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Further advancements in the near infrared light-emitting diode: review

Abstract

During the last decade, significant advances have been made in the application of using a near infrared LED light-emitting diode over the use of low-level laser light therapy for a wide range of healing and rehabilitation processes. Near infrared LED has been shown to represent a novel, non-invasive, and effective coadjutant therapeutic intervention for the treatment of numerous diseases. With the discovery of the use of gallium arsenate (red light), the near infrared light-emitting diode has shown to be an effective therapy in the use of wound, bone, and traumatic brain injuries. Specific applications include wound healing, dentistry, peripheral nerve injury, depression, neurological disease (including Parkinson's Disease, depression, and dementia), aging cerebrovascular disease, and traumatic brain injury. Most recently, the application of infrared light on brain tumors (photodynamic therapy) has started to provide a positive result. More evidence-based research is required to support this growing coadjutant therapeutic intervention.

Keywords: near infrared, light-emitting diode, organic light-emitting diode, malignant astrocyte tumor, sports medicine, dentistry, inflammation

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Abbreviations: NASA, national aeronautics and space administration; NIRS, near infrared spectroscopy; HIE, hypoxic ischemic encephalopathy; ATP, adenosine tri-phosphite; PBM, Photobiomodulation; PTSD, post-traumatic stress syndrome

Introduction

William Herschel was an astronomer and physicist who was born in Hanover, Germany in 1738 and died in England in 1822. In 1800, Herschel conducted an experiment using a spectrometer that measured the amount of heat that passed through the different color filters he used to observe sunlight. He found that different colors generated different amounts of heat when the light passed through a glass prism. He used this prism to create a spectrum, measuring the heat of each color. Hershel observed a pattern associated with each color as temperatures increased from violet to red along the spectrum. Herschel decided to measure the temperature "just beyond" the red portion of the spectrum. Although this segment of the band was absent of sunlight, it surprisingly had the highest temperature. Herschel called this area of the spectrum "calorific rays". These rays were reflected, refracted, absorbed, and transmitted in a matter similar to visible light.[1] At the beginning of the 1900s, near infrared light was used to analyze the chemical makeup of abnormal and normal tissue pathology. During the Industrial Revolution, approximately 50 years later, advancements allowed invisible light to be analyzed in both organic and inorganic materials. In 1962, the LED was invented. However, early LEDs lacked the capability to produce biologically relevant energies. In 2015, Opel et al.,[2] discovered red light was produced via an electrical current of 1.2 volts when passing through a gallium arsenate crystal, an inorganic light-emitting diode. This advancement opened a new chapter in the utilization of near infrared light (low-level laser therapy).

The National Aeronautics and Space Administration (NASA) and the University of Wisconsin collaborated in their efforts to experiment with the use of near infrared light-emitting diode for wound healing. In 1961, NASA discovered that they could also be used to grow vegetables and then tested this ability on the International Space Station with the Space Agency's Veggie Experiment. But wasn't until 2016 that NASA astronauts were able to eat salad from the vegetables they had grown in the Space Lab. Mark E. Kelly received a call from his twin brother, astronaut Scott J. Kelly while in Space, stating he was enjoying a salad grown with the help of near infrared light-emitting diode (NASA, 2005).

Today, the near infrared light-emitting diode is used across a broad range of industries and functions. Infrared security cameras are used by police and security systems as well as in firefighting to help find people and animals caught in smoke and for detecting hot spots in forest fires. Infrared imaging is used to measure ocean temperatures which assists meteorologists in climatic weather changes. Asphalt repairs utilize infrared to heat old asphalt and mix new asphalt for better repairs. In warfare, the military uses near infrared to detect heat by the use of night vision goggles and heat-seeking missiles, tanks, and armored vehicles. Art restoration applies near infrared to look under layers of paint to see if there are older layers and/or additional art underneath. Near infrared imaging spectrometers are used on Earth and in Space to help map hydrous minerals in surface layers of the ground. It is even used on rover missions on Mars to identify mineralogical species. Infrared astronomy uses near infrared to detect even very cold objects, including comets and asteroids, as any object which has a temperature radiates in the infrared (NASA, 2005). Home uses include heating with infrared panels, cooking with infrared ovens, TV remote controls, toasters, and heat lamps.

Spectroscopy

The penetration of the near infrared light beam of human tissue reveals that most of the light photons at wavelengths between 630-800nm travel approximately 23cm through the surface tissue and muscle between input and exit at the photon detector.[3] The prototype of visible-to-NIR light penetration is summarized based on the subsequent study of variables that include wavelength, coherence, operation mode, beam type, size, irradiation site, species, age, and gender.[4] Cerebral near infrared spectroscopy (NIRS) provides real-time information regarding changes in metabolism. Hemodynamic and oxygenation refractory light is commonly used in the surgical suite to analyze oxygen. Using a penetrating light of 4-6cm in depth, it can reach affected tissue (refractory near infrared).[5] When combined with other useful monitoring tools, such as an EEG, NIRS can provide great benefit in neuromonitoring to detect cerebral hyperoxygenation, increased cerebral perfusion, and loss of cerebral autoregulation in neonates under dystonic delivery or infants with severe Hypoxic Ischemic Encephalopathy (HIE).[6] Functional near infrared spectroscopy has assisted in the research of the infant brain and its ability to respond to sounds as early as 3 months in utero and how it advances at 6 months to varying social-communicative sounds.[7]

NIRS is a non-invasive method that can detect compromised tissue oxygenation and minute changes in regional tissue oxygenation.[8] NIRS can be used to better evaluate the tissue oxygenation and the amount of CO_2 in the tissue of newborns with congenital heart disease. Notably, neonatal patients with lower postoperative cerebral tissue oxygen are associated with poor neurodevelopmental outcomes. However, with NIRS preoperative cerebral near infrared spectroscopy monitoring through the utilization of a variability analysis, it can assist in the prediction of neurodevelopment outcomes in neonates undergoing surgery for congenital heart disease.[9] NIRS oxygen saturation has been favored to avoid neurological complications in diffuse correlation spectroscopy (NIR dcs), and diffuse reflectance spectroscopy (NIRdrs).[10] NIRdcs uses coherent NIR light to penetrate deep tissues and measure speckle fluctuations of the diffuse light, which are sensitive to the motions of red blood cells in tissue.[11] Diffuse correlation spectroscopy, a new rapidly developing technique, can continuously measure blood flow in the superficial muscles. The diffuse correlation spectroscopy methodology uses the unique approach of monitoring muscle blood flow by measuring the optical phase caused by moving blood cells. While NIRtrs and NIRpms are more accurate due to their ability to monitor changes in both absorption and scattering, they are limited in practicality by higher costs and complexity. This leaves the continuous wavelength devices (NIRsdcws and NIRmdcws) as affordable alternatives for measuring changes in oxygen levels in tissues, even if these devices cannot account for changes in scattering.

Inflammation

Inflammation can be characterized by acute and chronic phases. During acute inflammation, the release of chemical mediators modulates vascular and cellular phenomena such as chemotaxis, leukocyte activation, phagocytosis, and release of leukocyte products.[12] Histamine is an early mediator of inflammation released from mast cells during injury which causes vasodilation.[13] Stimulation via near-infrared LED or low-level lasers can modulate the number of mast cell degranulation.[14–16]

For acute inflammation, research has shown near infrared LED-induced therapy generated increases in Nitric Oxide, Adenosine Tri-Phosphite (ATP), and neurotransmitters, resulting in higher activity in cell proliferation and differentiation into mature cells.[17,18] Photobiomodulation (PBM) involves the use of near infrared LED to produce a beneficial effect on the cells or tissue and has a marked effect on stem cells.[19]

Chronic inflammation is characterized by the infiltration of mononuclear inflammatory cells, and tissue destruction.[20,21] The application of near infrared LED significantly inhibits the expression of interferon-y and IB and decreases inflammation by changing the expression of genes encoding inflammatory cytokines.[22, 23] Near infrared wavelengths (800-960nm) can penetrate through the scalp and skull (2-3%-1cm).[24] These near infrared wavelengths have the potential to improve the subnormal, cellular activity of compromised brain tissue by increasing ATP production in the mitochondria[25] and increasing regional cerebral blood flow.[26] Traumatic brain injuries are challenging given the elusiveness of the injury, the sensitivity and specificity of the evolving nature of concussive injury, cognitive dysfunction, post-traumatic stress syndrome (PTSD), and chronic traumatic encephalopathy.[27, 28, 29]

Cognitive and executive function

The mechanism of photobiomodulation (PBM) is based on bioenergetics, photochemistry, and photobiology. Specific molecules inside the neurons absorb the photons and change the rate of metabolic reactions within the cells, ultimately activating signaling pathways and transcription factors.[30–32] The primary molecular photoreceptor of red and near infrared light is cytochrome c oxidase, which is a key enzyme in the mitochondrial respiratory chain. PBM is a non-invasive technique that has been found to exert positive effects on cognitive function.[33] Hamblin recognized that using near infrared LED can be applied to different disorders such as traumatic events (stroke, traumatic brain injury, global ischemia), degenerative diseases (dementia, Alzheimer's, and Parkinson's Disease), and psychiatric disorders (depression, anxiety, post-traumatic stress disorder).[34] Cognitive impairment and mobility disability are key contributors to dementia and the loss of independence in the activities of daily living resulting in a negative synergistic effect.[35]

According to Henderson et al.,[33] the frontal lobe hypothesis of age-related cognitive decline suggests that the deterioration of the prefrontal cortical regions that occur with aging leads to executive function deficits. Executive function refers to a set of administrative and decision-making abilities that are important for behavior, namely the planning and initiation of actions, selection of relevant information, inhibition of irrelevant information, and flexible thinking.[36] In 2018, Hamblin recommended the use of NIR LED on cerebrovascular accidents due to the studies that have shown improvement in executive function, working memory, and sleep. He also stressed the activity of intracellular mitochondrial regarding an increase in the level of ATP and improvement of the oxygen energy channel.[37] The association of the neurocognitive and executive function was accomplished using the scanning near infrared analysis in what became the first study of its kind, using the oxygen in the brain. This analysis showed the frontal left lobe to be a primary target of this function.

Conclusion

This review only touched upon the surprising ability of near infrared LED in various healing and rehabilitation processes. Notably, the physiology of cellular change through this application is clinically supported (see other research papers presented by Burkow-Heikennan). Near infrared LED has been shown to represent a novel, non-invasive, and effective coadjutant therapeutic intervention for the treatment of numerous diseases. A key application includes allowing for real-time information to detect cerebral compromised oxygenation during surgical procedures. It has also been shown to be an effective coadjutant treatment for neurological diseases, psychiatric disorders, and traumatic brain disorders. Near infrared LED can also be used in the treatment of reducing inflammation and bone healing. While new research is on the horizon, more evidence-based research should be conducted on behalf of wound, bone, and traumatic brain injuries to develop this growing, noninvasive modality for healing and rehabilitation. To date, much of the research is anecdotal, but it suggests there would be true value in pursuing evidence-based investigation through both randomized and controlled studies.

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Conflicts of interest

The author declared no conflict of interest with any company.

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