don't get enough red light anymore, we are paying the price in the very core of our cells themselves – our mitochondria, the energy generators in our cells – and this has dire consequences for our health because we need near-infrared and red light therapy to generate energy efficiently in our cells.

Thus, this lack of near-infrared and red light today impacts every organ and tissue in our bodies – because every cell in our organs, tissues, skin, heart, liver, lungs, all contain mitochondria. This gives our heart energy to beat, our skin the energy to synthesize collagen more efficiently, our liver energy to detoxify, and so forth.

To understand the detailed mechanisms of how near-infrared and red light actually enhance mitochondria, you need a basic understanding of how our cells produce energy.

We produce ATP by going through a cycle of something called "cellular respiration" — which is what gives us energy to do anything. It gives our body energy to chew, breathe, sweat, produce hormones — everything.

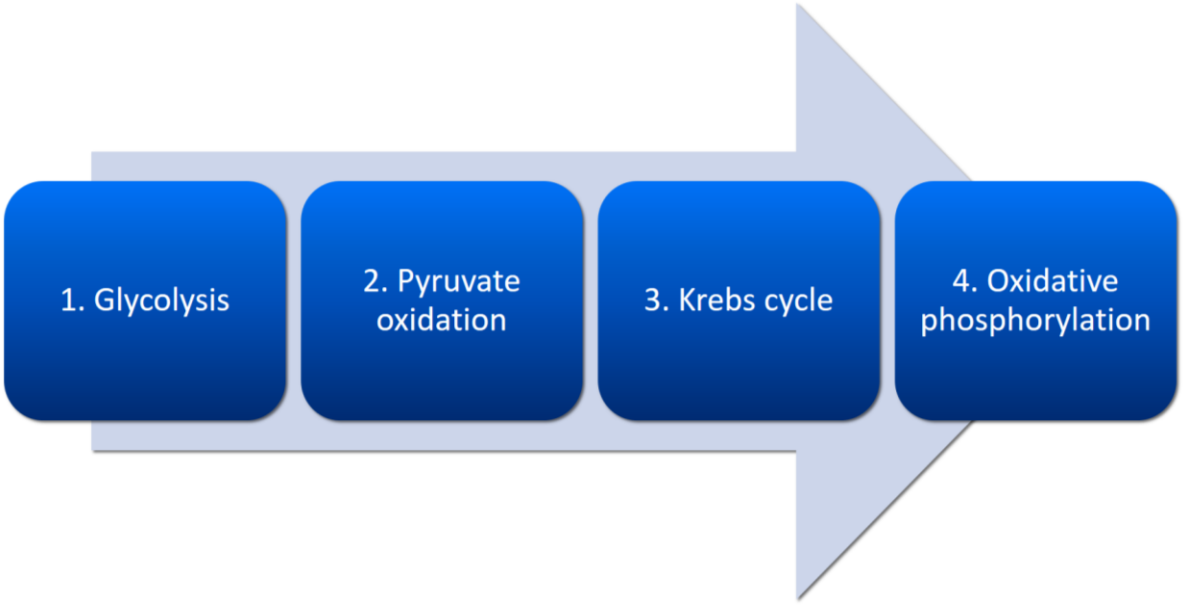
Cellular respiration has 4 steps:

1. Glycolysis (this the first step in cell respiration, which is the conversion of glucose/sugar to pyruvate)

2. Pyruvate oxidation (the next step in converting glucose to ATP, which entails converting pyruvate to acetyl-CoA, to enable ATP to be manufactured)

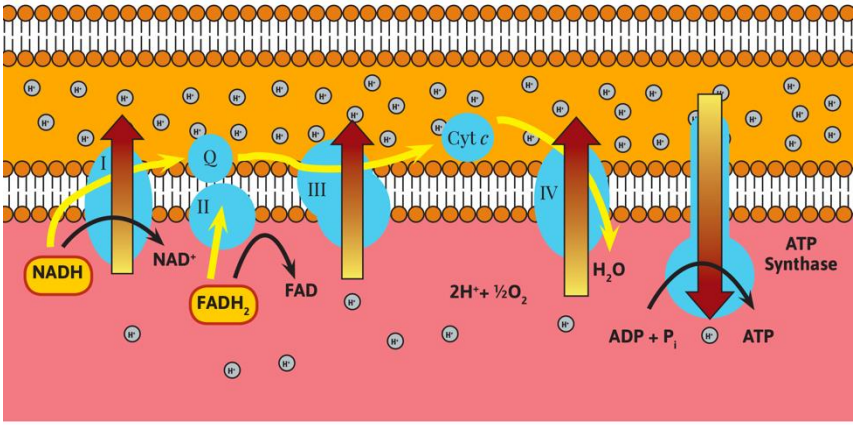
3. Krebs cycle (this uses acetyl-CoA to generate a pool of chemical energy substances (ATP, NADH, FADH2)

4. Oxidative phosphorylation (the last step in ATP production, where the mitochondria use the chemicals produced in the Krebs cycle to pump out ATP)



This last stage, oxidative phosphorylation, is the when red light (red and near-infrared light) does most of its magic.

There is a crucial step in the production of ATP, when electrons pass through the electron transport chain (ETC) in the mitochondria.



As these electrons travel down this chain, protons are pumped across the inner mitochondrial membrane into the space between the inner and outer mitochondrial membrane. This forms a gradient across the membrane, which in chemistry and physics has what's called "potential energy" since substances at a high concentration will be driven to move towards lower concentration.

And sure enough, the mitochondria harness this potential energy – as the proton moves back across the membrane to lower concentration, it passes through a little rotating motor called "ATP synthase" which uses the energy of the proton moving across the membrane to power the process of producing ATP (cellular energy).

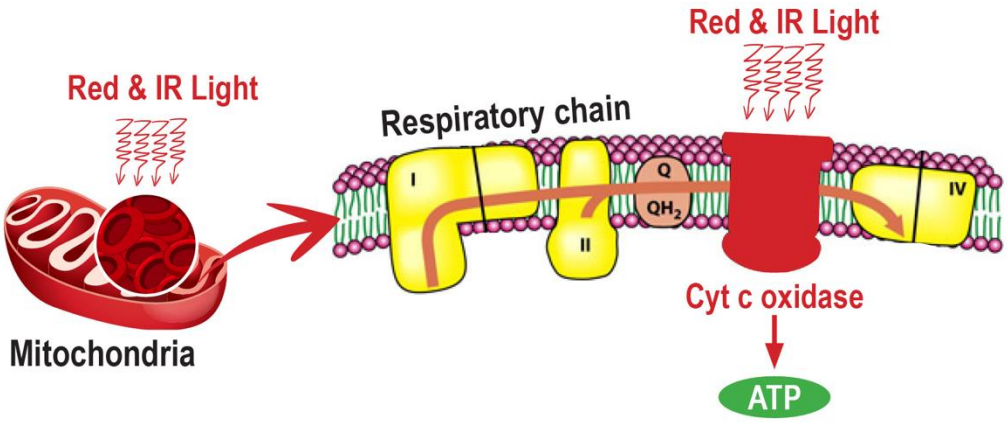
One of the key parts of this energy production in our mitochondria is a photoreceptor – cytochrome c oxidase – that helps oxygen be used efficiently by the mitochondria to power the ATP synthase pump.

A "photoreceptor" is something that absorbs light photons.

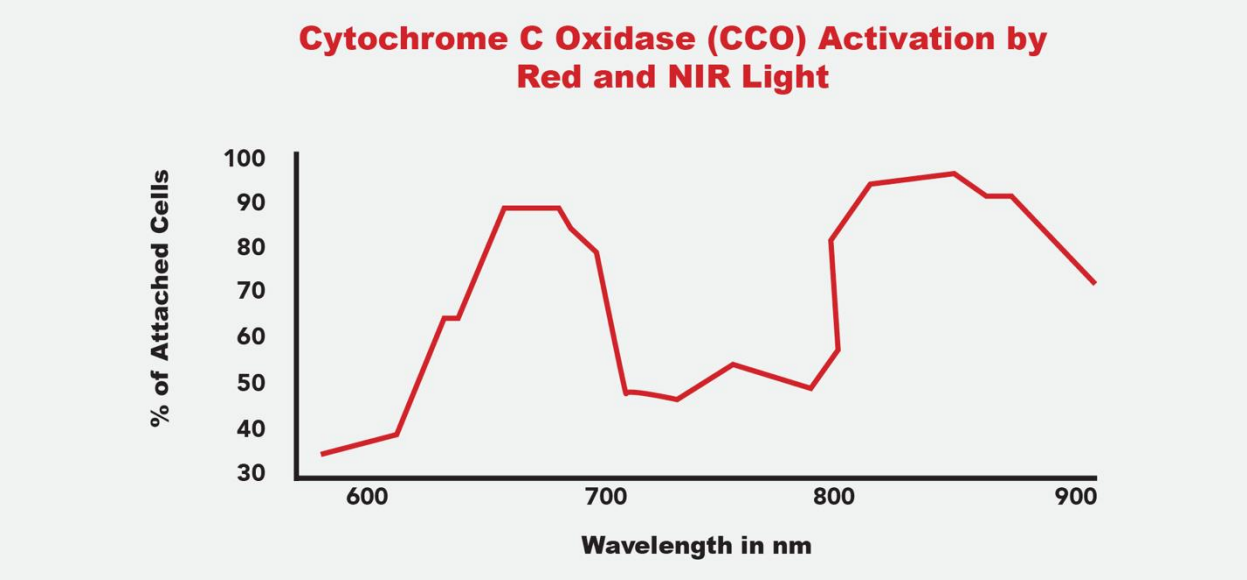
The first law of photobiology states that for light to have any effect on a living cell or body, the photons of light must be absorbed by something in that organism/cell. It turns out that there are indeed such things in many different organisms from plants to humans. It is well known by virtually everyone that plants have such a light photon absorber – chlorophyll, which is a "chromophore" light photon acceptor that turns photons into energy that the plant can utilize. What is not well known by most people is that *humans* also have light absorbing compounds (chromophores or photoacceptors) in our cells and our blood – hemoglobin (in your blood cells), cytochrome c oxidase, myoglobin, flavins, flavoproteins, porphyrins, and melanin in your skin (that's what gives your skin a tan). (Side note: It turns out that even plain old water – including the water that fills our cells – is also a photoacceptor that absorbs certain wavelengths of light.)

And it turns out that many of these light absorbing compounds in our bodies have been verified by research to absorb certain wavelengths of light, and translate that light into various biological effects.

When it comes to red/NIR, the photoacceptor cytochrome c oxidase in our mitochondria is of particular importance.



Cytochrome c oxidase is part of the respiratory chain in our mitochondria that is responsible for producing ATP (cellular energy). When red and near-infrared light photons hit the photoacceptor cytochrome c oxidase, it helps the mitochondria use oxygen more efficiently to produce ATP.



If all of this seems complex, let me simplify: Mitochondria need this little enzyme called cytochrome c oxidase to bind efficiently with oxygen to produce cellular energy (ATP) efficiently. Red and near-infrared light help make that happen.

Cytochrome c oxidase and oxygen working together well means good things are happening — energy production and cellular respiration — which yields energy for the body and all its functions.

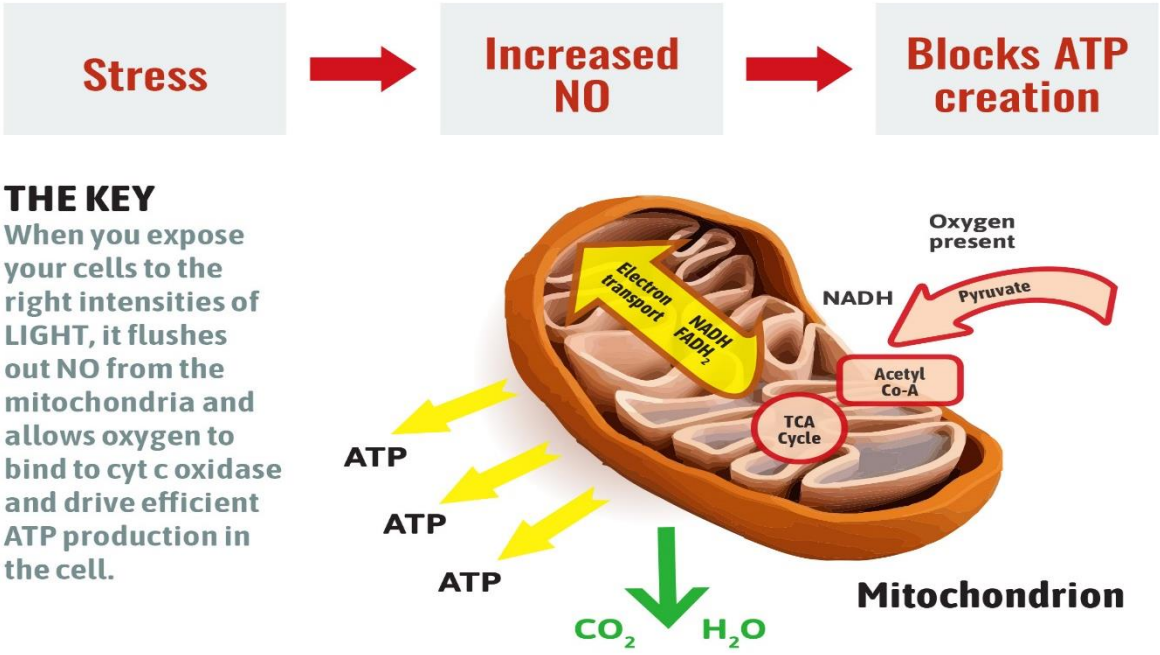
When cells are functioning poorly – **which most human's cells are today** because we live a life full of stressors, like job stress, toxins like BPA and pesticides and heavy metals in our food, too much artificial light at night, and air pollution (among others) – these toxic impacts hinder our cells' ability to produce energy.

While the exact mechanisms are still debated, many researchers (including Dr. Michael Hamblin) believe that nitric oxide (NO) plays a central role.[33,34]

NO of course plays many vital roles in the body, but when we have too much of it, too much in the wrong place, or when our cells don't have the antioxidant capacity to quell the buildup of NO, it can hinder ATP from being manufactured in the mitochondria. [35]

How?

Well, nitric oxide begins to compete with oxygen in the mitochondria.



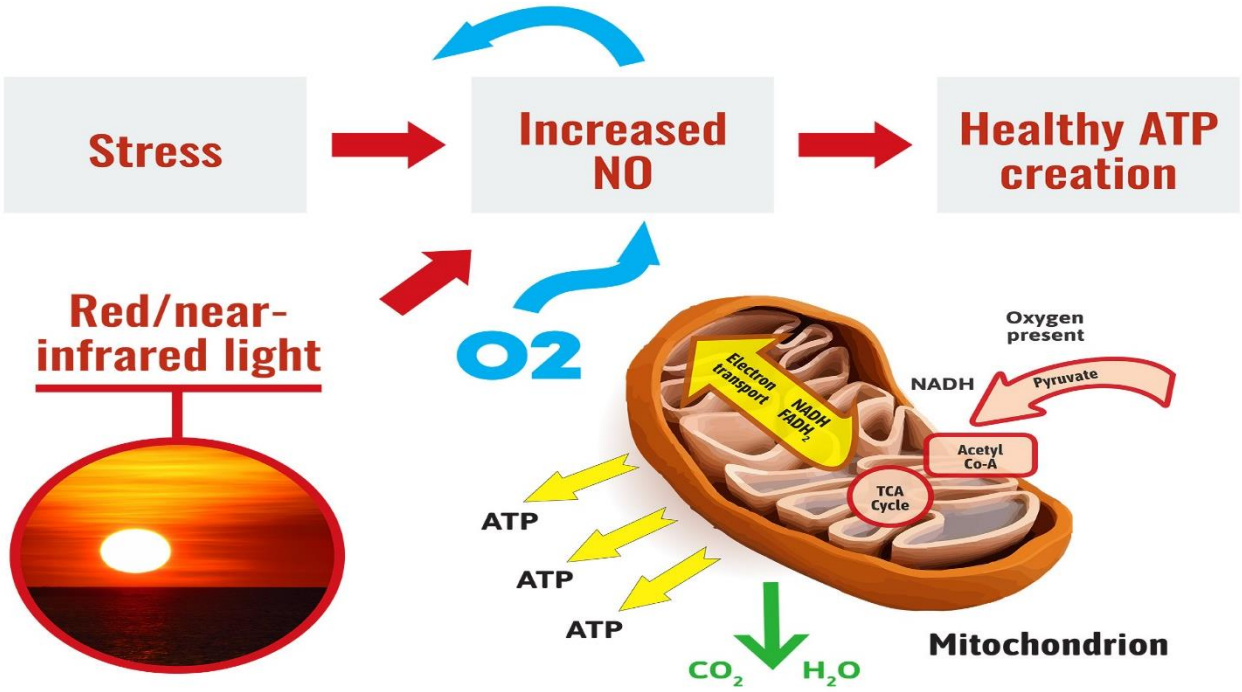
In fact, NO binds with cytochrome c — preventing it from binding with oxygen. It basically blocks the oxygen from being used by the mitochondria. Because of this, the NO inhibits efficient ATP production.

Mitochondria cannot generate ATP efficiently without oxygen. So anything that slows oxygen from being utilized by the mitochondria will slow energy production dramatically.

Therefore, in unhealthy cells, nitric oxide prevents cytochrome c from getting enough oxygen molecules. This hinders ATP production, which is a recipe for poor mitochondrial function, and thus, poor cellular function.

As shown by several research groups around the world, red and near-infrared light essentially prevents this pairing of NO with cytochrome c oxidase. It knocks the NO out and lets the oxygen in!

This allows cytochrome c to have its oxygen molecules and thus, allows for efficient mitochondrial function.



To have great mitochondrial function, we want to kick out the NO from the mitochondria and get the oxygen in.

This means oxygen can once again be utilized efficiently by the mitochondria, which then allows mitochondria to produce energy efficiently.

This is explained in more detail on the mechanisms by Farivar et al.:

> "The activity of cytochrome c oxidase is inhibited by nitric oxide (NO). This inhibition can be explained by a direct competition between NO and O2 for the reduced binuclear center CuB/a3 of cytochrome c oxidase, and is reversible. It was proposed that laser irradiation could reverse this inhibition by photodissociating NO from its binding sites. Because this coordinate binding is much weaker than a covalent bond, this dissociation is possible by LLL (low-level light). The dissociation of NO from Cox increases the respiration rate. Light can indeed reverse the inhibition caused by NO binding to cytochrome oxidase, both in isolated mitochondria and in whole cells. LLL can also protect cells against NO-induced cell death."[36]

In essence, near-infrared and red light therapy allow oxygen into the mitochondria (and prevent NO from halting energy production), which boosts mitochondrial function and improves the health of every organ and system in our body.

I should add here that, to some extent, the nuances of all of the exact mechanisms of how red/NIR light affect mitochondria are still debated amongst researchers, but **everyone is in agreement that red/NIR light does indeed increase mitochondrial energy production**.[37]

Also note that this cytochrome c pathway may not be the only way that red/NIR light increases cellular energy production. There are several more potential mechanisms by which red/NIR light can increase mitochondrial energy production that are described below – including increasing the size and number of mitochondria through hormesis, and more speculative theoretical mechanisms of how this type of light may interact with water in our cells and chlorophyll metabolites. See the section below on "potential mechanisms" for more on the evidence on ways that red/NIR light may potentially affect our cells.

This appears to be the major mechanism that drives many of the beneficial effects associated with red/NIR light on skin, muscles, bone, glands, and brain cells. In short, when mitochondria are stimulated, the cell produces more energy, and when the cell has more energy available, it essentially does everything better – heals faster, is more resistant to stress, produces more proteins (e.g. collagen) and performs better (e.g. muscular performance). Mitochondrial energy production is the heart of all optimal cell function.

Mechanism #2: Hormesis

Another key mechanism for how near-infrared and red light therapy work is through hormesis. Hormesis is the process by which a transient metabolic stressor stimulates adaptations that actually improve health. This may sound like an odd concept at first, but you're more familiar with it than you realize – exercise is a type of hormesis. Exercise works by transiently creating metabolic stress – stressing out the body (workouts are hard work!) and temporarily increasing reactive oxygen species, a.k.a. free radicals – and then in response to that stress, the body adapts to it with things like improved cardiovascular efficiency, improved blood delivery to the muscles, and by strengthening and growing the mitochondria. It also involves downregulating the genes involved in chronic inflammation and oxidative stress (two keys drivers of aging and disease), and upregulating the genes involved in energy production and the internal cellular antioxidant defense system.

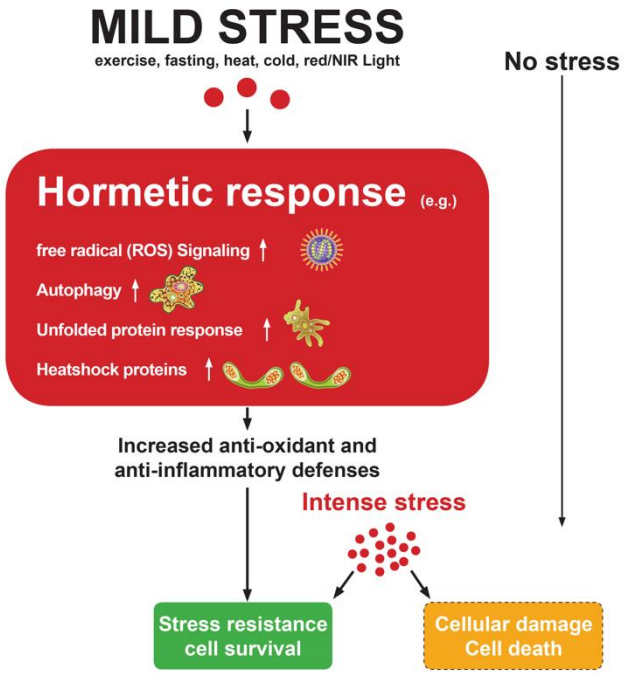
The mitochondria get temporarily stressed in a way that causes them to send signals back to the nucleus of the cell (which contains your DNA), and these signals are literally used by the nucleus to determine what genes should be expressed. This is called "retrograde signaling." It's a remarkable phenomenon,

because most people think that our genes do all the dictating of what happens in our cells. In fact, mitochondria generate signals (based on the environment) that signal back to the nucleus which genes to switch on and off!

In particular, the transient increases in ROS (free radicals) from red/NIR light activates many of the same cell defense systems that exercise does. The transcription factor NF-kB is activated through exposure to free radicals generated by red and near-infrared light, which promotes a very low level inflammatory response. This then engages a mechanism called the NRF2 pathway and the Antioxidant Response Element (A.R.E.) – our internal cellular antioxidant defense system – which helps put out the fire by eliminating the inflammation and free radicals. In short, in much the same way that exercise builds your muscles stronger by temporarily stressing them, light does the same thing to our internal anti-oxidant and anti-inflammatory defense system. It helps make your cells more tolerant to stress, combats inflammation, helps prevent the buildup of free radicals, and ultimately makes your cells healthier, more energetic, and more resilient.

It turns out that humans actually *need* some of these low-level stressors in their life. The absence of these stressors actually sabotages our health.

Light serves a transient low-level stress to your cells. The end result of these cellular adaptations to the temporary stress is *healthier* cells that produce more energy, have a stronger anti-oxidant and anti-inflammatory defense system, and are more resilient to overall stress.



This is the same way that exercise makes us healthier. Near-infrared and red light therapy also work by temporarily creating an increase in metabolic stress and increasing reactive oxygen species (free radicals), just like exercise.[38] In that sense, some researchers have called it an "exercise mimetic" because it mimics some of the same effects of exercise. (As you'll see in a later section, research shows that it also combines well with exercise and amplifies the benefits on fat loss and muscle gain). So near-infrared and red light therapy also are a form of hormesis, and benefit the mitochondria by creating a low dose stressor that the body then adapts to by becoming even stronger – the body increases production of internal antioxidant and anti-inflammatory systems, and builds up the size and strength of mitochondria.

In this way, red/NIR light become a powerful tool that doesn't just temporarily alleviate symptoms (like say, an anti-inflammatory or painkiller drug), but it stimulates your body making *lasting* adaptations at the cellular level that lead to more resilience against stressors and a greater capacity to produce energy.

Potential Mechanisms

In addition to these– what I consider to be the two most important general mechanisms – there are a couple of other fascinating potential mechanisms for how red/NIR light works inside our bodies. Some of these potential mechanisms may even revolutionize our understanding of human biology and how our cells produce energy. (I list these as "potential mechanisms" because we have some evidence for them, but not enough yet for there to be a consensus within the scientific community that they are "proven." Further

studies are still needed for widespread acceptance of these physiological mechanisms, but they are incredibly exciting nonetheless!)

Potential Mechanism #1: Interacts with water in our cells to produce more energy

Water itself is a photoacceptor. That means that water can actually absorb the energy from some wavelengths of light – including wavelengths in the red and near-infrared spectrum.

This may not be such a trivial fact.

Why?

Water fills our cells. While many people think of our cells as just bags of inert water– just a place for chemical reactions of other compounds to take place –this may in fact not be accurate. The water in our cells itself may be impacted by the light exposure in a way that affects cell function. That is, the water itself may have much more biological activity than we have previously thought.

Researchers have found that when water that is next to surfaces that are biochemically similar to structures in our cells, is exposed to red/NIR light, it literally changes the viscosity of water. The water literally changes in "thickness" and "wetness."

Think of it like this. Imagine swimming through a pool of water vs. swimming through a pool of Jell-O.

It's a heck of a lot easier to swim through regular water than through Jell-O, right?

The point is that things that are surrounded by liquid which need to move, will likely function a whole lot better if the liquid that surrounds them is not giving a lot of resistance. That's the basic idea here.

A 2015 study published in *Scientific Reports* titled "*Light Effect on Water Viscosity: Implication for ATP Biosynthesis"* suggests this may be exactly what is going on inside our mitochondria.

The researchers suggested that if this change in water viscosity occurs inside our cells, which is probable according to many experts – may allow the physical rotation of the ATP synthase pump on the mitochondria (the little motor on the mitochondria that actually pumps out cellular energy) to operate more efficiently.[39] (Side note: This is likely related to Gerald Pollack, PhD's work on the "fourth phase" of water, which he has written a book on and done several interviews and TED talks that can be found on YouTube).

To some extent, much of this has in fact already been demonstrated – that light does in fact affect water viscosity when next to surfaces that are ostensibly similar to cellular membrane surfaces, and that light increases ATP production. But as explained earlier, the conventional explanation for this is solely that red/NIR light impact the mitochondrial respiratory chain components (e.g. cytochrome c oxidase). Based on their findings, the researchers of this 2015 study suggest that it may be due (partly or mostly) to how light affects the water viscosity in the mitochondria and allows for easier rotation of the ATP synthase pump.

The researchers of this 2015 study summarized their findings by saying:

> "Thus, we feel justified to assume that the [red/NIR] irradiation upregulates ATP turnover by reducing the viscosity of the nanoscopic interfacial water layers which seem to control the efficiency of the mitochondrial nanomotor. The insight deduced from our laboratory experiments is expected to allow the improvement of the present theories and hypotheses of light-induced ATP synthesis, and promises to enhance the predictive capability of existing models. Explicitly, realistic models designed to explore the functioning of ATP synthase may have to consider interfacial viscosity gradients, within and around the nanoturbine [the ATP synthase pump]. This aspect is of considerable biological interest and may lead to a shift in the paradigm of ATP synthesis."[40]

In short, the idea here is that red/infrared light penetrates cells and makes the water thinner and more slippery, so the little ATP motor in the mitochondria rotates with less friction and ultimately pumps out more energy. Again, this is a potential mechanism still, and we need more research to know for sure if this is in fact a major mechanism of action. But it's pretty exciting to think of these possibilities!

Potential Mechanism #2: Interacts with chlorophyll in our cells to help our mitochondria produce more energy.

For most of the history of biology, plants and animals have been thought of as autotrophs and heterotrophs, respectively.

"Autotrophs" are those organisms which provide their own food sources. Plants do this by capturing sunlight and doing a process called photosynthesis. (Carbon dioxide + Water → Carbohydrates + Oxygen)

"Heterotrophs" are organisms which consume other organisms for food. E.g. Whether animals are herbivores, omnivores or carnivores, they are eating other organisms to acquire their energy.

For most of biology, we have generally classified organisms into these categories. But with some exceptions we have called "photoheterotrophs" or "mixotrophs." Most corals, for example, can both synthesize energy from sunlight as well as consume organisms like plankton. Another example is the Venus flytrap and other insect-eating plants that can derive energy both from sunlight and from the organisms they consume. More examples include some types of non-sulfur bacteria, heliobacteria, many types of plankton, and even many types of insects.

But of course, humans have always been conceptualized as purely "heterotrophs." We need to eat plants and animals of various kinds to get our energy.

Yet, I have already explained that hundreds of studies have now found that human cells – the mitochondria in our cells – *do actually produce more ATP when exposed to red/NIR light!*

And it even goes further than that…

A recent study has actually found that other organisms – including mammals that are biologically very similar to humans (like rodents and pigs) – have now been shown to be capable of taking up chlorophyll metabolites into their mitochondria, and using those metabolites to capture sunlight energy and amplify cellular energy production! The research suggests that some animals can use these chlorophyll metabolites to speed up the rate of energy production and increase the overall volume of ATP produced by fairly large amounts in many cases.

This revolutionary discovery was published in 2014 in the Journal of Cell Science in a study titled "**Light-harvesting chlorophyll pigments enable mammalian mitochondria to capture photonic energy and produce ATP**."

Here is a chunk of the abstract from this fascinating study, where researchers succinctly summarized their findings:

> "Sunlight is the most abundant energy source on this planet. However, the ability to convert sunlight into biological energy in the form of adenosine-59-triphosphate (ATP) is thought to be limited to chlorophyll-containing chloroplasts in photosynthetic organisms. **Here we show that mammalian mitochondria can also capture light and synthesize ATP when mixed with a light-capturing metabolite of chlorophyll**."[41]

So how do light and chlorophyll interact in our cells to help our mitochondria produce more energy?

Specifically, it appears that chlorophyll metabolites and light may have some synergy that affects one of the key players in mitochondrial energy production – CoQ10.

A 2013 study titled "Dietary chlorophyll metabolites catalyze the photoreduction of plasma ubiquinone" found something remarkable.
First, you need to understand a bit about how CoQ10 works in our cells. CoQ10 is often thought of as simply an "antioxidant," but it is much more than that – it does many things that go far beyond just neutralizing free radicals. In particular, it acts to facilitate electron transfer in mitochondria to allow energy production. Now, in order for CoQ10 to do its work of facilitating mitochondrial energy production, it has to be constantly "regenerated" from its oxidized form (ubiquinone) to its active form (ubiquinol). When much of the CoQ10 is being oxidized, but it's not being efficiently converted back into ubiquinol, we get problems. We accumulate ubiquinone and our ubiquinol stores are low. (In fact, CoQ10 deficiencies are very common. And that's why there is so much positive research around CoQ10 supplementation.)

But what if the reason our CoQ10 stores (especially ubiquinol) are decreased in the first place is actually a deficiency in sunlight exposure and chlorophyll consumption?

These researchers took dietary chlorophyll metabolites (compounds that our bodies actually make when we consume dietary chlorophyll) and mixed it with some CoQ10 in ubiquinone form.

Then they exposed the chlorophyll metabolite and CoQ10 solution to red light…

Guess what happened?

The ubiquinone form of Coq10 was regenerated into ubiquinol CoQ10!

But without the chlorophyll metabolites or the red light, no ubiquinone gets converted to ubiquinol!

Pretty damn amazing, right?!
It turns out that light can actually interact with chlorophyll metabolites in a way that leads to the regeneration of CoQ10!

What kind of light has this effect?

Well, as luck (or biological design) would have it, it's the kind of light that penetrates deep into our body – red/NIR light. (Remember, most light only gets absorbed at the skin, but red/NIR light can penetrate beyond the skin, deep into our body.) In short, this research suggests that we are in fact designed by nature in such a way that the wavelengths of light that happen to penetrate deeply into human tissues are biologically active in human cells, and do a lot of amazing things – including, interacting with chlorophyll metabolites and helping to regenerate the active form of CoQ10.

The researchers of this study suggest that red/NIR light and chlorophyll may in fact be the key players in helping our cells maintain the proper ratio of ubiquinone to ubiquinol.

But you might be wondering "Can't this only affect the cells that light can penetrate into? And since red/NIR light can only penetrate a couple inches into the body, this wouldn't affect all the cells of our body deeper than that, right?"

Interestingly, it turns out that ubiquinol can be carried in our bloodstream. So theoretically, the ubiquinol that cells produce could be carried to cells throughout the entire body via the bloodstream. Hence the light may have effects on all the cells of the body, not just the cells that light can penetrate directly.

In the words of the researchers of this remarkable study:

> "The mechanisms responsible for maintenance of plasma ubiquinol are poorly understood. Here, we show that metabolites of chlorophyll can be found in blood plasma of animals that are given a

> chlorophyll-rich diet. We also show that these metabolites catalyze the reduction of plasma ubiquinone to ubiquinol in the presence of ambient light, in vitro. We propose that dietary chlorophyll or its metabolites, together with light exposure, regulate plasma redox status [the balance of oxidants to antioxidants] through maintaining the ubiquinol pool."[42]

And here is the astounding conclusion from these researchers of the previously mentioned chlorophyll study:

> "Both increased sun exposure and the consumption of green vegetables are correlated with better overall health outcomes in a variety of diseases of aging. These benefits are commonly attributed to an increase in vitamin D from sunlight exposure and consumption of antioxidants from green vegetables. Our work suggests these explanations might be incomplete. Sunlight is the most abundant energy source on this planet. Throughout mammalian evolution, the internal organs of most animals, including humans, have been bathed in photonic energy from the sun. Do animals have metabolic pathways that enable them to take greater advantage of this abundant energy source? The demonstration that: (1) light-sensitive chlorophyll-type molecules are sequestered into animal tissues; (2) in the presence of the chlorophyll metabolite P-a, there is an increase in ATP in isolated animal mitochondria, tissue homogenates and in C. elegans [roundworms], upon exposure to light of wavelengths absorbed by P-a; and (3) in the presence of P-a, light alters fundamental biology resulting in up to a 17% extension of life span in C. elegans suggests that, **similarly to plants and photosynthetic organisms, animals also possess metabolic pathways to derive energy directly from sunlight.**"[43]

I must say that I personally found these studies to be some of the most exciting and potentially revolutionary studies I have read in years! Who would've thought that human cells have the ability to use chlorophyll to capture energy from sunlight?

A quick funny story: When I was in high school 20 some years ago, I had a biology teacher who everyone thought was totally nuts, because she would drink vegetable juices and then go lay in the sun. She was convinced that there was some synergy between consuming the chlorophyll and exposing her body to the sunlight.

We used to joke around that our crazy biology teacher thought she was a plant and that she could photosynthesize! We thought the whole idea was total nonsense and that she was crazy.

But hey, 20 years later, it turns out that maybe she was onto something after all! Human mitochondria may in fact have the ability to use dietary chlorophyll metabolites and red/NIR light to more efficiently produce energy!

Mechanisms Summary

In short, it is clear that humans can indeed harness sunlight energy and translate it into energy production by our mitochondria – either through the conventional cytochrome c pathway (the widely accepted pathway), or through how light affects water viscosity and the ability of mitochondria to pump out ATP, or by using chlorophyll metabolites to more efficiently produce energy, or through increased production of CoQ10 in the mitochondria, or perhaps through some combination of all of these mechanisms. More research is certainly needed to confirm these speculative pathways, but they are certainly fascinating to think about, and if proven, they have the potential to revolutionize our understanding of human biology.

Now let's move away from the more speculative mechanisms and cutting-edge research, and get back to the scientific consensus…

The bottom line here is that we have scientific evidence for several mechanisms of how near-infrared and red light therapy enhance mitochondrial energy production and overall cell function.

In essence, what this all boils down to is that near-infrared and red light therapy help mitochondria produce more energy, decrease inflammation, and help build the cell defense systems to increase resiliency.

But as mentioned above in the list of factors known to be affected by red/NIR light, there are also many other mechanisms of action of near-infrared and red light therapy which researchers are still elucidating. It is likely that other effects on specific compounds (e.g. BDNF, cAMP, nitric oxide, etc.), on stem cells,[44] on hormones,[45,46] DNA repair,[47] or some other specific effects on gene expression[48,49,50] also play a role in mediating many of the positive effects of red/NIR light therapy.

The truth is that it's possible to get endlessly complex and nuanced about all the different molecular and biochemical pathways involved. An entire textbook could be written on the various pathways. (And that's acknowledging that many of the mechanisms are still being elucidated, and some may even yet to be discovered.) One study gave a nice brief encapsulation of the mechanisms by saying:

> "During near-infrared phototherapy, absorption of red or near-infrared photons by COX (cytochrome c oxidase) in the mitochondrial respiratory chain causes secondary molecular and cellular events, including activation of second messenger pathways, changes in NO levels, and growth factor production. NILT (near-infrared light therapy) leads to the reduction of excitotoxicity, the production of neurotrophic factors, the modulation of ROS, the transcription of new gene products with protective or pro-proliferative properties, and the release of numerous growth factors for neurons and other cells. near-infrared appears to initiate a cascade of subcellular events which can yield immediate, delayed, and persistent beneficial changes in the injured neuron or other cell."[51]

So the reality is that there are dozens of signaling pathways in the cell and between cells that are affected by red/NIR light. But again, to simplify all this, most experts agree that the primary mechanism of action is how it works to increase mitochondrial energy production.

In essence, red and near-infrared light "lights up" this engine of the cell, driving ATP production by the mitochondria. And since everything cells do depend on energy supplied by the mitochondria, red light and near-infrared light therapy have been linked with a wide range of amazing benefits:

- Anti-aging effects in the skin (enhancing collagen synthesis, production, and elastin production for youthful skin and dramatically reducing cellulite) [52]
- Lowering inflammation
- Enhancing fat loss[53]
- Enhancing physical performance and muscle recovery afterward[54]
- Boosting testosterone[55]
- Speeding wound healing[56]
- Spurring neurogenesis in the human brain, strengthening synapses, spurring brain cell growth[57]
- Helping prevent cognitive decline[58]
- Reducing waist circumference and liberating fat from cells so it can be burned again[59]
- Enhancing physical performance and muscle recovery afterward[60]
- Enhancing fertility[61]
- Combatting gingivitis and promoting healthy gums[62]
- Enhancing stem cell implantation and proliferation[63]
- Enhancing gland health from the thyroid to the lymphatic system
- Clearing skin for sufferers of acne, rosacea, eczema, psoriasis[64]
- Improving eye health[65]
- Fighting chronic fatigue and fibromyalgia[66,67,68]
- Potentially helping the body to fight cancer (in tandem with chemotherapy)[69]
- Removing wrinkles, lines, and veins on the surface of the skin[70]
- Increasing energy
- Improving the appearance of scars[71]

- Killing pain[72]
- Protecting cells against damage from stress[73]

This list might seem too good to be true. How could one technology benefit so many totally different types of conditions?

It almost seems to claim that it's a panacea. So it's only natural to express skepticism.

Yet, the reason it can benefit all these radically different conditions is actually quite simple: **The health of every organ and every cell in the body depends on the energy being produced by the mitochondria in those cells. Thus, because red/NIR light therapy work to enhance mitochondrial energy production in essentially *every* type of cell in the body, it can enhance the cellular processes and cellular health of potentially almost every type of cell in the body.**

In essence, the basic principle is this: Whatever cells you shine it on – whether muscle, skin, gland, or brain – those cells will work *better* when the mitochondria in those cells are producing more energy.

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