THE GUY FOUNDATION

Quantum Biology and Cancer

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(Eds.)

Abstract proceedings of the meeting convened by
Cancer Research Horizons and The Guy Foundation,
17 October 2023

Driving innovation in medicine through quantum biology

Published January 2024

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PROCEEDINGS OF THE
QUANTUM BIOLOGY AND CANCER MEETING
HELD ON 17 OCTOBER 2023

Introduction

Betony Adams & Alistair Nunn

Cancer is one of the world's primary causes of mortality. While progress has been made in understanding and treating cancer, there is still much to be learnt. The Guy Foundation thus co-convened a meeting with Cancer Research Horizons. The purpose of the meeting was to collectively consider whether there are particular areas at the intersection of quantum and cancer biology that would warrant further investigation. This involved a look at the general principles behind the effects that electromagnetic radiation, including photobiomodulation, and electric fields have on cancer cells, and expanding this to include the effects of magnetic fields.

The meeting began on a theoretical note with Professor Alistair Nunn from The Guy Foundation and University of Westminster giving an overview of quantum biology and discussing the role that fields, particularly electromagnetic fields, play in quantum biological research and how this might be relevant to understanding cancer. Cancer exploits fundamental processes in biological systems, such as cellular growth and division. In order to investigate how it does this, Professor Nunn returned to origins of life principles. In particular he discussed how life can be understood as emerging from thermodynamic principles as a way to dissipate excess energy. Life, to paraphrase Szent-Györgyi, is nothing but an electron looking for a place to rest.

Dr Nathan Babcock, from Howard University, expanded on this discussion of field effects in his talk 'Introduction to electromagnetic fields in biology'. He detailed the underlying quantum physical properties of the bioelectrical processes that control cell growth, sensing, energy flow, morphology,

and redox metabolism. He also presented a number of medical treatments that utilise principles of quantum electrodynamics. Whereas Dr Babcock spoke more generally about bioelectromagnetics, further talks expanded on the specific roles that electric and magnetic fields play in biology and specifically cancer. Professor Wendy Beane from Western Michigan University gave a talk entitled 'Introduction to weak magnetic fields and stem cell growth'. She shared experimental results that clearly demonstrated the effects of weak magnetic fields on stem cell growth and proliferation. Furthermore, these experiments showed a link between magnetic fields, stem cell growth and reactive oxygen species. The interaction of magnetic fields with important cellular processes may offer valuable insights towards understanding how similar processes become pathological in the context of cancer. Electric fields, specifically the electric potentials caused by the distribution of charged ions across cell membranes, were the subject of the talk given by Professor Michael Levin from the Allen Discovery Center at Tufts University. His presentation 'Introduction to morphogenetic fields', outlined research in the field of embryogenesis and regeneration and how cancer can be understood within this paradigm. He also discussed how disorders of the collective intelligence of cellular aggregates, which contribute to the development of cancer, might possibly be detected and corrected.

As an overarching theme of interest to The Guy Foundation, mitochondria were also the subject of a number of the presentations. The meeting was aimed towards widening the scope of cancer research beyond conventional approaches that focus on genetic mutations. The role that bioenergetics and mitochondrial function play in the development of cancer has been a growing field of research since the discovery of the Warburg effect. These different approaches are not necessarily mutually exclusive. Dr Payam Gammage from the Beatson Institute, Glasgow gave a talk called 'New perspectives on mitochondrial oncogenetics' that demonstrated the links between these genetic and bioenergetic angles. He discussed the fact that analysis of cancer datasets shows that mutations in mitochondrial DNA are common across all solid cancers. Professor Nick Lane, from UCL, also focused on metabolic approaches to cancer with his talk 'New perspectives on metabolism and cancer'. In particular he discussed how the Krebs and reverse Krebs cycles balance processes integral to oxidative phosphorylation and biosynthesis. He outlined how the direction of the Krebs cycle depends on respiratory complex I and can cause profound metabolic shifts that may result in cancer.

While many of these presentations focused on a mechanistic understanding of cancer, there were also a number of talks about how quantum biology might be leveraged towards new therapeutics.

Professor Michael Hamblin from the University of Johannesburg gave a talk entitled 'Potential of photobiomodulation in treating cancer'. Light has long been thought to be contraindicated in the context of cancer. Photobiomodulation, or the therapeutic use of low intensity light, has, however, shown therapeutic promise in a number of disease contexts, including cancer. Professor Martyn A Sharpe, from the Houston Methodist Hospital, also gave a talk that referred to electromagnetic concerns in the treatment of cancer. His presentation, 'Rotating magnetic fields and cancer', detailed a radical new approach to targeting cancer growth that is rooted more in quantum biological principles that genetic approaches. Building on the fact that electromagnetic fields can be used to influence the spin states of reactive oxygen species, he discussed how carefully parametrised spinning magnets can stop electron transfer in mitochondrial electron transport chains. This technique is currently being examined for the treatment of aggressive brain cancers such as glioblastoma. Electromagnetism in the context of cancer was also the subject of Dr Phuoc T Tran from the University of Maryland School of Medicine. His talk, 'Tumor Treating Fields: at the crossroads between physics and biology for cancer treatment', addressed the use of alternating electric fields in the treatment of cancer. While conventional cancer treatments do include the use of electromagnetic therapies such as radiation to kill cancer cells, Tumor Treating Fields are unique in that they target the endogenous electrical properties of cancer cells in a non-ionising fashion, by attracting and repelling charged proteins to inhibit mitotic processes.

The aim of the meeting was to gain an understanding of emerging quantum biology technologies and therapies that may be applied to the diagnosis and treatment of cancer. There is not yet an established, organised network of scientists solely dedicated to examining the potential of quantum biology in cancer and so this introductory meeting will hopefully contribute to a way forward.

Introduction to The Guy Foundation

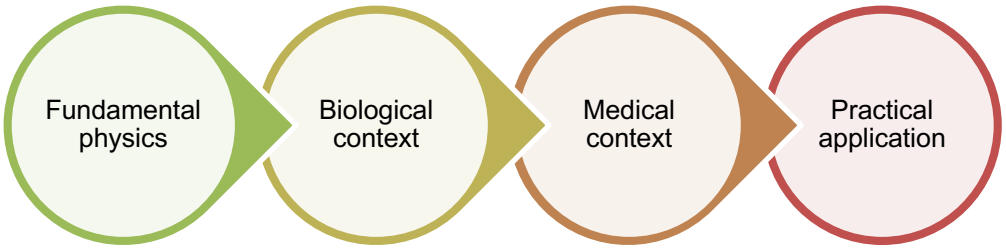
Professor Geoffrey Guy

Founder and Chairman, The Guy Foundation

The Guy Foundation aims to support and promote the investigation of quantum effects in biology, with the aim of improving our understanding of disease and thus medicine. Our belief is that significant quantum effects may well have been essential for life to get going, but also enabled it to grow in complexity by amplifying these effects both in space and time. All living systems depend on iron-sulphur compounds that display interesting tunnelling properties, which could be enhanced by the addition of proteins and chromophoric molecules. These molecules were all created by well understood geochemical/interstellar chemical processes long before life began, which coupled with established thermodynamic mathematical principles involving self-organisation of dissipative structures in energy gradients, do provide the basis of a starting point for life. In short, if significant quantum effects are part of life, the failure to maintain this state probably plays a role in disease and thus, the ageing process, and, of course, medicine.

The pioneers of thermodynamics and quantum physics, and – over the years – scientists, embracing many different disciplines, have discussed the possibility that biology could be using significant quantum effects. Some, such as Roger Penrose, have even gone as far as suggesting it could explain consciousness itself, which, even today in the 21st century, is still far from being understood. In fact, with time, despite the 20th century optimism that by the 21st century mankind would have found cures for cancer and many other diseases, and possibly even for ageing itself, a deeper understanding of life seems to be still out of reach. It could be even further away as emerging global obesity appears to be *shortening* both a healthy and absolute life expectancy, which is resulting in spiralling health care costs across the planet. Despite mankind's emerging technical mastery of nature, we still have a very long way to go in terms of truly understanding it.

The Guy Foundation thus leads, supports and contributes to quantum biological and related research with the ultimate aim of advancing the development of new medical diagnostics and therapeutics. The Foundation believes this advancement can be achieved in a number of ways, which is reflected by the research we fund as well as the cross-section of scientists invited to give presentations. Our approach is summarised as encompassing research from bench to bedside.



Our priorities encompass the spectrum of theoretical, experimental, and practical advances. Understanding the fundamental physics (e.g., quantum mechanics, electrodynamics, thermodynamics) is important. More specifically we aim to understand this physics within the biological and physiological contexts, with the emphasis on furthering the study of medicine. Overall, we would like to see this knowledge translated and applied in new diagnostics and therapeutics.

The Foundation therefore aims to provide a platform and a forum for upstream push through and downstream pull through of the understanding of the role of quantum effects in biology in health and disease. With an emphasis on building a research community to further investigate these interests, The Guy Foundation operates in a spirit of collaboration rather than straightforward grant funding, to advance the course of useful knowledge towards the mainstream and bring it to the attention of more conventional funders. We aim to do this in various ways. For instance, by curating a programme of scientific meetings and publications that incorporates the diverse aspects of the field and facilitates engagement from scientists across relevant disciplines; as well as by identifying what we see as research priorities and building a network of interested scientists through the funding of collaborative projects to accelerate relevant high-quality scientific research.

Professor Geoffrey Guy MB BS, LRCP MRCS, LMSSA, DipPharmMed, BSc, DSc
Founder and Chairman of the Board of Trustees, The Guy Foundation

Abstract Proceedings

These are abstracts of a meeting convened by Cancer Research Horizons and The Guy Foundation, that took place in London and online, on 17th October 2023.

They have been written by the presenters and have not been formally peer-reviewed. We hope you enjoy them.

Why we may need to think about quantum mechanics and thermodynamics to better understand and treat cancer

Professor Alistair Nunn

The Guy Foundation and University of Westminster

Quantum biology is the study of the extent that quantum mechanics (QM), above and beyond its conventionally accepted roles in physics and chemistry, may play in life. In effect, has the warm and wet world of biology somehow enhanced and expanded quantum effects beyond their normally accepted limits in time and space of the atomic world, which physics might suggest it couldn't do. For example, is it enhancing the existence of the wave part of the wave-particle duality, and thus coherence and superposition, suggesting life is more reliant on properties like tunnelling, entanglement, and spin, leading to the requirement to include explanations of how life works from a non-classical perspective. However, to date, as QM is complex and counter-intuitive, it is not often taught to biologists, especially as classical approaches to biology have been reasonably successful in explaining many, but not all phenomena. It is also extremely difficult to prove experimentally. However, if the wave and field concepts implicit in QM are introduced to biology, then not only might this help to explain its origins, but why today it can be manipulated by electromagnetic fields and photons. Indeed, it does seem that the warm and wet world of biology, through phenomena such as resonance, vibronics and quantum beating doesn't hinder potentially significant quantum effects but may even enhance them. This therefore modulates metabolism not just at the microscale, but may help in explaining things like consciousness, ageing and morphogenetics, regeneration and cooperation. In seems that not only is life electrical, as it is based on the movement of charged particles that generate fields, which hold information, but it is also photonic, as it generates photons during metabolism that is itself based on aromatic and chromophoric molecules that can absorb these photons.

Key in understanding this is that the fundamental principles of adaptive thermodynamics led to life in the first place as it fulfilled the laws of entropy. One of the strongest theories on the origins of life involves dissipation of energy potential in a hydrogen gradient, perhaps in an alkaline thermal vent that was also generating photons. The process of dissipative self-organisation led to far from equilibrium "negentropic" structures that could evolve and replicate. In short, life is simply an entropic

mechanism to dissipate energy, as suggested by folk like Erwin Schrödinger, Léon Brillouin and Ilya Prigogine. In a way, the existence of life indicates that not only may we need to rethink physics, but the physics means we may need to have a new approach to understanding life.

For example, it appears that programmed cell death, and the need to cooperate, evolved very early in prokaryotic evolution, but this had to be set against the background of competition, and the need to move under difficult conditions. Indeed, a species of Archaean prokaryote has been discovered that has a primitive cytoskeleton that can modulate its membranes, suggesting that its ancestors could have been the forerunner of the cell that got together with a bacterium to form the modern eukaryote. Putting this together, it seems that evolution resulted in a drive towards complexity, which in thermodynamic terms, meant structures that could last longer to continue dissipating and could adapt, to a certain degree, to stress – the process of hormesis. Key in this ability to adapt is to learn, which requires immediately accessible information – "smart adaptation" – using the past to predict the future. This rapidly accelerated with the evolution of the eukaryotic cell, and of course, the mitochondrion, and resulted in ever higher levels of cooperation between cells, but the trade-off, as an individual organism lived longer, was that Darwinian natural selection involving genes took longer – going from days for prokaryotes to centuries for long-lived mammals. However, at the level of all life, this explains why we see an enormous range of lifespans, and thus ageing, as each species has adapted to a particular niche. This is exactly what thermodynamics might predict, given the high variability in environments that have been constantly changing for billions of years; it is a composite of organisms that can rapidly evolve via genetic selection, especially under very high stress, to those that survive as individuals via smart adaption – but only up to a certain point. Species come and go, but life survives. In summary, by thinking in terms of QM and thermodynamics, we might therefore be able to suggest a few things:

1) Maintenance of the quantum underground determines the rate of ageing, loss of say, the ability to tunnel, would result in degrading bioenergetics, but an increasing ROS signal leading to either adapt or die. For multicellular systems, this is ultimately about cooperation, for instance, dying for the greater good
2) Inflammation and hormesis are flipsides of the same process, inflammation is a mechanism to try and repair, while hormesis enhances the ability to repair – which is why, with age, the ability

to adapt decreases and inflammation increases as maintenance fails. Inflammation, at a local level, is a reversion to simpler state to enable rebuilding

3) Increasing stress will always drive a reversion to simpler structures to explore “phase space” to find new solutions to maintain dissipation; this operates at all scales, from the molecular up to whole species – a classic example is mitophagy, or apoptosis. It seems that as “damaged” structures can hinder the functioning of their “healthier” cousins, “dying for the greater good” is explainable from adaptive thermodynamics
4) In terms of carcinogenesis, this suggests that with increasing age, there is an increasing drive for complex organisms to revert to an ancient and simpler state, which is reflected in the emergence of cells that stop cooperating and try and evolve to survive, which is likely linked into inflammation
5) In terms of treatment, this suggests that cancer is an ancient reversion programme to a simpler state, which means we might learn how to control it. Indeed, we have already learnt how to do this to some degree with drugs. As ever, however, nature is already giving us clues – both calorie restriction and physical activity seem to be protective: “cooperate for the greater good”. From the QB perspective, manipulation of cell function via EMF and photons may represent a much more nuanced way of doing this; both of these techniques can be anti-inflammatory and induce resolution of wounds, and there is evidence of anti-cancer actions with these techniques. There may well be programming language we need to learn – as we know, life is electrical. The origins of why we can do this likely go back to the origins of life itself.

Introduction to electromagnetic fields in cancer

Dr Nathan Babcock

Howard University

Global incidences of cancer are rising with predictions that 13 million people will die yearly from cancer by 2030 [1]. Although cancer is one of the most common causes of death worldwide, most cancer treatments produce serious side effects and few patients can expect complete remission [2]. This indicates a need for greater understanding of factors that cause cancer and determine its progression.

Many cancer treatments are based on the model of cancer as a genetic disorder, even though cancer was recognized as a metabolic disease about a century ago [3]. As a result, much cancer research has been based on the hypothesis that metabolic changes found in tumor cells are a corollary effect, rather than the central transformation of cancer [4]. Controversy surrounding the metabolic basis for cancer was resolved in 2009 with the discovery of the “reverse” Warburg effect [5] and the re-invention of Warburg's original idea of a transition to aerobic glycolysis to promote tumor metabolism as the primary metabolic transformation of the cancer cell environment [6].

Here I provide an overview of the key role played by quantum electrodynamics in a variety of established medical treatments before reviewing the importance of quantum mechanical processes in governing many fundamental metabolic activities of the cell. Quantum effects are shown to influence many biomedical factors including rates of tissue repair, inflammation reduction, and pain relief. I describe how several novel therapies show promise to revolutionize outcomes of cancer treatments and I highlight prospects for many more.

I conclude by outlining the essential quantum physics of the bioelectrical processes that control cell growth, sensing, energy flow, morphology, and redox metabolism. This quantum picture of a healthy cellular microenvironment provides the necessary basis to understand, control and potentially reverse the progression of cellular dysregulation found in all metabolic phenotypes of cancer.

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New perspectives on metabolism and cancer

Professor Nick Lane

Department of Genetics, Evolution and Environment, University College London

This year marks the centenary of Warburg's first paper on the tendency of cancer cells to switch to aerobic glycolysis [1]. It is now clear that mitochondrial metabolism, especially Krebs cycle flux, is perturbed in many cancer cells [2]. While the oxidative Krebs cycle is the main source of NADH for oxidative phosphorylation, the reverse Krebs cycle is an engine of CO_2 fixation in anaerobic bacteria [3]. Non-cyclic (anaplerotic) flux is likewise a major source of metabolic precursors for biosynthesis in many cells, notably cancer cells [4]. The direction of flux through the Krebs cycle depends critically on respiratory complex I, which is the main sink for matrix NADH as well as cytosolic NADH imported via the malate-aspartate shuttle. Good complex I function is associated with greater fertility, longer lifespan and better physical activity in fruit flies [5]. Importantly, complex I is also a major source of reactive oxygen species (ROS) in mitochondria. ROS flux can be maintained within homeostatic limits by suppression of complex I, to the point of death in fruitflies [6]. Suppression of complex I with age is therefore predicted to impact on Krebs cycle flux, driving reverse flux and export of citrate to form cytosolic acetyl CoA, oxaloacetate and NADH. Together, these metabolic shifts induce an epigenetic change via sirtuins and mTOR, towards a senescent state that likely increases the risk of cancer [7]. Intriguingly, some mutations in complex I induce hypersensitivity to anaesthetics, potentially via the dissipation of electron-spin polarization [8], which slows down respiration and alters mitochondrial membrane potential. Whether this effect is direct, altering electromagnetic fields generated by spin polarization in complex I, or indirect, through the collapse of ATP availability, is relevant not only to anaesthesia but also to mitochondrial function in ageing and cancer.

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New perspectives on mitochondrial oncogenetics

Dr Payam Gammage

Beatson Institute, Glasgow

Dr Gammage presented new research that is still in the process of being published. To see more about his research visit the **Beatson Institute webpage**. He has published previous related research in the following papers.

[1] Respiratory complex and tissue lineage drive recurrent mutations in tumour mtDNA
https://www.nature.com/articles/s42255-021-00378-8

[2] Therapeutic Manipulation of mtDNA Heteroplasmy: A Shifting Perspective
https://doi.org/10.1016/j.molmed.2020.02.006

[3] Mitochondrial DNA: the overlooked oncogenome?
https://bmcbiol.biomedcentral.com/articles/10.1186/s12915-019-0668-y

[4] Genome editing in mitochondria corrects a pathogenic mtDNA mutation in vivo
https://www.nature.com/articles/s41591-018-0165-9

Introduction to weak magnetic fields and stem cell growth

Professor Wendy Beane

Western Michigan University

Stem cells have special capabilities no other cell type possesses, namely the ability during the same division to give rise to both a cell like itself (another stem cell) and a cell different than itself (for example, one that will mature or differentiate into a neuron). Environmental cues are critical in regulating stem cell activities, both cues from the cell's microenvironment (the stem cell niche) as well as the larger organism's environment (such as the geomagnetic field). One local environmental cue is cellular signaling, such as reactive oxygen species (ROS) signaling. ROS, including superoxide (O_2-) and hydrogen peroxide (H_2O_2), are highly reactive oxygen-containing molecules formed as a part of cellular metabolism. ROS signaling works via thresholds, where different ROS levels result in different outcomes (cell migration, cell division, cell death, etc.). Both very low and very high ROS levels can damage cells, but intermediate levels positively drive cell signaling[1]. In stem cells, ROS can regulate cell cycle decisions, with low levels producing stem cell renewal or quiescence, intermediate levels promoting differentiation, and high levels causing senescence (aging)[2]. Using the highly regenerative planarian model system[3], our research has shown that ROS accumulate at the wound within 1 hour after injury, and this increase is required to activate *hsp70* expression, which increases stem cell proliferation (division) and progeny numbers[4]. Thus, our data suggest that ROS signaling regulates new tissue growth after injury. We also have been investigating the effects of weak magnetic fields (WMFs, <1 mT), which the radical pair mechanism proposes can affect biological processes via quantum effects[5]. Our data show that based on field strength, WMFs can either increase (500 µT) and decrease (200 µT) ROS levels and downstream signaling, and thus regulate the amount of new tissue that is produced[6]. Our investigations found that although H_2O_2 peaks at 1 hour after injury and O_2- and the downstream peroxynitrite peak at 2 hours, WMF exposure had no effect on H_2O_2 but did alter O_2- levels[6]. Together, the data suggest that WMFs affect O_2- signaling in stem cells, and thus represent a potential way to non-invasively regulate proliferation and tissue growth.

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2 Sinenko, S. A., Starkova, T. Y., Kuzmin, A. A. & Tomilin, A. N. Physiological Signaling Functions of Reactive Oxygen Species in Stem Cells: From Flies to Man. *Frontiers in cell and developmental biology* **9**, 714370 (2021). **https://doi.org:10.3389/fcell.2021.714370**

3 Ivankovic, M. *et al.* Model systems for regeneration: planarians. *Development (Cambridge, England)* **146** (2019). **https://doi.org:10.1242/dev.167684**

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6 Kinsey, L., Huizen, A. V. & Beane, W. Weak Magnetic Fields Modulate Superoxide to Control Planarian Regeneration. *Frontiers in Physics* **10** (2023). **https://doi.org:https://doi.org/10.3389/fphy.2022.1086809**

Introduction to morphogenetic fields

Professor Michael Levin

Allen Discovery Center at Tufts University

Embryonic development, regeneration, and cancer are phenomena tied together by a fascinating central concept: the shifting boundaries of an emergent higher-order agent. In this talk, I briefly present ideas stemming from our efforts to understand morphogenetic problem-solving (a.k.a., intelligence, not just emergent complexity) as the behavior of a cellular collective in anatomical space. We have studied bioelectrical signaling among cell networks as a kind of cognitive glue that binds the agential material of cells into collectives with many interesting competencies. I present techniques for reading and writing the biophysically-encoded pattern memories of tissues in vivo, which form an important layer of the morphogenetic field. Finally, I discuss cancer as a dissociative disorder of the collective cellular intelligence, and show techniques by which cancer can be detected early, induced in the absence of genetic damage or carcinogens, and best of all, normalized despite powerful human oncogenes. Bioelectrical strategies for re-inflating the border between the multiscale agent and its outside world is a promising roadmap for addressing cancer without toxic chemotherapy.

Potential of photobiomodulation in treating cancer

Professor Michael Hamblin

The University of Johannesburg

Photobiomodulaton (PBM) describes the use of red and/or near-infrared (NIR) light to heal, restore and stimulate multiple physiological processes, including reducing pain and inflammation, and repairing tissue damage caused by injury or disease. PBM initially used "low level laser therapy" but now light emitting diodes (LEDs) have rapidly gained popularity, due to their much lower cost and the absence of safety concerns. LED arrays can deliver up to 100 mW/cm^2 over relatively large areas of the body, and can mix red and NIR wavelengths together. PBM exhibits a "biphasic-dose response" (1, 2) because the optimum parameters (energy density or power density) provide a benefit, while if these parameters are substantially exceeded, the benefits disappear.

The mechanism of action of PBM is mainly based on stimulating mitochondrial metabolism, increasing membrane potential, oxygen consumption and ATP production. Signaling pathways and transcription factors are activated, leading to long-term changes after relatively brief exposure to light. The activation of oxidative phosphorylation in cells has two important consequences. Firstly, autologous stem cells are activated and mobilized from the bone marrow, so they can migrate to sites of tissue damage. Secondly, M1 polarized macrophages are switched to the anti-inflammatory M2 phenotype thus reducing inflammation.

Because PBM was shown to stimulate the growth of cancer cells in cell culture studies, it was asserted that PBM may be contra-indicated in patients with cancer (3), but there is little hard evidence for this. On the other hand, PBM is highly effective in the mitigation of side-effects of cancer therapy (4, 5), including oral mucositis, chemotherapy-induced peripheral neuropathy and alopecia, radiation dermatitis, lymphoedema, and disorders of taste, smell and hearing.

There are three ways that PBM may be used in the actual treatment of cancer. The first involves the direct effect of the light on the tumor cells themselves, and may be thought of as a deliberate use of the biphasic dose response curve to "overdose" the cancer cells (6). The second method relies on taking advantage of a differential effect of PBM between malignant cancer cells compared to the

effects seen on healthy normal cells. This involves combining PBM with an additional cytotoxic anti-cancer therapy, so that it increases the killing of cancer cells, while at the same time protecting normal healthy cells. This may be related to the Warburg effect, in which the mitochondria of cancer cells change their metabolism to carry out aerobic glycolysis instead of oxidative phosphorylation (7). Because of restricted blood supply the cancer cells become tolerant to chronic hypoxia. In cancer cells, where ATP supply is quite limited, the ATP boost given by PBM may allow the cancer cells to respond to pro-apoptotic cytotoxic stimuli more efficiently (8).

Santana-blank et al (9) carried out a Phase 1 trial of PBM on 17 patients suffering from a variety of "advanced malignancies". They used a 904nm infrared laser, pulsed at 3 MHz, with a 10-mm beam diameter and placed at right angles to the surface of the patient's chest. Statistically significant increases in performance status and quality-of-life were observed at all of the follow-up intervals compared with pretreatment values. In the six surviving patients, one patient had a complete response, 1 partial response, 4 stable disease >12 months, and 1 progressive disease. The mechanisms operating in this clinical study require more investigation, but if it can be repeated, it could be very promising.

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Rotating magnetic fields and cancer

Professor Martyn A Sharpe

Houston Methodist Hospital

Professor Sharpe presented new research that is still in the process of being published. To see more about his research visit the **Houston Methodist Hospital webpage**. He has published previous related research in the following papers.

[1] Spinning magnetic field patterns that cause oncolysis by oxidative stress in glioma cells **https://doi.org/10.1038/s41598-023-46758-w**

[2] Rotating Magnetic Fields Inhibit Mitochondrial Respiration, Promote Oxidative Stress and Produce Loss of Mitochondrial Integrity in Cancer Cells **https://doi.org/10.3389/fonc.2021.768758**

[3] Case Report: End-Stage Recurrent Glioblastoma Treated With a New Noninvasive Non-Contact Oncomagnetic Device **https://doi.org/10.3389/fonc.2021.708017**

[4] Selective induction of rapid cytotoxic effect in glioblastoma cells by oscillating magnetic fields **https://doi.org/10.1007/s00432-021-03787-0**

Tumor Treating Fields: at the crossroads between physics and biology for cancer treatment

Dr Phuoc T Tran

University of Maryland School of Medicine

Dr Tran presented new research that is still in the process of being published. To see more about his research visit the **University of Maryland School of Medicine webpage**. He has published previous related research in the following paper. To see his other papers on the topic of cancer see the above webpage.

[1] Tumor Treating Fields: At the Crossroads Between Physics and Biology for Cancer Treatment
https://www.frontiersin.org/journals/oncology/articles/10.3389/fonc.2020.575992/full

Closing Note

Professor Geoffrey Guy

Founder and Chairman, The Guy Foundation

The Guy Foundation has been set up to explore the potential role that quantum biology could play in enhancing medicine. We propose that examining possible routes for research and development of cancer therapeutics that exploit non-chemical mechanisms could be very fruitful. Non-chemical mechanisms in biological systems have a long history of interest. It has been proposed that because life is largely electrical and exploits the existence of voltages across membranes, it is likely that it is using some kind of "field" based homeostasis. This coupling between matter and fields is very well established in the physics world and can be described using quantum mechanics. These ideas, in the biological context, have been largely overshadowed by breakthroughs in the discipline of genetics, which sought to explain all biological processes through the information contained in the genome. Cancer research is a case in point, being largely thought of as resulting from genetic mutations. Despite advances made in this direction, however, cancer remains both prolific and difficult to treat. As such it seems apposite to investigate in other directions as well, hence this meeting between Cancer Research Horizons, part of Cancer Research UK (CRUK), the world's largest independent cancer research organisation, and The Guy Foundation, who have some experience in moving biology in the bioenergetic and quantum direction.

What became clear as the talks progressed was that there were a number of emerging and related themes. Mitochondria, metabolism, electron transfer chains, membrane potential and reactive oxygen species recurred in a variety of different contexts. Central to this seemed the fact that both molecules and fields allow biological systems to communicate and signal, to bend energy and information into action. This happens both within cells and cellular collectives, and cancer is only one of the outcomes of situations in which this signalling seems to change. In order to better understand cancer, therefore, genetic approaches need to be augmented by these other concerns. Indeed, though the meeting was focused towards understanding cancer through the lens of bioenergetics, the important role that mitochondrial DNA plays in cancer suggests that there is an interplay between genetics and energetics, possibly involving epigenetics. In terms of therapeutics, molecular approaches could again be augmented by field-based or quantum approaches that leverage light-matter interactions and magnetically sensitive spin-based chemistry.

As quantum biology develops further in both theory and application, we hope to see it turned to the purpose of better understanding and treating cancer.

www.theguyfoundation.org