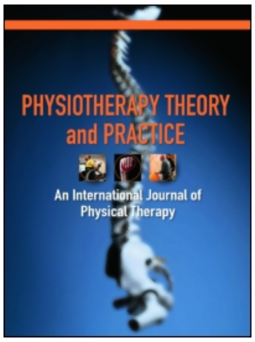

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The history of light therapy in hospital physiotherapy and medicine with emphasis on Australia: Evolution into novel areas of practice

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ABSTRACT

Objective: The objective of this narrative review was to investigate the history of light therapy in hospital settings, with reference to physiotherapy and particularly in an Australian context.
Types of articles and search method:a review of available literature was conducted on PubMed, Medline and Google Scholar using keywords light therapy, photobiomodulation, physiotherapy, low-level laser, heliotherapy. Physiotherapy textbooks from Sydney University Library were searched. Historical records were accessed from the San Hospital library. Interviews were conducted with the San Hospital Chief Librarian and a retired former Head Physiotherapist from Royal Prince Alfred Hospital.
Summary: Historically, light treatment has been used in both medical and physiotherapy practice. From its roots in ancient Egypt, India, and Greece, through to medieval times, the modern renaissance in 'light as therapy ' was begun by Florence Nightingale who, in the 1850s, advocated the use of clean air and an abundance of sunlight to restore health. Modern light therapy (phototherapy) had a marked uptake in use in medicine in Scandinavia, America, and Australia from 1903, following the pioneering work of Niels Finsen in the late 19th century, which culminated in Dr Finsen receiving the Nobel Prize for Medicine for the treatment of tuberculosis scarring with ultraviolet (UV) light, and treatment of smallpox scarring with red light. Treatment with light, especially UVB light, has been widely applied by physiotherapists in hospitals for dermatological conditions since the 1950s, particularly in Australia, Scandinavia, USA, England and Canada. In parallel, light treatment in hospitals for hyperbilirubinemia was used for neonatal jaundice. Since the 1980s light was also used in the medical specialties of ophthalmology, dermatology, and cardiology. In more recent years in physiotherapy, light was mostly used as an adjunct to the management of orthopedic/rheumatological conditions. Since the 1990s, there has been global use of light, in the form of photobiomodulation for the management of lymphedema, including in supportive cancer care. Photobiomodulation in the form of low-level laser has been used by physiotherapists and pain doctors since the 1990s in the management of chronic pain. The use of light as therapy is exemplified by its use in the San Hospital in Sydney, where light therapy was introduced in 1903 (after Dr. John Harvey Kellogg visited Niels Finsen in Denmark) and is practiced by nurses, physiotherapists and doctors until the present day. The use of light has expanded into new and exciting practices including supportive cancer care, and treatment of depression, oral mucositis, retinopathy of prematurity, and cardiac surgery complications. Light is also being used in the treatment of neurological diseases, such as Parkinson's disease, traumatic brain injury, and multiple sclerosis. The innovative uses of light in physiotherapy treatment would not be possible without the previous experience of successful application of light treatment.
Conclusion: Light therapy has had a long tradition in medicine and physiotherapy. Although it has fallen somewhat out of favour over the past decades, there has been a renewed interest using modern techniques in recent times. There has been continuous use of light as a therapy in hospitals in Australia, most particularly the San Hospital in Sydney where it has been in use for almost 120 years.

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Introduction

This paper will explore the relationship between the history of the use of light in physiotherapy and its potential as a novel treatment for a number of intractable diseases. A number of examples of traditional light therapy are presented along with the evolution of light therapy into photobiomodulation and experimental treatments for cardiovascular disease, neurological diseases such as multiple sclerosis and Parkinson's disease,

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and supportive cancer care, particularly the treatment of lymphedema and oral mucositis.

The history of light treatment in physiotherapy is closely paralleled by the history of light treatment in medicine. Light has been used in medicine in many guises, importantly as a diagnostic tool such as in microscopy, spectrometry, quantitative PCR and ELISA techniques. It is increasingly used for sophisticated optogenetic research in diagnosis and treatment. Light is used as a trigger for photodynamic therapy (PDT), where photosensitive dyes are activated to release reactive oxygen species in order to kill infective microorganisms or cancer cells (Hamblin, 2016). Light can also be used as a direct therapy, including thermal and non-thermal laser applications, light emitting diodes (LED), bright light and intravenous and transdermal UVB applications.

Light has been used as a treatment for medical conditions since ancient times, with its origins as "heliotherapy" (natural sunlight) for the treatment of skin diseases. Some 3,500 years ago, the ancient Egyptians used a weed grown on the banks of the Nile (*Amul majus*) followed by sun exposure, to treat vitiligo (Hönigsmann, 2013). This treatment is analogous to the modern photochemotherapy (PUVA) first applied in 1974, with extension of its use to various other conditions (Hönigsmann, 2013). The field of photochemotherapy has recently expanded into the treatment of multiple sclerosis (MS) using UVB (Hart, Finlay-Jones, and Gorman, 2009; Hart et al., 2018) after the work on the immunosuppressive effects of UVB (McGonigle et al., 2017).

Modern phototherapy has its origins in the latter part of the 19th century (Figure 1), with the observation, in 1877, that sunlight was beneficial in the treatment of anthrax infections (Downes and Blunt, 1877) and then in 1890, when it was employed for the treatment of rickets (Palm, 1890).

The combination of this early research in medicine, as well as the influence of Florence Nightingale with her view that … "*It is the unqualified result of all my experience with the sick that, second only to their need of fresh air, is their need of light; that, after a close room, what hurts them most is a dark room and that it is not only light but direct sunlight they want.*" (Nightingale, 1859) was the beginning of light therapy, both as heliotherapy (natural sunlight) and phototherapy (artificial light). Arnold Rikli also advocated the healing potential of light and heliotherapy, with the establishment of helio-hydrotherapy centers in the 1850s in Bled (Slovenia). The awarding of the 1903 Nobel Prize in Medicine to Niels Finsen, for his work on the use of light in treatment of disease, paved the way for the continued and expanded use of light therapy in the 20th century and beyond, including the use of light in physiotherapy.

History of light treatment in modern physiotherapy

Nonthermal light treatment in the disciplines of medicine and physiotherapy began with the treatment of dermatological conditions (Figure 1). In the late 1890s, Niels Finsen began treating lupus vulgaris with blue and UV light and smallpox scarring with red light, using lamps and filters. His results were published in the British Medical Journal in 1895 (Finsen, 1895) and in The Lancet in 1903 (Finsen, 1903). The Editorial in the BMJ (Valdemar, 1899) included "the uptake shows the treatment spread quickly around the world". One example of this uptake was by Dr. John Harvey Kellogg, who traveled to Denmark to work with Finsen and introduced light boxes to his clinics in Battle Creek, Michigan in 1891 (Schwarz, 2006). His brother, Dr. Merritt Kellogg, introduced light therapy into the newly formed Sydney Adventist (San) Hospital, also in 1903 (Michael Rigby, San Librarian, pers. com., Sydney Adventist Hospital archive marg\wpold\history). A full account of the treatment rationale and protocol was published by Dr. John Harvey Kellogg in 1910 (Kellogg, 1910) and as a result of his early medical practice, light therapy has been in use in the Seventh Day Adventist health institutions in various forms for over a hundred years.

Light treatment was originally performed by nurses and massage therapists. In 1906 these therapists joined the Australian Massage Association, which, in Australia, evolved into "physiotherapy" during World War I and the term was formalized in 1939 (McMeeken, 2008; Sellentin, 2015). Nurses at the San Hospital were taught massage and hydrotherapy from 1906 and in the 1940s were offered membership of the Society of Massage and Electrotherapy and given automatic registration into the society in 1946 (Michael Rigby, San Librarian, pers. com., Sydney Adventist Hospital archive marg\wpold \history) (Figures 1 and 2).

There was a period after the extensive use of light in the 1930s, when phototherapy, which includes UV and far-infrared (thermal) wavelengths, resulted in injury with home-use applications. This came about due to untrained persons, who without adequate considerations of dose and timing, caused burns. This controversy surrounding light therapy was well documented (Woloshyn, 2017). After Medical Board consultation in Britain, UVB light therapy was restricted to hospital use to be administered by health professionals including physiotherapists and nurses.

Mrs Pam Wilster, the former Head Physiotherapist of the Royal Prince Alfred (RPA) Hospital (Sydney) for over three decades, reported administering phototherapy to children in The London Hospital, for such diverse

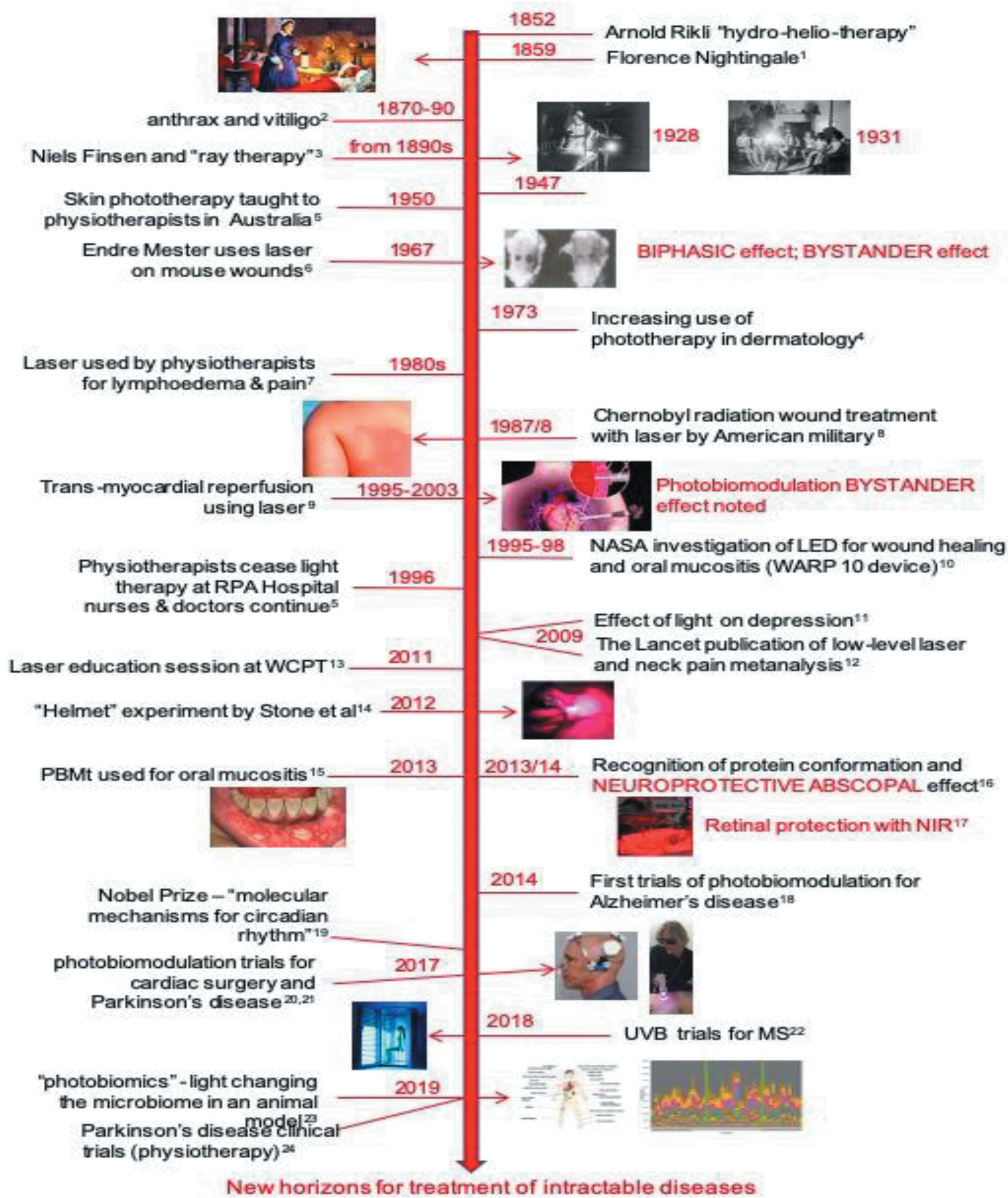

Figure 1. Timeline of the history of the use of light as therapy in physiotherapy and medicine. (1) Nightingale (1859); (2)https://flashbak.com/light-therapy-for-naked-children-delicate-adults-sick-pigs-and-quacks-photos-1900-1950-41389/(3 Finsen (1895); (4) Finsen (1903); (4) Hönigsmann (2013); (5) pers. com Pam Wilster, former Head Physiotherapist, Royal Prince Alfred Hospital, Sydney; (6) Mester, Juhász, Varga, and Karika (1968); (7) Piller and Thelander (1996); (8) Ralf Uwe et al. (1994); (9) Horvath et al. (2001); (10) https://spinoff.nasa.gov/database/spinoffDetail.php?this=/spinoff/msfc/MSFC-SO-161; (11) Schiffer et al. (2009); (12) Chow, Johnson, Lopes-Martins, and Bjordal (2009); (13) Nussbaum, Gabel, Bjordal, and Houghton (2011); (14) Stone, Johnstone, and Mitrofanis (2013); (15) Hallett (2015); (16) Liebert, Bicknell, and Adams (2014); (17) Natoli et al. (2013); (18) Hamblin (2016); (19) https://www.nobelprize.org/prizes/lists/all-nobel-laureates-in-physiology-or-medicine/(2018); (20) Hamilton et al. (2018); (21) Kiat (2017); (22) Hart et al. (2018); (23) Liebert et al. (2019); (24) Liebert and Bicknell (2019).

diseases as rickets, dermatitis, and autoimmune disorders such as asthma (Pam Wilster, pers. com.). These free treatments were available in London hospitals, including the Royal London Hospital, from 1899 (https://flashbak.com/light-therapy-for-naked-children-delicate-adults-sick-pigs-and-quacks-photos-1900-1950-41389/), and were given by nursing staff and masseurs, who went on to become registered physiotherapists (Woloshyn, 2017). Pam Wilster instigated this treatment at RPA in 1958 for the prevention of rickets and asthma. Physiotherapists were applying UVB treatment at RPA hospital in Sydney continuously until 1995 when the procedures were taken over by nurses and other health professionals. Light treatment was also used in Canada from the 19th century until the 1940s for the treatment of rickets (UVB), infantile paralysis and nervous diseases (electric light cabinets) (Connor and Pope, 1999). The treatments, which included light baths that were understood to have analgesic as well as anti-bacterial properties, was ongoing in many hospitals throughout the world at this time but is less widely used in current physiotherapy practice (Nuhu, Mohammed, and Muhammad, 2014). Newly graduated physiotherapists have therefore been denied the opportunity to experience the use of phototherapy and to be a part of an integrated approach to treatment for the medically compromised patient.

While UVB treatment continued to be used in the 1960s, there was also an increase in light treatment using red and infrared wavelengths. Light therapy increased in clinical applications in the 1970s for its application in the treatment of both dermatitis and hyperbilirubinemia (Brown, Kim, Wu, and Bryla, 1985). Intravenous therapy using UVB has also been used for many decades (Wu, Hu, and Hamblin, 2016).

Light treatment expanded after an incidental discovery in 1967 by Dr. Endre Mester who began to perform the first experiments using laser light to accelerate wound healing (as well as re-growing hair) in animals and patients (Mester, Juhász, Varga, and Karika, 1968). This treatment effect was biphasic in nature, such that increased dosage beyond an energy threshold resulted in no further increase in healing effect. Mester also documented a systemic effect of laser, where the stimulatory effect of the treatment could be seen in areas adjacent and remote from the point of application of the laser. Laser technology was championed by Dr. Tiina Karu, an Estonian scientist, who published more than 190 papers in the field of low-level laser therapy, particularly practiced by doctors and physiotherapists in Russia; later to expand to Israel and Iran (Moskvin, 2017; Oron et al., 2001). The effectiveness of the therapy was demonstrated after the Chernobyl nuclear accident in 1986, when radiation wounds were successfully treated with laser by the American military (Ralf Uwe, 2002; Ralf Uwe et al., 1994). This contrasted with the non-treated, non-healing radiation ulcers that were the rule after the nuclear blasts in Japan during World War II, that did not resolve in the lifetime of the victims. The evidence that red and near-infrared light was effective in healing wounds continued to grow after this time and set the stage for their contemporary use in radiation injuries and radiodermatitis resulting from cancer therapies (Robijns, Lodewijckx, and Mebis, 2019). The early work with laser light therapy has led to the use of what is now known as photobiomodulation therapy (Khan and Arany, 2015), which is the use of non-thermal light to stimulate beneficial cellular processes for therapeutic effect. This is a rapidly expanding field with physiotherapy applications reaching into treatment of musculoskeletal pain (Chow, Johnson, Lopes-Martins, and Bjordal, 2009), osteoarthritis pain (Stausholm et al., 2019), neurological conditions (Hamblin, 2016) and cancer-related lymphedema and oral mucositis.

In parallel with the early use of light as a therapy and its development over the next century (Figure 1), advances in the uses of light was also occurring in other areas of medicine. This included the use of blue light to treat hyperbilirubinemia in new-borns in the 1970s, and the wider use of light in the 1970s for diseases such as skin lesions and vitiligo, due in part to the development of lasers in the early 1960s, and the later development of cheaper LEDs.

Paradoxically, the expanded use of light in medicine (i.e. high-powered surgical lasers in dermatology, orthopedics, oncology, and ophthalmology) has been accompanied by decreased use in physiotherapy and a consequent diminishing of the knowledge and practice of light therapy for wounds and dermatological conditions by newly qualified physiotherapists. For example, in Nigeria, the lack of knowledge was reported to be accompanied by a lack of access to UV equipment, both being a barrier to effective treatment (Nuhu, Mohammed, and Muhammad, 2014). It is somewhat ironic that the continued use of UVB by physiotherapists since the 1950s for the treatment of dermatological conditions in the hospital setting (Fitzpatrick, 1988) (Sydney Adventist Hospital archive marg\wpold\history), has allowed the expedited use of UVB for the treatment of acute immune diseases, such as multiple sclerosis (MS) in medical research (Prue Hart, Research Fellow, University of Westerrn Australia, pers. com.).

The use of UVB in the treatment of MS is thought to regulate the vitamin D axis in a manner analogous to rickets (Hart et al., 2018). Other forms of light are also being investigated for the effect on cases of MS (Lyons, clinical trial https://clinicaltrials.gov/ct2/show/NCT03691766). Knowledge of the historical use of light and its effects is important in this context and its inclusion in teaching curricula would be beneficial.

Light therapy applications expanded in the eighties into the field of dentistry, for the treatment of oral wounds (including "dry sockets"); and for treating the cancer treatment side-effect of oral mucositis; a debilitating condition of the mucous membranes, where patients may need to be tube fed due to the pain and inflammation. PBM is used by many hospitals around the world now use photobiomodulation to successfully treat oral mucositis. It is now considered standard treatment for oral mucositis caused by chemotherapy or radiotherapy, under the Multinational Association for Supportive Care in Cancer (MASCC) guidelines (Zadik et al., 2019) and the National Institute for Health and Care Excellence (NICE) guidelines in Britain. https://www.nice.org.uk/guidance/ipg615. In Australia, this treatment has been introduced into The Royal Children's Hospital in Melbourne by Dr. Kerrod Hallett, after a successful pilot study (Hallett, 2015) and has been extended to the San Hospital in 2021. The use of photobiomodulation therapy and previously low-level laser therapy for lymphedema was first proposed following an incidental finding in 1989, where low-level laser treatment of arthritis by physiotherapists coincidentally showed an improvement in long-standing lymphedema. This led to extensive research at Flinders University in both animal and clinical models (Figure 1) to show the effective dosage and applications for this treatment (Piller and Thelander, 1996). A laser device, specifically designed to treat lymphedema has approval by both the Therapeutic Goods Association (Australia) and the Food and Drug Administration (USA).

Light, including sunlight, is important in all aspects of critical illness and has been shown to be an important consideration and to have direct modulating effects on illness (Castro, Angus, and Rosengart, 2011). For example, lighting in hospitals is incorporated into the architectural design of newly built hospitals to assist in medical care and optimal oncological management. Oncologists also recommend exposure to red light in the morning as being therapeutic (Holick, 2008). Differences in prenatal light exposure has also been linked with the risk of: Parkinson's disease (Gardener et al., 2010); MS (Hart et al., 2018); autism (Cieslinska et al., 2017); and schizophrenia (Kendell and Adams, 2002). These observations suggest potentially rich research areas of preventative medicine for otherwise intractable diseases. Bright light therapy is also used for seasonal affective disorder (Wirz-Justice et al., 1996) and Parkinson's disease (Willis, Boda, and Freelance, 2018). In summary Florence Nightingale's principle is still being applied in health practice and appears to be assuming an increased clinical importance.

Recent advances in the application of photobiomodulation have been pioneered in Australia, America, Canada, Norway, and Brazil. The advances follow from the understanding of light modulation on human tissues, physiology, and disease obtained by NASA (Whelan, 2002) in the 1970s when wounds that would not heal in microgravity, were shown to heal under the influence of light in the experimental hydroponic units of the space shuttle. These findings led to NASA spinoff technology and the development of the WARP 10 LED device (https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20090002502.pdf). The understanding of the mechanisms of action and the effect of various wavelengths, energy, modulation frequency, and other parameters of light treatment has improved the outcomes of light therapy and has led to increasingly successful clinical therapy trials. These trials have included the use of photobiomodulation to treat: chronic neck pain (Chow, Johnson, Lopes-Martins, and Bjordal, 2009); lymphedema (Smoot et al., 2015); arthritis (Alfredo et al., 2018); and muscle performance (Ferraresi, Huang, and Hamblin, 2016).

In the 1980s, an Australian manipulative physiotherapist Louis Gifford (1987) pioneered the study of circadian rhythms. He examined the importance of circadian rhythms on joint stiffness, by awakening volunteers every hour over a 24-hour period to measure changes in joint flexibility. He noted changes in tissue elasticity and collagen. This work was a precursor to the principles of chronobiology and has been an important background principle to photobiomodulation and how light more generally impacts health. The importance of chronobiology in health and disease was recognized with a Nobel Prize in 2017 to the researchers Jeffery Hall, Michael Rosbash and Michael Young "for their discoveries of molecular mechanisms controlling the circadian rhythm" (https://www.nobelprize.org/prizes/lists/all-nobel-laureates-in-physiology-or-medicine/).
Chronobiology appears to have an important clinical role for the timing of surgery, hospital lighting, prediction of the risk of such diverse diseases as Parkinson's disease, MS and some cancers, and the progression of diseases such as Alzheimer's disease. These recent advances in chronobiology and circadian rhythm research and their effects on seasonal affective disorder, miscarriage in shift workers, jet-lag and so on, have led to treatment of these disorders using light (Lushington et al., 2002).

Research in chronobiology and photobiomodulation suggests the possibility of incorporating phototherapy in the treatment of a range of diseases and the possibility for physiotherapists, as well as physicians, dentists and other health professionals, to further embrace phototherapy, including photobiomodulation therapy (red and near-infrared laser and LED) into their existing treatment options.

Since the late 1990s, photobiomodulation therapy has been taught in the Physiotherapy curricula in the University of Queensland and Griffith University in Australia. This follows from Professor Liisa Laakso and her long association with these universities subsequent to her PhD studies into mechanisms of low-level laser therapy (Laakso, Cramond, Richardson, and Galligan, 1994). Photobiomodulation is also in the scope of practice of physiotherapy, as well as the curricula at many universities worldwide, including in Brazil, Canada, Russia, Iran, and Europe. The breadth of photobiomodulation research has expanded from treatment of muscle, bone, and nerve disorders, to include applications in muscle strength and athletic performance, supportive cancer care, and neurological disorders.

At the San Hospital, light therapy has been used in patient care for over 100 years (Figure 2). Physiotherapists at this hospital were thus in a position to embrace laser technology for the treatment of lymphedema when this became available. The routine use of light therapy over many years also allowed for research into light therapy and the appointment of a Director of Photomolecular Research (a physiotherapist) at the Australasian Research Institute at the hospital in 2016, following on from a Phototherapy Biological Research Laboratory established in 2011. This appointment was facilitated by the fact that the CEO of the hospital at that time had been a nurse manager, who was aware of the tradition of the therapy. A Photobiomodulation Clinic has also been established with a physiotherapy as well as a medical focus for the treatment of chronic pain, arthritis, cardiac surgery pre-conditioning, and sports injuries. Clinical trials are being conducted in this hospital (and other centers including the Mater Hospital in Brisbane) to assess the effect of photobiomodulation treatment on the symptoms of Parkinson's disease (ANZCTR registered trial ACTRN12618000038291). Current research and clinical trials include assessing the effects of photobiomodulation on red blood cell stability, cardiac surgery outcomes, and pre-conditioning against postoperative cognitive decline (Liebert, Chow, Bicknell, and Varigos, 2016; Liebert et al., 2017).

Expanded use of light for cardiovascular medicine

In medicine, the importance of light on individual health is apparent. Patients in brightly lit cardiac casualty wards have improved survival compared to those in dark wards (Beauchemin and Hays, 1998). The timing of heart attack events is influenced by the onset of daylight saving time changes, in that there are increases in heart attacks when clocks are put forward (one less hour of sleep) and decreases when clocks are put back (Sandhu, Seth, and Gurm, 2014).

Laser light treatment had also been used clinically for inoperable intractable heart disease. The transmyocardial reperfusion technique, carried out in the 1990s and early 2000s, used a focussed high-powered laser beam to create microscopic holes in cardiac muscle to increase blood perfusion. The procedure reduced pain in patients for 5 or more years (Horvath et al., 2001). Academic surgeons who performed the procedures (Prof Clifford Hughes, Head of Infection Control, Macquarie University, pers. com.) were of the opinion that the observed improvement in symptoms could also be attributed to a (low-level) laser effect myocardial tissues adjacent to the focussed laser; the so-called "bystander effect" (Najafi, Fardid, Hadadi, and Fardid, 2014) that may have been part of the mechanism that reduced angina and improved the quality of life outcomes in a majority of patients. This therapeutic technique was discontinued after several years, due to the high inherent operative risks, which were deemed to outweigh the symptomatic benefits (Briones, Lacalle, Marin-Leon, and Rueda, 2015).

777Following their initial work on intravascular low-power red laser light as an adjunct to coronary stent implantation in porcine models (De Scheerder et al., 2001b), De Scheerder et al. (2001a) tested the feasibility and safety of intravascular low-power laser irradiation in an unblinded, single-arm clinical study of 68 patients undergoing percutaneous coronary intervention by stenting. The study showed a 6-month overall restenosis rate of 14.7%, from zero to 41.6% depending on the stented vessel size. In a similar study (Derkacz et al., 2013) with 52 patients receiving low-level laser treatment (49 in the control group), intra-coronary laser therapy showed a 6 month restenosis rate of 15% for the laser treatment group compared with 32.4% in the control group. The laser group also showed reduced pro-inflammatory markers (interleukin-1β, interleukin-6), reduced tumor growth factor-β1, reduced fibroblast growth factor-2 and increased anti-inflammatory markers (interleukin-10) and nitric oxide compared to controls. Additionally, the cardiac event rate defined as death, Q and non-Q wave myocardial infarction, coronary artery by-pass grafting, and repeat revascularization of the target vessel/lesion was 7.7% for the laser-treated group at both 6- and 12-month follow-ups, compared to 14.3% and 18.5% in the control group for these follow-ups (Derkacz et al., 2010). There were also marked differences in late coronary lumen loss, late lumen loss index, minimal lumen diameter and lower

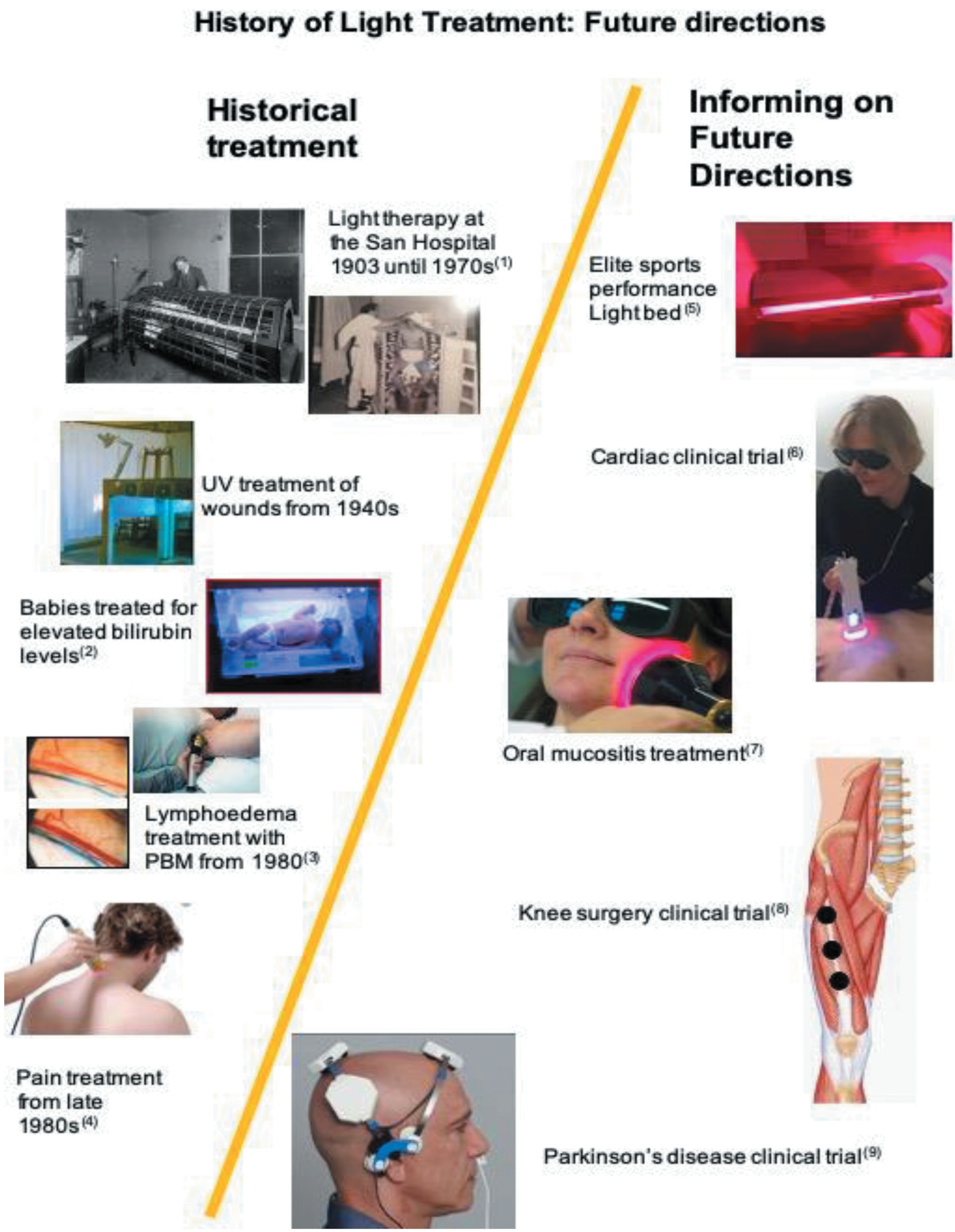

Figure 2. History of light treatment and future directions. (1) pers. com. Michael Rigby, Museum curator, San Hospital, Sydney; (2) Brown, Kim, Wu, and Bryla (1985); (3) Piller and Thelander (1996); (4) Chow, Johnson, Lopes-Martins, and Bjordal (2009); (5) Hamblin, Nelson, and Strahan (2018). (6) Liebert et al. (2017); (7) Zadik et al. (2019). (8) Vassão et al. (2020). (9) Liebert and Bicknell (2019).

6-7month restenosis rate (15.0% vs 32.4%) in favor of the laser-treated group. Infrared laser is currently being used in a cardiac stent trial (ANZCTR trial registration ACTRN12618001312235) in Tasmania by Dr.Michael Fox, a medical doctor and registered physiotherapist (pers. com.) to determine the effect on rates of restenosis, mortality, and morbidity. To date, 190 participants have been treated. The trial was formulated on the basis of case studies conducted at the San Hospital in Sydney (Kiat, 2017)

The original transcranial reperfusion using high-powered laser and the concomitant bystander effect on myocardial symptoms has been the inspiration for the use of red and infrared low-level laser as a preconditioning and/or post-conditioning treatment in cardiac surgery (Liebert et al., 2017). The technique has been used by physiotherapists and doctors in Russia and Iran for heart patients for more than a decade (Kazemi Khoo et al., 2014; Moskvin, 2017). A single-arm clinical study of ischemic heart disease found that low-level laser therapy improved angina symptoms, systolic blood pressure, and exercise capacity, while reducing frequency of ischemia (Zyciński et al., 2007). A controlled trial in patients undergoing elective coronary bypass surgery conducted by Kazemi Khoo et al. (2014) showed improved cardiac and other biomarkers (i.e. creatinine kinase activity, creatine kinase myocardial band, lactate dehydrogenase, neutrophil and lymphocyte counts) post-operatively for those who received peri-operative low-level laser therapy compared to controls, which may indicate cardiac cellular damage and inflammation. Photobiomodulation therapy also has the potential to accelerate the healing and reduce the trauma and nonunion of the sternotomy wound that is a feature of coronary artery bypass graft surgery (Helmy et al., 2019).

The best-suited areas of cardiovascular medicine for low-level laser therapy, optimized treatment algorithm including energy spectrum, dose, timing, anatomic application sites, delivery modes (e.g. percutaneous and intravascular) remain pressing questions to be addressed by robust, prospective, double-blind, randomized, placebo-controlled and multicenter clinical testing and validation studies. Nonetheless, based on the prevailing extensive experimental research output and several clinical studies pertinent to the field, the clinical future of low-level laser therapy in cardiovascular medicine seems likely to expand.

Expanded use of light for neurodegenerative disease

It has long been recognized that light is important in the management of neurological disorders, including Alzheimer's disease, for circadian rhythm stabilization, and improving sleep and behavior (Ancoli-Israel et al., 2003; Satlin et al., 1992; Van Someren, Kessler, Mirmiran, and Swaab, 1997). Experimental evidence from animal models has extended understanding of the systemic effects of photobiomodulation including the effects of photobiomodulation on areas of the body remote from the application of light, known as the bystander and abscopal effects. The helmet experiment in 2012 (Stone, Johnstone, and Mitrofanis, 2013), demonstrated that photobiomodulation had the potential to protect against neurological damage in the brain even when light was used on a site remote to the head. This finding has paved the way for recent innovations in the use of light as photobiomodulation and bright light therapy for both the transcranial and remote site treatment of neurological diseases such as: Parkinson's disease (Ganeshan et al., 2019; Johnstone, Mitrofanis, and Stone, 2015; Liebert and Bicknell, 2019; Mitrofanis, 2017); Alzheimer's disease (Blivet, Meunier, Roman, and Touchon, 2018); traumatic brain injury (Hamblin, 2016); and MS (Hart et al., 2018). It is now understood that many of these diseases have a strong gut/microbiome/brain connection and, at least in animal models, that changing the gut microbiome is a potential treatment option (Lubomski et al., 2020). The observation that photobiomodulation can change the gut microbiome (Bicknell, Liebert, Johnstone, and Kiat, 2018) suggests both a mechanism for the effect of remote light application and also a treatment option to expand current practice. These treatment protocols have followed on, not only from the understanding of the principles of light treatment, especially the effect of light on ion channels (Liebert, Bicknell, and Adams, 2014) and metabolomics more generally (Liebert, 2018), but also from observations during physiotherapy treatment of neurological disorders and observations that light is important in the management of Alzheimer's symptoms (Figueiro et al., 2014). The effect of circadian rhythms on the metabolome and the microbiome and other oscillatory processes in humans has paved the way for research into "photobiomics", the effect of light on the microbiome/metabolome interaction (Liebert et al., 2019), as well as the application of remote light application to the abdomen of mice to modulate a model of Parkinson's disease (Bicknell, Liebert, Johnstone, and Kiat, 2018; El Massri et al., 2018) and Alzheimer's disease (Blivet, Meunier, Roman, and Touchon, 2018). The effect of photobiomodulation on the microbiome of mice has now been replicated in clinical case studies (Liebert and Bicknell, 2019).

Future directions

Novel and expanding practice of light treatment is in the area of neurological disease such as: Parkinson's disease; multiple sclerosis; Alzheimer's disease; and motor neurone disease (Figure 2). Registered trials have been conducted in Sydney, Adelaide, and Brisbane, with preliminary results published in 2019 (Liebert and Bicknell, 2019; Vassão et al., 2020).

Depression as an accompanying symptom of chronic pain (Doan, Manders, and Wang, 2015), including the pain of Parkinson's disease (Martinez-Martin et al., 2017) and other central pains such as fibromyalgia and unresponsive cervicogenic headache (Liebert and Bicknell, 2017; Liebert et al., 2013) may be amenable to photobiomodulation therapy by laser and transcranial LED. Physiotherapists and pain doctors have been using photobiomodulation for chronic neck pain and accompanying headache since the 1990s with good effect (Chow, Johnson, Lopes-Martins, and Bjordal, 2009), including quality of life and mood improvements. A current trial for the reduction in symptoms of Parkinson's disease has shown an improvement in the non-motor symptoms of mood, sleep, and cognition (Liebert and Bicknell, 2019). A small trial using transcranial infrared light showed promising results for the reduction of symptoms of depression (Schiffer et al., 2009). There is also a potential role for managing other depressive symptoms that accompany chronic pain conditions using photobiomodulation, as a therapy delivered by physiotherapists (Askalsky and Iosifescu, 2019; Cassano et al., 2016; Hamblin, 2016). More opportunities will open up in the future and a strong historical basis makes this possible.

Conclusion

The use of light therapy in physiotherapy and medicine spans 120 years and has been continuous in some locations, especially in hospitals such as the San Hospital in Sydney. This continuity and intergenerational practice has allowed for the emergence of new and innovative treatments for familiar conditions (e.g. wounds, lymphedema, and pain) and also intractable diseases and conditions. These conditions include persistent ulcers caused by metabolic diseases such as diabetes, cognitive and musculoskeletal decline of aging, metabolic-related cardiovascular disease, cancer therapy sequalae such as oral mucositis, post-surgical complications such as post-operative cognitive dysfunction, and neurological diseases such as MS, motor neurone disease, Parkinson's and Alzheimer's diseases.

Inter-generational practice unique to the physiotherapy profession, including the employment of light therapy, from the 19th century use of light boxes to the 21st century use of lasers, is important to maintain a diverse professional foundation. The ability to understand and incorporate beneficial aspects of the history of physiotherapy is important for many reasons. It assists in maintaining the scope of practice and prevents the attrition and diminishment of therapies to other health practitioners. It also gives a historical as well as an evidence-based rationale for physiotherapy practice, the importance of which should never be underestimated. It is incumbent on all of us to encourage newly graduated physiotherapists to be aware of the past and simultaneously, to innovate for the future. With knowledge of what has been done before, young physiotherapists can have a positive attitude toward the therapeutic potential of light as an adjunct therapy. The opportunity for the physiotherapy profession to embrace past therapeutic practices and apply them in novel areas of health care, such as intractable diseases is very attractive.

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Declaration of Interest

The authors declare no conflict of interest.

References

Alfredo PP, Bjordal JM, Junior WS Lopes-Martin RA, Stausholm MB, Casarotto RA, Marques AP, Joensen J 2018 Long-term results of a randomized, controlled, double-blinded study of low-level laser therapy before exercises in knee osteoarthritis: Laser and exercises in knee osteoarthritis. Clinical Rehabilitation 32(2): 173–178. doi:10.1177/0269215517723162

Ancoli-Israel S, Gehrman P, Martin JL, Shochat T, Marler M, Corey-Bloom J, Levi L 2003 Increased light exposure consolidates sleep and strengthens circadian rhythms in severe Alzheimer's disease patients. Behavioral Sleep Medicine 1 (1): 22–36. doi:10.1207/S15402010BSM0101_4

Askalsky P, Iosifescu DV 2019 Transcranial photobiomodulation for the management of depression: Current perspectives. Neuropsychiatric Disease and Treatment 15: 3255–3272. doi:10.2147/NDT.S188906

Beauchemin KM, Hays P 1998 Dying in the dark: Sunshine, gender and outcomes in myocardial infarction. Journal of the Royal Society of Medicine 91(7): 352–354. doi:10.1177/014107689809100703

Bicknell B, Liebert A, Johnstone D, Kiat H 2018 Photobiomodulation of the microbiome: Im-plications for metabolic and inflammatory diseases. Lasers in Medical Science 34(2): 317–327. doi:10.1007/s10103-018-2594-6

Blivet G, Meunier J, Roman FJ, Touchon J 2018 Neuroprotective effect of a new photo-biomodulation technique against Aβ25–35 peptide–induced toxicity in mice: Novel hypothesis for therapeutic approach of Alzheimer's disease suggested. Alzheimer's and Dementia: Translational Research and Clinical Interventions 4: 54–63.

Briones E, Lacalle J, Marin-Leon I, Rueda J 2015 Transmyocardial laser revascularization versus medical therapy for refractory angina. Cochrane Database of Systematic Reviews 2: CD003712.

Brown AK, Kim MH, Wu PY, Bryla DA 1985 Efficacy of phototherapy in prevention and management of neonatal hyperbilirubinemia. Pediatrics 75(2 Pt 2): 393–441.

Cassano P, Petrie SR, Hamblin MR, Henderson TA, Iosifescu DV 2016 Review of transcranial photobiomodulation for major depressive disorder: Targeting brain metabolism, inflammation, oxidative stress, and neurogenesis. Neurophotonics 3(3): 031404. doi:10.1117/1.NPh.3.3.031404

Castro R, Angus D, Rosengart M 2011 The effect of light on critical illness. Critical Care 15(2): 218. doi:10.1186/cc10000

Chow RT, Johnson MI, Lopes-Martins RA, Bjordal JM 2009 Efficacy of low-level laser therapy in the management of neck pain: A systematic review and meta-analysis of randomised placebo or active-treatment controlled trials. The Lancet 374(9705): 1897–1908. doi:10.1016/S0140-6736(09)61522-1

Cieslinska A, Simmelink J, Teodorowicz G, Verhoef H, Tobi H, Savelkoul HF 2017 Distribution of month of birth of individuals with autism spectrum disorder differs from the general population in the Netherlands. In: Fitzgerald M, Yip J Eds Autism - paradigms, recent research and clinical applications, pp. 43–54. London: IntechOpen.

Connor JT, Pope F 1999 A shocking business: The technology and practice of electrotherapeutics in Canada, 1840s to 1940s. Material Culture Review 49: 60–70.

De Scheerder IK, Wang K, Kaul U, Singh B, Sahota H, Keelan MH. Kipshidze NN, Moses J 2001a Intravascular low-power laser irradiation after coronary stenting: Long-term follow-up. Lasers in Surgery and Medicine 28(3): 197–285. doi:10.1002/lsm.1040

De Scheerder IK, Wang K, Zhou XR, Szilard M, Verbeken E, Ping QB, Yanming H, Jianhua H, Nikolaychick V, Moses JW, et al. 2001b Optimal dosing of intravascular low-power red laser light as an adjunct to coronary stent implantation: Insights from a porcine coronary stent model. Journal of Clinical Laser Medicine & Surgery 19(5): 261–265. doi:10.1089/10445470152611991

Derkacz A, Protasiewicz M, Poreba R, Doroszko A, Andrzejal R 2013 Effect of the intravascular low energy laser illumination during percutaneous coronary intervention on the inflammatory process in vascular wall. Lasers in Medical Science 28(3): 763–768. doi:10.1007/s10103-012-1142-z

Derkacz A, Protasiewicz M, Poreba R, Szuba A, Andrzejak R 2010 Usefulness of intravascular low-power laser illumination in preventing restenosis after percutaneous coronary intervention. American Journal of Cardiology 106(8): 1113–1117. doi:10.1016/j.amjcard.2010.06.017

Doan L, Manders T, Wang J 2015 Neuroplasticity underlying the comorbidity of pain and depression. Neural Plasticity 2015: 504691. doi:10.1155/2015/504691

Downes A, Blunt T 1877 Researches on the effect of light upon bacteria and other organisms. Proceedings of the Royal Society of London 26: 488–500.

El Massri N, Weinrich TW, Jaimie Hoh, Jeffery G, Mitrofanis J 2018 Photobiomodulation reduces gliosis in the basal ganglia of aged mice. Neurobiology of Aging 66: 131–137. doi:10.1016/j.neurobiolaging.2018.02.019

Ferraresi C, Huang YY, Hamblin MR 2016 Photobiomodulation in human muscle tissue: An advantage in sports performance? Journal of Biophotonics 9(11–12): 1273–1299. doi:10.1002/jbio.201600176

Figueiro MG, Plitnick BA, Lok A, Jones GE, Higgins P, Hornick TR, Rea MS 2014 Tailored lighting intervention improves measures of sleep, depression, and agitation in persons with Alzheimer's disease and related dementia living in long-term care facilities. Clinical Interventions in Aging 9: 1527. doi:10.2147/CIA.S68557

Finsen N 1895 The red light treatment of small-pox. British Medical Journal 2(1823): 1412–1414. doi:10.1136/bmj.2.1823.1412-a

Finsen N 1903 Remarks on the red-light treatment of small-pox: Is the treatment of small-pox patients in broad daylight warrantable? British Medical Journal 1(2214): 1297–1298. doi:10.1136/bmj.1.2214.1297

Fitzpatrick TB 1988 The validity and practicality of sun-reactive skin types I through VI. Archives of Dermatology 124(6): 869–871. doi:10.1001/archderm.1988.01670060015008

Ganeshan V, Skladnev NV, Kim JY, Mitrofanis J, Stone J, Johnstone DM 2019 Pre-conditioning with remote photobiomodulation modulates the brain transcriptome and protects against MPTP insult in mice. Neuroscience 400: 85–97. doi:10.1016/j.neuroscience.2018.12.050

Gardener H, Gao X, Chen H, Schwarzschild MA, Spiegelman D, Ascherio A 2010 Prenatal and early life factors and risk of Parkinson's disease. Movement Disorders 25(11): 1560–1567. doi:10.1002/mds.23339

Gifford LS 1987 Circadian variation in human flexibility and grip strength. Australian Journal of Physiotherapy 33(1): 3–9. doi:10.1016/S0004-9514(14)60579-1

Hallett K 2015 LLLT in the Treatment of Oral Mucositis. AMLA Conference: Low-Level Laser Therapy (Photobiomodulation) in Dentistry and Orofacial Pain. April 2015, Sydney.

Hamblin MR 2016 Shining light on the head: Photobiomodulation for brain disorders. BBA Clinical 6: 113–124. doi:10.1016/j.bbacli.2016.09.002

Hamblin MR, Nelson ST, Strahan JR 2018 Photobiomodulation and cancer: What is the truth? Photomedicine and Laser Surgery 36(5): 241–245. doi:10.1089/pho.2017.4401

Hamilton C, Hamilton D, Nicklason F, El Massri N, Mitrofanis J 2018 Exploring the use of transcranial photobiomodulation in Parkinson's disease patients. Neural Regeneration Research 13(10): 1738. doi:10.4103/1673-5374.238613

Hart PH, Finlay-Jones JJ, Gorman S 2009 Photoneuroimmunology: Modulation of the neuro-immune system by UV radiation. In: Granstein RD, Luger TA Eds

Neuroimmunology of the Skin: Basic Science to Clinical Practice, pp. 125–136. Berlin, Heidelberg: Springer.

Hart PH, Jones AP, Trend S, Cha L, Fabis-Pedrini MJ, Cooper MN, d'Este C, Geldenhuys S, Carroll WM, Byrne SN, et al. 2018 A randomised, controlled clinical trial of narrowband UVB phototherapy for clinically isolated syndrome: The PhoCIS study. Multiple Sclerosis Journal 4: 2055217318773112.

Helmy ZM, Mehani SH, El- Refaey BH, Al-Salam EH, El-Sayed Felaya E 2019 Low-level laser therapy versus trunk stabilization exercises on sternotomy healing after coronary artery bypass grafting: A randomized clinical trial. Lasers in Medical Science 34(6): 1115–1124. doi:10.1007/s10103-018-02701-4

Holick MF 2008 Vitamin D and sunlight: Strategies for cancer prevention and other health benefits. Clinical Journal of the American Society of Nephrology 3(5): 1548–1554. doi:10.2215/CJN.01350308

Hönigsmann H 2013 History of phototherapy in dermatology. Photochemical and Photo-biological Sciences 12(1): 16–21. doi:10.1039/C2PP25120E

Horvath KA, Aranki SF, Cohn LH, March RJ, Frazier OH, Kadipasaoglu KA, Boyce SW, Lytle BW, Landolfo KP, Lowe JE 2001 Sustained angina relief 5 years after transmyocardial laser revascularization with a CO2 laser. Circulation 104(12 Suppl 1): I81–I84. doi:10.1161/hc37t1.094774

Johnstone DM, Mitrofanis J, Stone J 2015 Targeting the body to protect the brain: Inducing neuroprotection with remotely-applied near infrared light. Neural Regeneration Research 10(3): 349–351. doi:10.4103/1673-5374.153673

Kazemi Khoo N, Babazadeh K, Lajevardi M, Fataneh F, Dabaghian H, Mostafavi E 2014 Application of low-level laser therapy following coronary artery bypass grafting (CABG) surgery. Journal of Lasers in Medical Science 5: 86–91.

Kellogg J 1910 Light therapeutics: A practical manual of phototherapy for the student and the practitioner. Battle Creek, MI: The Good Health Publishing Company.

Kendell R, Adams W. 2002 Exposure to sunlight, vitamin D and schizophrenia. Schizophrenia Research 54(3): 193–198. doi:10.1016/S0920-9964(01)00264-X

Khan I, Arany P 2015 Biophysical approaches for oral wound healing: Emphasis on photo-biomodulation. Advances in Wound Care 4(12): 724–737. doi:10.1089/wound.2014.0623

Kiat H 2017 Laser and LED light therapy in cardiovascular disease. San doctor (Autumn ed). Sydney: San Hospital.

Laakso L, Cramond T, Richardson C, Galligan JP 1994 Plasma ACTH and betaendorphin levels in response to low level laser therapy (LLLT) in myofascial trigger points. Laser Therapy 6(3): 133–142. doi:10.5978/islsm.94-OR-07

Liebert A 2018 Emerging applications of photobiomodulation therapy: The interaction between metabolomics and the microbiome. Photomedicine and Laser Surgery 36(10): 515–517. doi:10.1089/pho.2018.4527

Liebert A, Bicknell B 2017 Clinical Trial Involving Sufferers and Non-Sufferers of Cervicogenic Headache (CGH): Potential Mechanisms of Action of Photobiomodulation. Proceedings Volume 10048, Mechanisms of Photobiomodulation Therapy XII; 1004803 SPIE BiOS. February 2017, San Francisco, California.

Liebert A, Bicknell B 2019 PBMt and the Microbiome: The Photobiomic Implications for Metabolic and Neurological Disease. 17th International ISLA Conference for Medical Laser Applications. June 2019, Beverungen, Germany.

Liebert A, Bicknell B, Adams R 2014 Protein conformational modulation by photons: A mechanism for laser treatment effects. Medical Hypotheses 82(3): 275–281. doi:10.1016/j.mehy.2013.12.009

Liebert A, Bicknell B, Johnstone D, Gordon L, Kiat H, Hamblin MR 2019 "Photobiomics": Can light, including photobiomodulation, alter the microbiome? Photobiomodulation, Photomedicine, and Laser Surgery 37(11): 681–693. doi:10.1089/photob.2019.4628

Liebert A, Chow RT, Bicknell BT Varigos E 2016 Neuroprotective effects against POCD by photobiomodulation: Evidence from assembly/disassembly of the cytoskeleton. Journal of Experimental Neuroscience 10: 1–19. doi:10.4137/JEN.S33444

Liebert A, Krause A, Goonetilleke N, Bicknell B, Kiat H 2017 A role for photobiomodulation in the prevention of myocardial ischemic reperfusion injury: A systematic review and potential molecular mechanisms. Scientific Reports 7 (1): 42386. doi:10.1038/srep42386

Liebert A, Rebbeck T, Elias S, Hawkins D, Adams R 2013 Musculoskeletal physiotherapists' perceptions of non-responsiveness to treatment for cervicogenic headache. Physiotherapy Theory and Practice 29(8): 616–629. doi:10.3109/09593985.2013.783894

Lubomski M, Tan AH, Lim SY, Holmes AJ, Davis RL, Sue CM 2020 Parkinson's disease and the gastrointestinal microbiome. Journal of Neurology 267(9): 2507–2523. doi:10.1007/s00415-019-09320-1

Lushington K, Galka R, Sassi LN, Kennaway DJ, Dawson D 2002 Extraocular light exposure does not phase shift saliva melatonin rhythms in sleeping subjects. Journal of Biological Rhythms 17 (4): 377–386. doi:10.1177/074873002129002582

Martinez-Martin P, Rojo-Abuin JM, Rizos A, Rodriguez-Blazquez C, Trenkwalder C, Perkins L, Sauerbier A, Per Odin P, Antonini A, Chaudhuri KR 2017 Distribution and impact on quality of life of the pain modalities assessed by the King's Parkinson's disease pain scale. Npj Parkinson's Disease 3(1): 8. doi:10.1038/s41531-017-0009-1

McGonigle TA, Keane KN, Ghaly S, Carter KW, Anderson D, Scott NM, Goodridge HS, Dwyer A, Greenland E, Pixley FJ, et al. 2017 UV Irradiation of skin enhances glycolytic flux and reduces migration capabilities in bone marrow–differentiated dendritic cells. American Journal of Pathology 187 (9): 2046–2059. doi:10.1016/j.ajpath.2017.06.003

McMeeken J 2008 La physiothérapie en Australie: Formation, qualification et exercice [Physiotherapy in Australia: Training qualification and exercise]. Physiotherapy Review 8: 36–44.

Mester E, Juhász J, Varga P, Karika G 1968 Lasers in clinical practice. Acta Chirurgica Academiae Scientiarum Hungaricae 9(3): 349–357.

Mitrofanis J 2017 Why and how does light therapy offer neuroprotection in Parkinson's disease? Neural Regeneration Research 12(4): 574–575. doi:10.4103/1673-5374.205092

Moskvin S V. 2017 Low-level laser therapy in Russia: History, science and practice. Journal of Lasers in Medical Sciences 8 (2): 56–65. doi:10.15171/jlms.2017.11

Najafi M, Fardid R, Hadadi G, Fardid M 2014 The mechanisms of radiation-induced bystander effect. Journal of Biomedical Physics and Engineering 4(4): 163–172.

Natoli R, Valter K, Barbosa M, Dahlstrom J, Rutar M, Kent A, Provis J 2013 670nm photobio-modulation as a novel protection against retinopathy of prematurity: Evidence from oxygen induced retinopathy models. PLoS One 8(8): e72135. doi:10.1371/journal.pone.0072135

Nightingale F 1859 Notes on nursing: What it is and what it is not. London: Harrison.

Nuhu JM, Mohammed J, Muhammad M 2014 UV therapy: Physiotherapists‘ perception of therapeutic efficacy and barriers to usage. Hong Kong Physiotherapy Journal 32(1): 44–48. doi:10.1016/j.hkpj.2014.02.002

Nussbaum E, Gabel P, Bjordal JM, Houghton P 2011 Promoting Tissue Healing with Electrophysiological Agents and Laser: Understanding Therapeutic Actions, Including Prevention, Assessment and Treatment of Chronic Wounds. 16th International WCTP Congress. June 2011, Amsterdam.

Oron U, Yaakobi T, Oron A, Mordechovitz D, Shofti R, Hayam G, Dror U, Gepstein L, Wolf T, Haudenschild C, et al 2001 Low-energy laser irradiation reduces formation of scar tissue after myocardial infarction in rats and dogs. Circulation 103(2): 296–301. doi:10.1161/01.CIR.103.2.296

Palm T 1890 The geographical distribution and aetiology of rickets. The Practitioner. October and November.

Piller N, Thelander A 1996 Treatment of chronic postmastectomy lymphedema with low level laser therapy: A 2.5 year follow-up. Lymphology 31: 74–86.

Ralf Uwe P 2002 Management of cutaneous radiation injuries: Diagnostic and therapeutic principles of the cutaneous radiation syndrome. Military Medicine 167(suppl_1): 110–112. doi:10.1093/milmed/167.suppl_1.110

Ralf Uwe P, Braun-Falco O, Birioukov A, Hacker N, Kerscher M, Peterseim U, Ruzicka T, Konz B, Plewig G 1994 Chronic cutaneous damage after accidental exposure to ionizing radiation: The Chernobyl experience. Journal of the American Academy Dermatology 30: 19–23.

Robijns J, Lodewijckx J, Mebis J 2019 Photobiomodulation therapy for acute radiodermatitis. Current Opinion in Oncology 31(4): 291–298. doi:10.1097/CCO.0000000000000511

Sandhu A, Seth M, Gurm HS 2014 Daylight savings time and myocardial infarction. Open Heart 1(1): e000019. doi:10.1136/openhrt-2013-000019

Satlin A, Volicer L, Ross V, Herz L, Campbell S 1992 Bright light treatment of behavioral and sleep disturbances. American Journal of Psychiatry 149: 1028–1032.

Schiffer F, Johnston AL, Ravichandran C, Polcari A, Teicher MH, Webb RH, Hamblin MR 2009 Psychological benefits 2 and 4 weeks after a single treatment with near infrared light to the forehead: A pilot study of 10 patients with major depression and anxiety. Behavioral and Brain Functions 5(1): 46–59. doi:10.1186/1744-9081-5-46

Schwarz R 2006 John Harvey Kellogg: Pioneer health reformer. Hagerstown, MD: Review and Herald.

Sellentin R 2015 The changing role and treatment techniques of the Australian military physiotherapist on active service. Journal of Military Veterans Health 19: 20–24.

Smoot B, Chiavola-Larson L, Lee J, Manibusan H, Allen D 2015 Effect of low-level laser therapy on pain and swelling in women with breast cancer-related lymphedema: A systematic review and meta-analysis. Journal of Cancer Survivorship 9(2): 287–304. doi:10.1007/s11764-014-0411-1

Stausholm MB, Naterstad IF, Joensen J, Lopes-Martins RA, Saebo H, Lund H, Fersum KV, Bjordal JM 2019 Efficacy of low-level laser therapy on pain and disability in knee osteoarthritis: Systematic review and meta-analysis of randomised placebo-controlled trials. British Medical Journal Open 9: e031142.

Stone J, Johnstone D, Mitrofanis J 2013 The Helmet Experiment in Parkinson's Disease: An Observation of the Mechanism of Neuroprotection By Near Infra-Red Light. 9th WALT Congress. August 2014, Gold Coast, Australia.

Valdemar B 1899 Remarks on Finsen's phototherapy. British Medical Journal 2(2022): 825–830. doi:10.1136/bmj.2.2022.825

Van Someren EJ, Kessler A, Mirmiran M, Swaab DF 1997 Indirect bright light improves circadian rest-activity rhythm disturbances in demented patients. Biological Psychiatry 41 (9): 955–963. doi:10.1016/S0006-3223(97)89928-3

Vassão PG, Smith BM, Bennett G, Murphy M, Liebert A, Chow R, Laakso EL 2020 Pre-conditioning and post-operative photobiomodulation therapy via a novel light patch system for knee arthroplasty: A protocol for a phase 1 study. Photobiomodulation, Phototherapy and Laser Surgery 38: 206–214. doi:10.1089/photob.2019.4751

Whelan HT 2002 The Use of NASA Light-Emitting Diode Near-Infrared (IR) Technology for Biostimulation Second International Conference on Near-Field Optical Analysis: Photodynamic Therapy and Photobiology Effects: 32–39; (NASA/CP-2002-210786).

Willis GL, Boda J, Freelance CB 2018 Polychromatic light exposure as a therapeutic in the treatment and management of Parkinson's disease: A controlled exploratory trial. Frontiers in Neurology 9: 741. doi:10.3389/fneur.2018.00741

Wirz-Justice A, Graw P, Kräuchi K, Sarrafzadeh A, English J, Arendt J, Sand L 1996 'Natural' light treatment of seasonal affective disorder. Journal of Affective Disorders 37(2–3): 109–120. doi:10.1016/0165-0327(95)00081-X

Woloshyn TA 2017 Soaking up the rays: Light therapy and visual culture in Britain, c 1890-1940. Manchester: Manchester University Press.

Wu X, Hu X, Hamblin MR 2016 Ultraviolet blood irradiation: Is it time to remember "the cure that time forgot"? Journal of Photochemistry and Photobiology. B, Biology 157: 89–96. doi:10.1016/j.jphotobiol.2016.02.007

Zadik, Y, Arany PR, Fregnani ER, Bossi P, Antunes, HS, Bensadoun RJ, Gueiros, AM, Nair RG, Ranna V, Tissing WJ, et al 2019 Systematic review of photobiomodulation for the management of oral mucositis in cancer patients and clinical practice guidelines. Supportive Care in Cancer 27: 3969–3983. doi:10.1007/s00520-019-04890-2

Zyciński P, Krzemińska-Pakuła M, Peszyński-Drews C, Kierus A, Trzos E, Rechciński T, Figiel L, Kurpesa M, Plewka M, Chrzanowski L, et al 2007 Laser biostimulation in end-stage multivessel coronary artery disease: A preliminary observational study. Kardiologia Polska 65 (1): 13–23