

REVIEW



Biophotonic Signaling in Energetic Biocommunication: A Conceptual Framework and Experimental Strategy for Validating Weak Optical Interactions in Biofields

Rick Sá^{1,*}¹ *Brazilian Academic Consortium for Integrative Health, Brazil*

Abstract: Ultraweak photon emissions (UPEs) represent a plausible yet underexplored biophysical mechanism underlying energetic biocommunication between human organisms, particularly in the context of biofield therapies (BTs) such as Reiki, Therapeutic Touch, and External Qigong. Although biophotonic emission is a well-documented property of living systems across all kingdoms of life, the present perspective focuses specifically on the human organism as a photoinformatic system. The central methodological gap obstructing empirical validation lies in the inability to simultaneously detect UPEs from a human source and correlate them with the resulting biochemical and functional changes induced in a target biological system. This work presents a restructured, convergent framework built around three pillars: (i) a theoretical and experimental basis for evaluating four interrelated hypotheses concerning selective photonic biocommunication; (ii) a tripartite laboratory strategy integrating multimodal multiphoton tomography, stimulated Raman spectroscopy, and polychromatic spectral analysis of UPEs; and (iii) an explicit discussion of limitations. The framework anchors energetic biocommunication in measurable parameters such as photon flux, spectral distribution, coherence, and biological responses, providing operational foundations for rigorous investigation of BTs as potential modulators of endogenous photonic signaling and paving the way for standardized biophotonic measurement technologies in precision medicine.

Keywords: biofield therapy, UPE, biophotons, endogenous photobiomodulation, biocommunication

1. Introduction

In the 1920s, the Russian embryologist Alexander Gurwitsch demonstrated through experiments with onion roots that the tip of one root could stimulate cell division in a second root separated exclusively by a quartz plate, but not by glass or opaque materials. He concluded that the signal had to be a form of ultraviolet radiation so faint that he named it mitogenetic radiation [1], marking the first experimental evidence of what we now call biophotonic communication: the transmission of biological information through ultraweak photon emission (UPE). At the cellular level, biophotons are generated by oxidative metabolism, which inevitably produces molecules in electronically excited states; a small fraction of this excitation energy relaxes through radiative decay, resulting in the emission of ultraweak photons at rates typically on the order of a few photons·s⁻¹·cm⁻², increasing to hundreds under stress conditions [2]. UPE is a universal phenomenon confirmed over the last century in bacteria, yeast, plant seedlings, developing embryos, excited nerves, beating hearts, malignant tumors, human skin, and isolated mitochondria [3–8].

Methodological advances, from single-photon-counting photomultiplier tubes (PMTs) and cooled charge-coupled device (CCD) cameras to polychromatic spectroscopic systems resolving emission patterns approximately 1,000 times below the human visual threshold [9–19], have opened new windows into psychophysiology: negative emotional states measurably increase trunk UPE intensity [20], and photoencephalography passively records scalp UPEs correlated with functional brain states [21]. Parallel to these developments, biofield therapies (BTs), including Reiki, Therapeutic Touch, and External Qigong, have attracted clinical interest [22, 23]. Reiki has been shown to significantly increase photon emission in intervertebral disk cells under stress [24], and BT practitioners can modulate their own UPE intensity through intentional focus [25, 26], yet a coherent biophysical framework explaining how these ultraweak signals trigger measurable physiological changes has remained elusive.

Biofields have been defined as fields not necessarily electromagnetic in nature, hypothetically involved in biological communication and information transfer [27–29], comprising photonic biofields through which information can be primarily transmitted [30]. This work addresses one measurable component of that framework: biocommunication mediated by the spatially and temporally patterned emission of ultraweak photons

*Corresponding author: Rick Sá, Brazilian Academic Consortium for Integrative Health, Brazil. Email: ricksa@cabsin.org.br

between human bodies, grounded in empirical photometric and spectroscopic methods rather than metaphysical concepts.

Although the mechanisms of photobiomodulation (PBM)/low-level laser therapy (LLLT) and pulsed electromagnetic fields are well-characterized [31–42], as are signaling via biochemical, piezoelectric, and electro/galvanotactic pathways [43, 44] and the well-characterized processes of human wound healing [45], the possibility of biophoton-mediated information transfer remains largely unexplored. This gap motivates the central hypothesis of the present perspective: BTs may operate through energetic bio-communication, that is, the transfer of biological information mediated by UPEs, modulating cellular processes via resonant interactions with endogenous chromophores without significant net transfer of chemical energy. This article presents a methodological framework synthesizing available evidence into a coherent biophysical model, explicitly framed as a perspective culminating in testable predictions and an experimental roadmap for validation. Section 2 presents the theoretical and experimental basis for four interrelated sub-hypotheses; Section 3 describes laboratory analysis techniques; Section 4 discusses limitations; Section 5 presents conclusions.

2. Hypotheses of Selectivity: Irradiance Signature, Coherence Shielding, and Proposed Mechanisms

The central hypothesis of this theoretical framework, namely, that external UPEs from a BT's hands, guided by the recipient system's endogenous waveguides, preferentially interact with the distinct photonic signatures of diseased tissues as opposed to healthy ones to induce selective cytolytic effects, rests on a well-established empirical asymmetry: diseased cells exhibit high incoherent irradiance and intense yet disorganized biophoton emission, lacking the active photon absorption capacity characteristic of coherent healthy systems [46]. Because coherence is used throughout this article in a physical rather than a figurative sense, the term requires an operational definition at the outset. Coherence here denotes the degree of first-order correlation of the optical field, quantified by the normalized correlation function $g^{(1)}(\tau)$ and expressed as a coherence time and a corresponding coherence length, together with the photon statistics of the emission characterized by $g^{(2)}(0)$, which distinguishes a chaotic from a coherent source. Spontaneous emission arising from uncorrelated molecular relaxation events is expected to be chaotic on both measures, and claims of coherence in UPE therefore stand or fall on direct measurement of these quantities rather than on the presence of spectral structure or of non-exponential decay kinetics, neither of which is by itself sufficient. No such measurement has yet been reported for human emission, and supplying it is accordingly treated here as a prerequisite for the hypotheses that follow rather than as an established premise. This differential in photonic signatures provides the physical basis for selective interventions using external biological light. Based on the premise that humans possess not only chemotrophic but also *chemophotogenic* properties (from the Greek: *chemo-*, chemical; *photo-*, light; *-genic*, producing; denoting the capacity to absorb primary external photons, transduce them into chemical energy, and re-emit endogenous biophotons that carry the spectral signature of the original signal, functioning as secondary photonic messengers capable of being conducted by biological waveguides to specific target tissues) and that BTs may share a transduction pathway with photobiomodulation while operating in a different dose regime, four interrelated sub-hypotheses are proposed. Two distinct propositions are advanced in this article and are kept

terminologically separate throughout, because they carry very different photon budgets. *Endogenous photobiomodulation* denotes the internal system developed in Section 2.4, in which emission generated within a cell or tissue is absorbed by chromophores in its immediate vicinity, with no intervening distance or epidermal barrier. *Interpersonal photonic signaling* denotes the transfer of emission from a practitioner to a recipient, which requires propagation through air and through the epidermis before reaching a chromophore. The first is not subject to the dosimetric constraint set out in Section 2.3; the second is. These are explicitly presented as speculative propositions grounded in available experimental evidence, albeit lacking robust confirmation, rather than established biological facts.

H1 (Speculative): Chemophotogenic organisms emit and absorb biophotons in a nonrandom manner. An endogenous network of biomolecules acts as a system of biological antennas capable of directing photonic energy via an environment-assisted quantum walk mechanism [47] to cellular sites most in need of regulatory signaling, such as damaged or tumorous tissues.

H2 (Hypothesis with experimental grounding): Diseased cells absorb external coherent UPEs through interaction with the cell membrane, modulating redox signaling pathways and potentially inducing bioelectric and mitochondrial reorganization toward apoptosis or the suppression of uncontrolled proliferation. External Qi has been reported to cause lysis of BxPC3 pancreatic cancer cells without affecting normal fibroblasts [48]. Reports of this kind establish an association between the intervention and the outcome; they do not identify the mediating channel. Because a practitioner delivers thermal, mechanical, acoustic, and near-field electromagnetic inputs concurrently, attribution of such effects to photon transfer requires the discriminating measurements set out in Section 3 and is not assumed here. It has also been shown that Therapeutic Touch reduced lymph node metastasis and decreased the expression of pro-inflammatory cytokines (IL-1 α , IL-1 β , MIG, MIP-2) in a mouse model of breast cancer [49]. Additionally, BT reduced the resting membrane potential of PANC-1 cells by 36.7% relative to sham controls ($p < 0.01$), resulting in cell cycle arrest at the G1 phase, mitochondrial ultrastructural disruption, reduced invasiveness, and decreased liver metastasis in orthotopic models ($p < 0.05$), with FOXM1 identified as a key downstream mediator [50].

H3 (Speculative with mechanistic basis): Coherent UPEs originating from a BT may increase the quantum coherence of the patient's healthy cells, rendering them more resistant to the chaotic UPEs of neighboring tumor cells, a mechanism that would operate through interference between the two emissions [8, 30]. This proposal carries a stringent physical requirement, since interference between independent sources presupposes a stable phase relationship between them, which spontaneous emission arising from uncorrelated molecular relaxation events does not by itself provide. H3 should therefore be read as a prediction contingent on the demonstration of first-order coherence in UPE, as defined above, rather than as an inference from it. Microtubules (MTs) sustain coherent quantum states with relaxation times exceeding excitation times by 9–10 orders of magnitude at physiological temperatures [51]. Hydrated DNA has been shown to undergo a macroscopic quantum phase transition at room temperature, producing a Fröhlich condensate [52].

H4 (Speculative): Coherent UPEs may modulate the galvanotaxis of immune cells, stimulating NK cell migration to injury sites while simultaneously inhibiting M2 macrophages and regulatory T cells. Direct current fields (0.4–1.4 V/cm) induce directional lymphocyte migration via Erk1/2 and Akt

activation [53]; macrophages exhibit galvanotactic polarity that adjusts according to infection status [54]; and fibroblast electrotaxis occurs through integrin redistribution [55]. BT modulates these populations: Healing Touch preserved NK cell cytotoxicity over six weeks in patients with cervical cancer undergoing chemoradiotherapy, whereas a decline occurred in the control group ($p = 0.018$) [56]; and Therapeutic Touch reduced lymph node metastasis and macrophage cytokine expression in a mouse breast cancer model [49]. The mechanistic relationship between biophotonic emission and the electrotactic guidance of immune cells has yet to be experimentally established.

2.1. Quantifying biofield therapies through biophotons

Biophoton emission offers a physicochemical framework for exploring mechanisms underlying BTs. UPE measurement provides a potential means to detect and quantify interactions with the supposed subtle biological energy field. Early studies showed an inverse correlation in Qigong practitioners: hand biophoton emission increased while skin temperature decreased, challenging the thermal model and suggesting willpower-controlled phenomena [57]. A beginner showed increased finger temperature during practice, while an untrained individual exhibited increased emission during light visualization, indicating conscious concentration can influence these parameters [26]. Subsequent research used living organisms as biosensors: pieces of cucumber (*Cucumis sativus*) were employed to detect Ki fields and noncontact healing effects, quantifying the interaction between healer intention and biological samples through the J-value index ($J = \ln[I_E/I_C]$). The direction of the correlation between a healer's age and healing power proved unstable across studies, and the instruction given to the healer emerged as a more decisive factor than age in determining the outcome. After the confounding influence of different healing methods was removed through principal component analysis, a significant negative correlation was found between healer age and gas J-value ($r = -0.46$; $p = 0.034$): younger healers succeeded in driving the biosensor in the intended direction, whereas older healers did not. These findings indicate that the relationship between healer characteristics and measurable effect is method-dependent and that further confounding factors remain to be identified [58].

Regarding the effect of mental concentration, the response depended on the individual: some subjects showed an increase and others a decrease in emission, a variability the authors linked to the degree of concentration each subject was able to achieve. Across seven subjects, mental concentration alone was associated with changes in fingertip biophoton emission, and the subjects separated into two consistent response groups whose directional tendency held across all three experimental days. This provided early evidence that focused intention, a central component of many biofield techniques, might have a measurable photonic correlate [26].

The most direct evidence comes from studies involving experienced practitioners. In a comprehensive investigation, the UPEs of energy healers and individuals performing bioenergetic exercises were measured. Researchers found that emission from the therapists' hands decreased significantly after the healing session—a statistically significant reduction of 11% in biophoton emission from healers' right and left palms combined ($p = 0.019$), with the dominant right palm showing $p = 0.05$. Additionally, subjects performing bioenergetic exercises with directed intention were able to voluntarily increase emission from the forehead by 62–106% and from the cardiac region by up to 282%, demon-

strating a capacity for conscious and directional modulation of biophotonic output consistent with conceptual models of energy direction in BTs [25].

In nonhuman models to control for psychological placebo effects, initial trials in germinated seeds and anesthetized mice did not report statistically significant changes in UPE resulting from noncontact healing [59]. However, Reiki has been shown to significantly increase photon emission in intervertebral disk cells of cultured stressed mice, directly linking BT to a quantifiable photonic response in a biological system: Reiki post-treatment photon emission significantly exceeded both Reiki pre-treatment values and sham post-treatment values ($p < 0.05$), a difference maintained on each of the three measurement days ($p < 0.01$). Concurrently, RT-PCR revealed that Reiki significantly upregulated collagen II and aggrecan expression in the treated cells ($p < 0.05$ vs. sham), linking the photonic response to a measurable anabolic healing cascade [24].

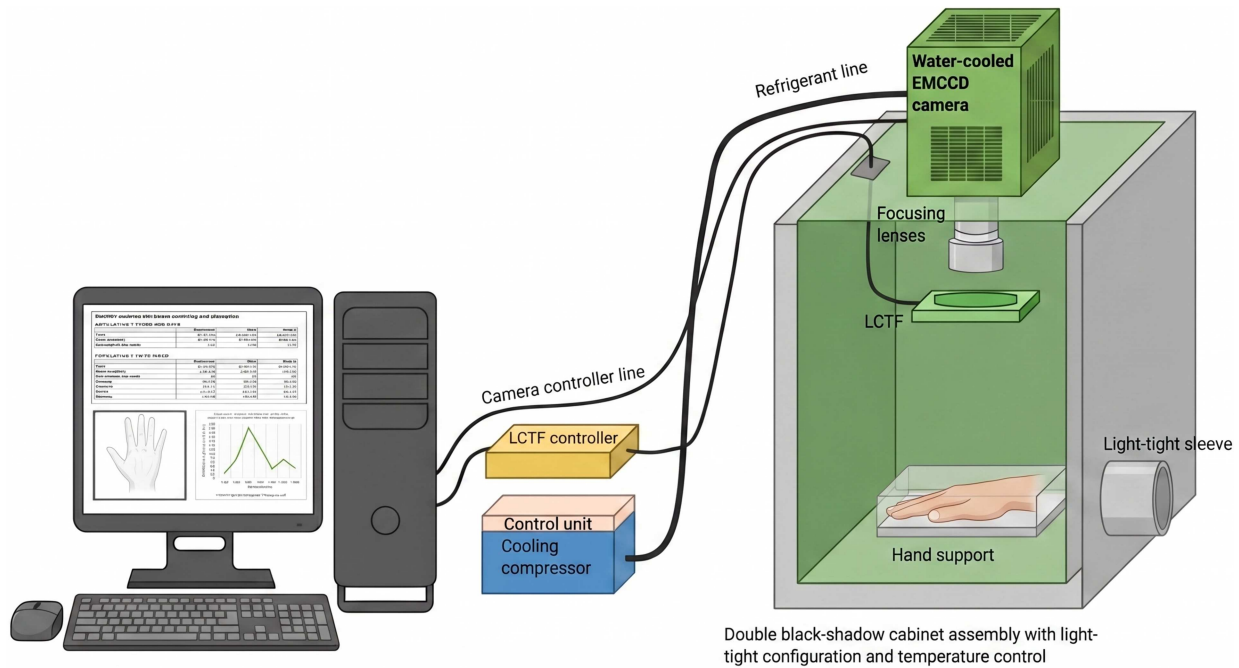
2.2. Quantification of the energy provided by external biophotons in humans

The energy associated with human UPE, while quantifiable, is too low to be considered a direct energy source in any conventional biochemical or biophysical sense. Unlike conventional bioluminescence or laser emissions, UPE cannot be directly measured in watts using standard photometric techniques. Instead, it is typically quantified as photon flux, the number of photons emitted per second, normalized per unit area ($\text{photons} \cdot \text{s}^{-1} \cdot \text{cm}^{-2}$). Compiling data from multiple studies, spontaneous UPE from human skin, particularly the palms and fingertips, consistently ranges from tens to hundreds of $\text{photons} \cdot \text{s}^{-1} \cdot \text{cm}^{-2}$ [60–62]. For example, approximately $10.4 \text{ photons} \cdot \text{s}^{-1} \cdot \text{cm}^{-2}$ have been reported in normal skin, while another study measured about 20 $\text{photons} \cdot \text{s}^{-1}$ above the background level in the palm of the hand [61, 62]. A comprehensive review confirms that the UPE of human skin typically ranges from 1 to 1000 $\text{photons} \cdot \text{s}^{-1} \cdot \text{cm}^{-2}$, depending on physiological conditions and measurement protocols [63].

The experimental setup illustrated in Figure 1 [63] employs a high-sensitivity UPE spectrometer comprising an electron-multiplying charge-coupled device (EMCCD) camera (iXon Ultra 888, cooled to -95°C), a telecentric lens module, and a liquid crystal tunable filter (LCTF) spanning 400–720 nm, housed within a light-shielded dark chamber. Operating sequentially across discrete wavelengths over 10-minute acquisition periods, this system enables the simultaneous capture of spatial and spectral information from the dorsal surface of the hand. Spectral distributions obtained with this configuration revealed a peak emission of approximately 880 photons at 500 nm after dark signal subtraction. This approach captures not only total intensity but also the spectral fingerprint of UPE, information critically linked to reactive oxygen species (ROS) dynamics and metabolic states of living tissue [63].

The spectral fingerprint captured by this system provides the empirical basis for a mechanistic interpretation of UPE origin based on photon energy. Emission at higher energies ($>3 \text{ eV}$; 200–420 nm) is attributed to radicals and ROS from oxidative metabolism [3, 64]. Lower-energy emission ($<3 \text{ eV}$; 420–1000 nm), which constitutes the majority of detectable UPE and encompasses the 500 nm peak recorded in Figure 1, has been associated with proton current flow in mitochondrial ATP synthase complexes [64]. This hypothesis posits that excitation of the proton system in active ATP synthase, particularly the F_0 unit, generates light analogous to a laboratory proton light-emitting diode (H^+LED) [65]. Each actively rotating ATP synthase molecule

Figure 1
Design of the UPE system for measuring one subject's hand



Note: Adapted from Ortega-Ojeda et al. [63] (Figure 1)

operates at approximately 300 rotations/s with approximately 1000 protons per cycle, generating a cooperative proton current of $3 \times 10^5 \text{ H}^+/\text{s}$ ($4.8 \times 10^{-14} \text{ A}$) [66]. Assuming two photons emitted per proton ($\text{H}_3\text{O}^+ + \text{OH}^- \rightarrow 2 \text{H}_2\text{O}^*$), this yields a theoretical maximum of 6×10^5 photons/s per ATP synthase molecule, of which roughly half is retained in H^+ -LED simulations as an upper bound on radiative output [65, 66]. This figure is a ceiling on emission at the molecular level and not a prediction of detectable flux. Taken at face value and multiplied by the number of enzyme complexes in a tissue volume, it would exceed measured cutaneous UPE by many orders of magnitude, so the great majority of the emission implied by the model must be lost to non-radiative decay, to reabsorption by intervening chromophores, and to scattering before reaching the tissue surface. Quantifying that attenuation factor is a necessary test of the model rather than a detail of its application. This model explains the anatomical distribution of UPE intensity: organs with high mitochondrial density (brain, heart, liver) exhibit stronger UPE signals, correlating with regions of high emission near the head, thorax, and abdomen [27, 60]. Water plays an essential role, enabling proton conduction channels and acting as the molecular medium for light emission [64].

To translate this photon flux into a physically significant radiant power, it is necessary to consider the energy carried by each individual photon, which depends on its wavelength. Polychromatic spectral analyses have demonstrated that human UPE spans the visible to near-infrared range (400–750 nm). Published accounts of the position of the maximum do not converge. Fingertip emission has been reported to peak in the 570–670 nm region [67, 68], whereas the spectral distribution obtained with the configuration of Figure 1 peaks near 500 nm [63], and this disagreement is itself one of the measurements the framework proposed here is designed to settle. A representative wavelength is adopted below for the purpose of an order-of-magnitude estimate, and the estimate is insensitive to which of the reported max-

ima is assumed. Taking a representative wavelength of 600 nm ($6 \times 10^{-7} \text{ m}$) within this peak, the energy per photon is given by the Planck–Einstein relation $E = h \cdot c / \lambda$, where h is Planck's constant ($6.626 \times 10^{-34} \text{ J}\cdot\text{s}$) and c is the speed of light ($3 \times 10^8 \text{ m/s}$), yielding approximately 3.31×10^{-19} joules per photon.

Multiplying this value by a typical flux of 100 photons·s⁻¹·cm⁻² results in a radiant power density of approximately $3.31 \times 10^{-17} \text{ W/cm}^2$, that is, 33.1 aW/cm² or 0.0331 fW/cm² (1 aW = 10^{-18} W ; 1 fW = 10^{-15} W). Integrated over the entire palmar surface of approximately 100 cm², the total emitted power is of the order of $3 \times 10^{-15} \text{ W}$, that is, a few femtowatts. This places UPE detection at the very limits of current photometric sensitivity, requiring specialized instrumentation such as cooled PMTs, single-photon counting modules, and rigorous environmental shielding.

Calculations based on empirical measurements during states of focused intention further illustrate this point. In one such study, the emission was characterized by a frequency of 780 THz (corresponding to a wavelength of approximately 385 nm in the near-ultraviolet range) and a flux of 1,600,000 photons per second under intentional, non-spontaneous conditions [69]. This value warrants explicit qualification. Distributed over a palmar surface of approximately 100 cm², it corresponds to some 1.6×10^4 photons·s⁻¹·cm⁻², which exceeds by more than an order of magnitude the upper bound of the range reported for spontaneous cutaneous emission, and the stated wavelength of 385 nm falls outside the 400–750 nm interval reported elsewhere in this section. The calculation below is therefore presented as an upper-bound illustration derived from a single report, and the benchmark comparison that follows does not depend on it. Substituting a flux at the upper end of the consensus range lowers the estimated power by roughly the same factor without altering the conclusion. Applying the Planck–Einstein relation ($E = h \cdot f$) yields a single-photon energy of 5.168×10^{-19} joules. The total detected

power is then $P = (5.168 \times 10^{-19} \text{ J}) \times (1.6 \times 10^6 \text{ s}^{-1}) = 8.268 \times 10^{-13} \text{ W}$, or approximately 0.83 pW. By comparison, the spontaneous emission of the whole palm amounts to some 3 femtowatts, so the power reported under intentional conditions exceeds spontaneous emission by more than two orders of magnitude. This reinforces the qualification above and should be borne in mind in the comparisons that follow.

To contextualize this power level within established biological signaling thresholds, three benchmarks are instructive. The human rod photoreceptor is activated by a single photon carrying approximately $3.6 \times 10^{-19} \text{ J}$, with the visual system reliably detecting flashes of 5–7 photons [70]. Cryptochrome photoreceptors, mediating circadian entrainment and magnetoreception, are activated by single-photon absorption events in the 400–450 nm range (approximately $4.4 \times 10^{-19} \text{ J}$ per photon), overlapping with the spectrum of intentional UPE measured in humans [23], with a single absorption event sufficient to initiate a measurable redox signaling cascade [71, 72]. A single neural action potential consumes approximately 10^{-12} J , placing the 0.83 pW intentional biophotonic signal ($8.3 \times 10^{-13} \text{ J}$ per second) within the same order of magnitude. This last equivalence holds for the intentional case alone. Spontaneous emission lies about three orders of magnitude below the energy of a single action potential. These comparisons demonstrate that biophotonic power levels are not anomalously weak but precisely within the range at which evolved biological sensors operate.

A critical qualification concerns the fraction of emitted biophotons effectively absorbed by a recipient's skin. At dominant UPE wavelengths of 450–670 nm, the single-pass absorbed fraction within the epidermis, taken as a mean thickness of 0.1 mm, is small. Using pooled *in vivo* absorption coefficients, it lies below 1% in the red and reaches only a few percent toward the blue, rising to between 6% and 27% when the full combined depth of epidermis and dermis is considered, with the value depending on wavelength, skin phototype, and depth [73]. These single-pass estimates are lower bounds, since reduced scattering exceeds absorption by 1–2 orders of magnitude across this range and substantially lengthens the optical path within the tissue. The absorbed dose available at the chromophore is therefore well below the emitted power. This does not undermine biological relevance; it reinforces it. Cryptochrome activation requires only a single-photon absorption event per receptor molecule [71, 72], and rod photoreceptors operate reliably at 5–7 photons per flash. The biologically relevant parameter is therefore not total emitted power but absorbed dose at the chromophore level, a quantity determinable using the polychromatic spectral analysis described in Technique 3.

The relationship between interpersonal photonic signaling and therapeutic photobiomodulation requires explicit statement, since the two are readily conflated. Photobiomodulation is applied at fluences of the order of $0.1\text{--}10 \text{ J cm}^{-2}$. A 20-minute exposure at a surface flux of $100 \text{ photons} \cdot \text{s}^{-1} \cdot \text{cm}^{-2}$ delivers on the order of $10^{-13} \text{ J cm}^{-2}$, so the two regimes are separated by some 12–14 orders of magnitude, and no adjustment of exposure duration or hand-to-skin distance closes that gap. It follows that interpersonal photonic signaling cannot inherit the evidential support accumulated for photobiomodulation, and no such inheritance is claimed here. What the two may share is the transduction pathway, namely, the same endogenous chromophores and the same downstream redox cascades, and not the dose at which that pathway is engaged. Any mechanism proposed for the interpersonal case must therefore be one in which the limiting quantity is the number of photons reaching a chromophore rather than the

energy they deposit, and it is on that basis, not on analogy with photobiomodulation, that the hypotheses below are to be judged.

This rules out mechanisms based on direct energy transfer. Endogenous biophotons may contain information encoded in photon counting time series [74], with emerging diagnostic applications [75]. A flux in the femtowatt to picowatt range is biologically insignificant as a bioelectrical charge yet precisely within the range theorized to act as a coherent low-entropy signal, consistent with the Arndt–Schulz Law [76]: weak stimuli slightly accelerate vital activity, moderately stronger stimuli increase it further, and very strong stimuli suppress function. The 0.83 pW signal represents the quintessential weak stimulus, capable of synchronizing endogenous cellular oscillations and modulating cryptochromes, PI3K/Akt [77], TNF- α [78], tubulin and β -actin [79], and telomeres [80]. The effectiveness of BT lies not in energy brute force but in the precision and coherence of its information [81–83], acting as an external tuning signal that recalibrates the recipient's endogenous biophotonic network without constituting the source of biological energy driving the therapeutic response. For a comprehensive methodological overview, see Supplementary Material S1.

2.3. The role of biological waveguide candidates

The hypothesis is that the human body possesses a sophisticated endogenous photobiomodulation system. This system captures light from the external environment (artificial light or exogenous biophotons), generates (*photogenesis*), and transmits coherent endogenous biophotons through a network of photobiomodulatory sensor potentials and biological waveguides, regulating cellular function and systemic homeostasis. This biophysical puzzle is explained in detail in the following subsections, but first, a preamble to this topic is necessary.

Research comparing normal human fibroblasts with *xeroderma pigmentosum* (XP) cells deficient in DNA excision repair provides direct evidence for this concept [84]. Normal cells possess an efficient mechanism for capturing ultraweak photons, exhibiting a characteristic hyperbolic decay of photon re-emission after pre-illumination, interpreted as coherent re-scattering from collective nucleic acid excitation. XP fibroblasts lack this photon-storage capacity, releasing a pronounced burst of emission upon subsequent illumination [59]. This suggests that DNA repair machinery is integral to light-energy conversion: UV-induced pyrimidine dimer formation acts as a light-trapping step, analogous to retinal isomerization in vision [85], with subsequent excision and repair converting captured photonic energy into biochemical signals influencing melanogenesis [86].

Based on the established biochemical paradigm, mammals are classically defined as chemotrophic organisms that rely on the oxidation of chemical substrates to produce ATP. This hypothesis proposes an expansion of that concept by introducing the term *chemophotogenic* to describe a complementary mechanism. Beyond chemical nutrition, mammalian biological systems capture environmental light signals and employ them not as an energy source per se but as a signal for preconditioning photobiomodulation. This external optical signal acts as coherent information that drives the generation of ultra-weak endogenous photon emissions through redox reactions and the activation of molecular constellations in a state of quantum coherence, functioning as a biophotonic communication system that orchestrates cellular processes, modulates signaling pathways, and optimizes mitochondrial function.

The external signal is transmitted throughout the body via specialized structural pathways or biological waveguides. Four candidates are proposed: human skin [87–90], the interstitium [91], the primo-vascular system (PVS) [92–95], and liquid-crystalline collagen networks [96–99], which are described in detail in Supplementary Material S2.

2.4. Photophysical events and information

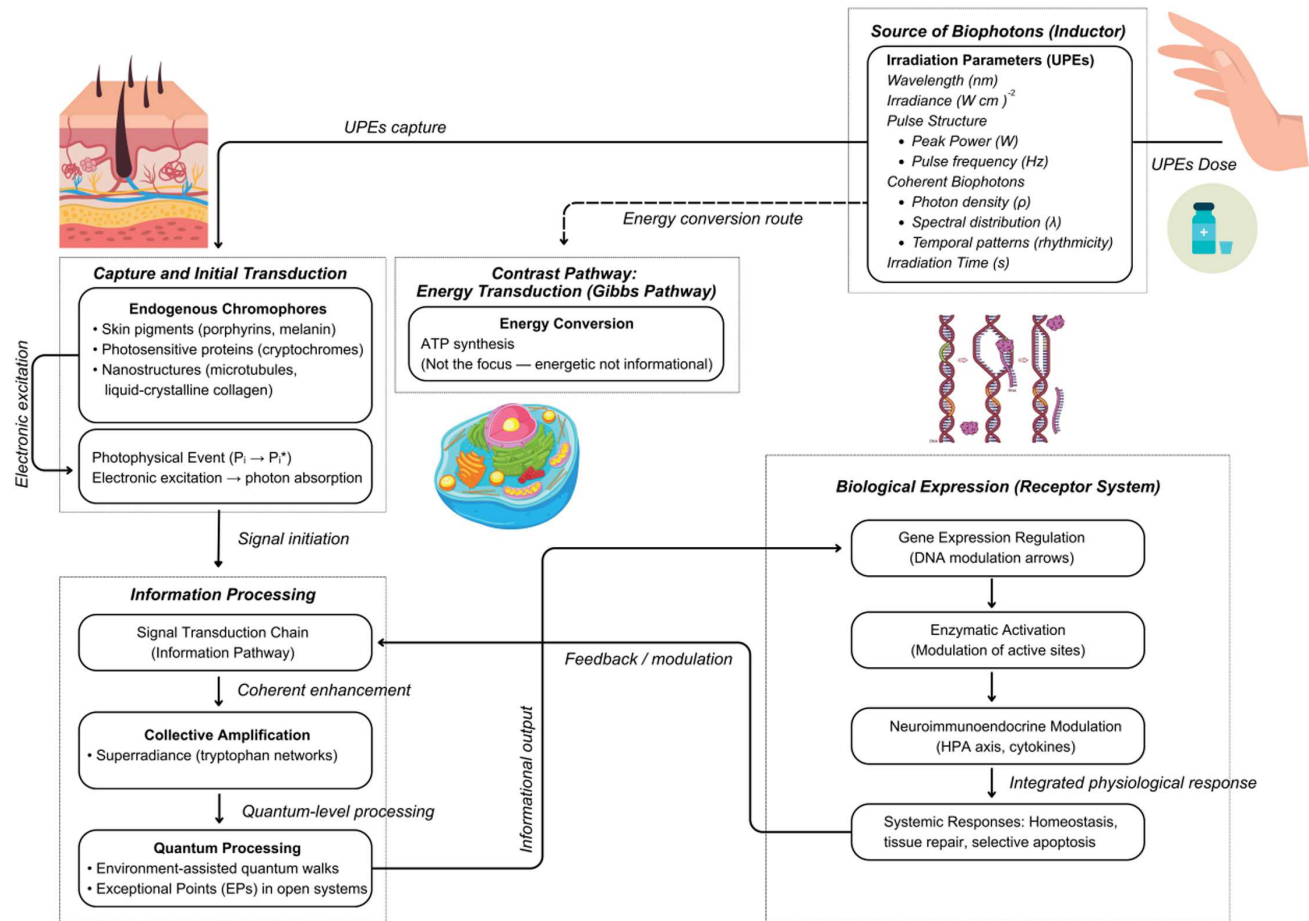
Cells organize pigments into nanometric architectures that fine-tune photophysical events, optimizing reactant distances, modulating optical and redox transitions, and isolating specific reactions, conferring exceptional control over photoinduced processes. As schematized in Figure 2, incident photon streams create electronically excited states in pigments (P_i^*), triggering two distinct reaction chains: (I) signal transduction chain (information): processes informational content encoded in wavelength, intensity, temporal pattern, and coherence. From enzymatic activation to vision, informational richness emerges from subsequent signaling cascades that amplify and interpret the initial photochemical event; (II) Gibbs energy transduction chain: converts and stores radiation energy in chemically usable forms, as in photosynthesis, meeting fundamental energy demands of life [100, 101].

In the context of energetic biocommunication and BTs, it is proposed that exposing the skin of a recipient human organism to radiation in the UPEs spectrum, whether endogenous, from another organism, or from a therapeutic source, predominantly activates the signal transduction chain. UPEs, with their

intensity orders of magnitude below the thermal damage threshold, do not possess sufficient raw energy to act as a significant metabolic fuel. Their role, therefore, is not energetic, but informational. In this way, information emerges as the final product of biocommunication between biological materials with optical properties. This information, encoded in the pattern of incident photons, is transduced by the network of cellular chromophores (in the skin, membranes, cytoplasm, and mitochondria) and, through signaling cascades, is finally expressed in the recipient organism as a measurable physiological change. Such changes can range from the regulation of gene expression and modulation of enzymatic activity (documented in studies with BTs) to systemic effects such as neuroendocrine-immune modulation. This conceptual model positions the human body as a *photoinformatic* (from Greek: *photo-*, light; *informatic*, pertaining to information processing; meaning “a system that encodes, transmits, and decodes biological information through light”) system, where light acts as the medium for a biocomputation that regulates homeostasis, converting specific patterns of ultraweak electromagnetic radiation into precise regulatory instructions.

The excitation and transduction of photonic signals within a living biological system represent a sophisticated interplay between endogenous chromophores and cellular nanostructures. The foundational step involves the absorption of specific electromagnetic wavelengths by a distributed network of photogenic sensors. As detailed in Supplementary Material S3, these sensors are strategically localized across different cellular compartments.

Figure 2
Conceptual model of information transduction mediated by biophotons in biological systems



2.5. Optoelectronics and cellular function

A cell's bioelectric potential, a key indicator of physiological state, is linked to redox metabolism. Mitochondria generate biophotons whose intracellular intensity can be orders of magnitude greater than externally detectable, suggesting significant potential for intracellular signaling [102]. This electromagnetic energy can be absorbed by endogenous chromophores, influencing electron transport chains and ion channel conformations. A biophysical model introduces MTs as critical intermediaries [4]. MTs act as quantum-electrodynamic cavities, supporting coherent states and interacting with electromagnetic fields. Thus, MT states modulated by mitochondrial biophotons influence membrane electrical properties, synaptic strength, and neuronal computation, establishing a biophoton-microtubule-membrane electricity signaling axis.

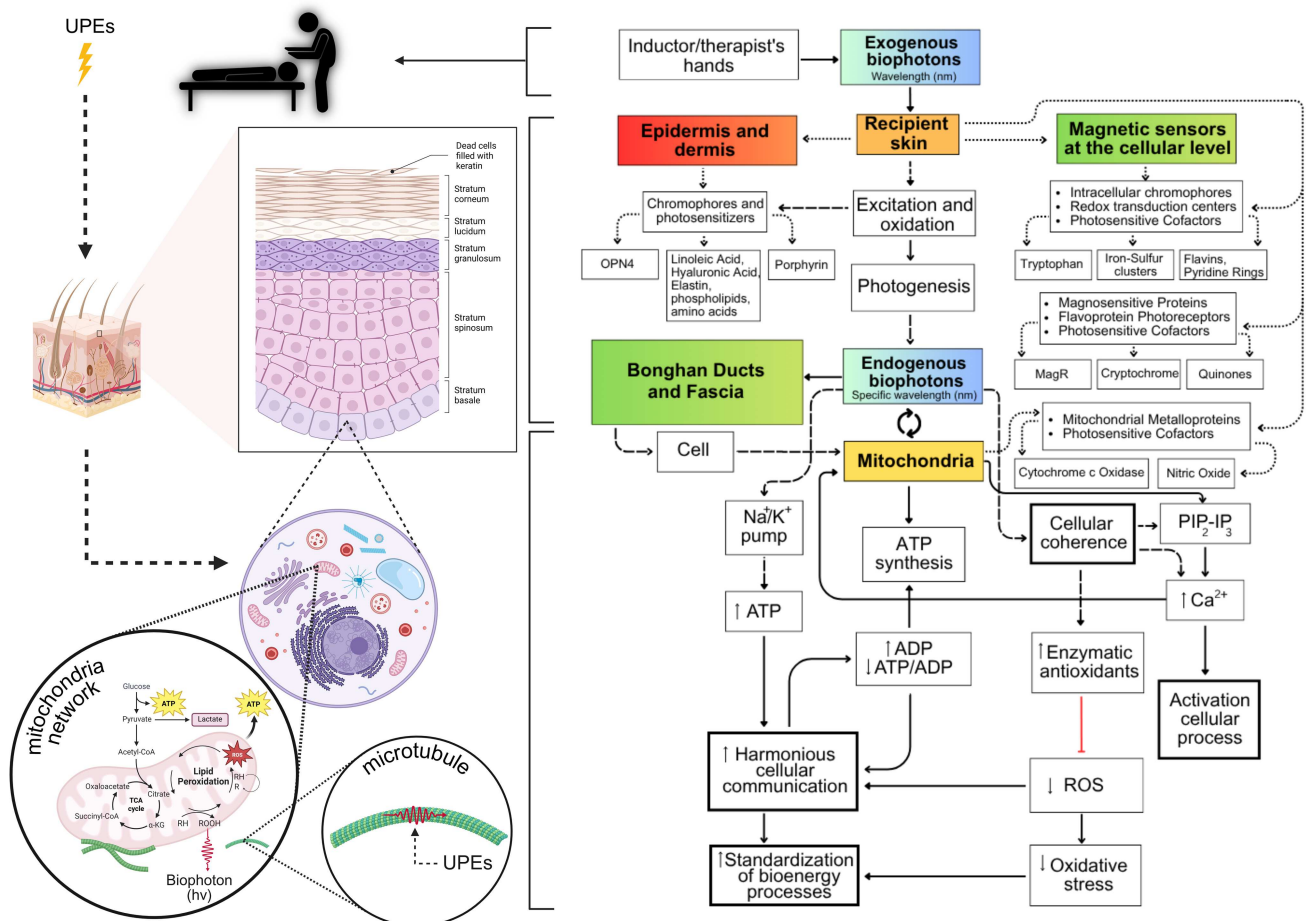
This electric field can explain diverse cellular responses to light [103], including modification of enzymatic activity, altered kinetics of adenine nucleotides, stimulation of the Na⁺/K⁺ ATPase pump, regulation of intracellular Ca²⁺, and enhanced mitochondrial ATP synthesis. Therefore, the bioelectric potential of the cell emerges not only as a product of ionic gradients and metabolic energy but also as a property susceptible to modulation by its own intrinsic photonic emissions, creating a sophisticated cycle of energetic and informational feedback. The diagram in Figure 3 organizes the mechanism of this hypothesis of energetic biocommunication with an intentional focus on healing between a biofield healer and the recipient/patient's skin.

3. Laboratory Analysis Techniques

To transcend the theoretical realm and subject the hypothesis of energetic biocommunication via biophotons to empirical scrutiny, a robust, multilevel approach is imperative. The central challenge lies in detecting and quantifying ultraweak photon signals while simultaneously capturing the potential alteration induced in cells and tissues. The core of this approach is the direct correlation between the photon count emitted from human hands (the proposed vector of communication) and the resulting biochemical and functional signatures in targeted biological systems.

Three techniques were selected to address (1) quantification of spontaneous and induced biophoton emission, (2) imaging of metabolic and morphological changes in living tissues with sub-cellular resolution, and (3) mapping of the molecular landscape with high chemical sensitivity and specificity. The experimental techniques described below are designed to probe the endogenous chromophores and photosensitive structures detailed in Supplementary Material S3: MPT will assess metabolic changes in NAD(P)H and flavins within epidermal and dermal tissues; stimulated Raman spectroscopy (SRS) will map vibrational signatures of lipids, proteins, and metabolites in the same regions; and polychromatic spectral analysis will characterize the UPE emitted by these very chromophores under various conditions. Future implementation of these techniques should incorporate explicit controls, sham conditions, blinding procedures, and sufficient sample sizes to enable rigorous statistical inference.

Figure 3
The hypothesis: An endogenous photobiomodulation system



3.1. Technique 1: multimodal multiphoton tomography (MPT)

MPT is a state-of-the-art, noninvasive imaging technology for high-resolution, label-free optical biopsies of living tissues [104–111]. MPT relies on nonlinear optical interactions of near-infrared laser pulses with endogenous tissue components, providing simultaneous imaging through three modalities: two-photon autofluorescence (AF) from NAD(P)H and flavins for single-mitochondria visualization; second harmonic generation (SHG) from collagen for extracellular matrix delineation; and fluorescence lifetime imaging (FLIM) for quantitative metabolic readouts. Reflectance confocal microscopy provides contrast from cell membranes and melanosomes. MPT is specifically suited to probe the biological targets of H1 and H2 because its two-photon AF channel directly excites NAD(P)H and flavins at the single-mitochondria level, while its FLIM readout quantifies the metabolic shift between bound and free NAD(P)H—the most sensitive available marker of oxidative phosphorylation changes induced by UPE absorption in dermal and epidermal tissues.

The MPT compact integrates an air-cooled femtosecond fiber laser (780 nm) into a 360° imaging head [104], with subcellular lateral resolution (0.3 μm). With functional metabolic data *in vivo*, MPT enables early diagnosis of skin pathologies and *in situ* evaluation of interventions, potentially reducing the need for physical biopsies [104]. In the context of this framework, MPT is linked to the chromophore network detailed in Supplementary Material S3: it directly images NAD(P)H and flavin activity, providing functional readouts of the metabolic state that determines UPE intensity and coherence. MPT is therefore the technique of choice for assessing morphological and metabolic responses in recipient tissue following BT exposure.

3.2. Technique 2: stimulated Raman spectroscopy (SRS)

SRS [112–118] constitutes an advanced analytical technique based on nonlinear optical processes that enables the detection and imaging of molecular species with high sensitivity and chemical specificity, without the need for external labels [112]. SRS relies on coherent interaction between pump and Stokes beams tuned to match molecular vibrational frequencies; under resonance, energy transfer occurs between beams, producing a signal proportional to analyte concentration.

For biophoton research, the SRS technique offers high sensitivity for real-time, subcellular monitoring of lipids, proteins, and metabolites. Its coherent, directional signal enables rapid imaging of dynamic processes, while its hyperspectral capability allows for the simultaneous mapping of multiple molecular components to identify vibrational signatures of bioenergetic states. SRS is specifically linked to the molecular targets of H2 and H4: it can map alterations in tubulin, β -actin, lipid composition, and metabolic cofactors, precisely the biomolecules that exhibit Granger-causal coupling with the electroencephalogram (EEG) of a BT practitioner during healing sessions [79]. A critical distinction must be noted: the SRS technique described here employs coherent laser sources as probe beams, which are not equivalent to human biophoton emission. Relevant similarities lie in the spectral overlap between SRS probe wavelengths and UPE emission bands, as well as in shared molecular targets, and this distinction must be explicitly addressed in future experimental designs. The implementation utilizes synchronized femtosecond/picosecond lasers focused through a high-numerical-aperture objective, employing balanced

detectors and lock-in amplification. For human studies, SRS must be combined with ultrasensitive photon detectors to correlate molecular changes with biophoton emission patterns (Supplementary Material S4).

3.3. Technique 3: polychromatic spectral analysis of ultraweak biophotonic emissions

The application of an advanced polychromatic spectroscopy system, specifically designed to characterize spectral patterns of UPE in humans, provides a solid methodological foundation for investigations into energetic biocommunication between individuals. The system overcomes the limitations of conventional filter-based spectroscopy methods, which operate under a monochromatic scheme with low temporal resolution [119–121], using an optical lens, diffraction grating, and cooled CCD camera for simultaneous spectral acquisition across 450–750 nm. This polychromatic approach is essential for capturing biophotonic emissions approximately 1,000 times below the human visual threshold.

Spectral analysis of spontaneous fingertip UPE has revealed dominant emission between 570 and 670 nm with a primary peak at 600–650 nm, distinct from melanin/linoleic acid chemiluminescence (550–600 nm), suggesting the involvement of additional fluorophores beyond melanin [67, 68]. Polychromatic spectral analysis is the only technique among the three capable of directly quantifying the UPE signal itself, resolving its spectral distribution across 450–750 nm, and thereby providing the reference measurement against which the molecular changes detected by MPT and SRS can be causally attributed to biophotonic stimulation rather than to thermal or mechanical artifacts. This positions Technique 3 as the anchoring measurement of the tripartite framework: without a direct photonic correlate established by spectral analysis, the biochemical readouts of MPT and SRS remain mechanistically unanchored. Importantly, the experimental setup shown in Figure 1 is a research-grade UPE measurement system, not a standard commercial device, and its performance characteristics including sensitivity, dark noise, and acquisition time should be explicitly described in any experimental protocol to allow reproducibility assessment. For biocommunication research, this technique offers noninvasive detection of natural biophotonic emissions without external markers, complete spectral patterns for identifying biochemical signatures of physiological, emotional, or pathological states, and potential for developing diagnostic tools through databases correlating UPE spectra with skin type, age, health status, and interpersonal states.

4. Limitations

A rigorous evaluation of this framework requires acknowledging several interconnected limitations spanning instrumentation, biological variability, and theoretical grounding. UPE intensities in the range of 1–1,000 photons·s^{−1}·cm^{−2}, equivalent at 600 nm to approximately 3×10^{-19} to 3×10^{-16} W/cm², place detection at the outer limits of current photometric technology, demanding cooled detectors (−80 to −100 °C), complete optical isolation, and extended acquisition times, with rigorous pre- and post-session baselines to distinguish genuine biophotonic modulation from instrumental drift.

Reproducibility is inseparable from biological heterogeneity. Beyond circadian rhythm, emotional state, and hydration, skin phototype of both practitioner and recipient represents an under-controlled variable: Fitzpatrick types I–II exhibit higher epidermal

transmittance in the 450–670 nm range than types V–VI, introducing systematic variability across subject pairs. Standardization protocols incorporating phototype characterization of both individuals, fully shielded environments, and operator-independent acquisition systems are essential but not yet established.

Maintaining coherence across biological distances remains the most significant theoretical gap. It has not yet been experimentally demonstrated how a signal at the picowatt scale preserves coherence while traversing warm, hydrated, and structurally complex tissue layers over clinical distances between practitioner and recipient. Furthermore, BT studies are susceptible to placebo effects and operator-dependent variability, and rigorous double-blind experimental designs incorporating sham conditions are essential yet rare.

Three of the four candidate waveguide structures proposed in Supplementary Material S2 require substantially more experimental investigation: the PVS lacks broad scientific consensus and independent replication; the fascial collagen network, while biophysically plausible, lacks direct demonstration of photon propagation under physiological conditions; and the interstitium has not yet been the subject of direct biophotonic measurements. The skin remains the exception, with its photoreceptive and absorptive roles well-established. Resolving these uncertainties will require polychromatic spectral analysis combined with tissue-specific optical coherence methods, alongside advances in EMCCD sensor cooling, LCTF spectral ranges, and signal processing, aiming to map the distribution of absorbed biophotons with the resolution necessary to test hypotheses H1 through H4.

5. Conclusions

This perspective has presented a biophysical framework positioning the human body as a photoinformatic system, explicitly framed as speculative but empirically grounded hypotheses. The chemophotogenic model proposes that UPEs serve as a regulated medium for energetic biocommunication rather than a metabolic epiphenomenon. The four sub-hypotheses articulate distinct mechanisms through which internal biophotons from a BT practitioner might modulate a recipient's biological state: chromophore-mediated signal transduction (H1), redox pathway modulation (H2), coherence enhancement of healthy cells (H3), and immune cell guidance via galvanotaxis (H4).

The proposed tripartite experimental strategy, combining MPT for metabolic imaging, SRS for molecular mapping, and polychromatic spectral analysis for UPE characterization, provides a methodological foundation that, when implemented with rigorous controls including sham conditions, blinding, and adequate sample sizes, offers a path toward empirical validation or refutation of these hypotheses. By grounding energetic biocommunication in measurable parameters and explicit mechanistic predictions, this work aims to stimulate the design of experiments that will determine whether BTs operate through endogenous photonic signaling and how this knowledge might be translated into evidence-based clinical applications.

Acknowledgment

The author gratefully acknowledges the Brazilian Academic Consortium for Integrative Health (CABSIN) for its invaluable institutional support and for fostering the scholarly environment conducive to advancing research in the area of BTs. Special thanks to Dr. Richard Hammerschlag for his helpful comments on the properties of fascia and bibliographic references.

A pre-publication version of this manuscript was previously posted on Optica Open [122].

Ethical Statement

This study does not contain any studies with human or animal subjects performed by the author.

Conflicts of Interest

The author declares that he has no conflicts of interest to this work.

Data Availability Statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

Author Contribution Statement

Rick Sá: Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing, Visualization.

Supplementary Materials

The supplementary materials are available from the article webpage at <https://doi.org/10.47852/bonviewJOPR62028840>.

References

- [1] Tong, J. (2024). Biophoton signaling in mediation of cell-to-cell communication and radiation-induced bystander effects. *Radiation Medicine and Protection*, 5(3), 145–160. <https://doi.org/10.1016/j.radmp.2024.06.004>
- [2] Pospíšil, P., Prasad, A., & Rác, M. (2014). Role of reactive oxygen species in ultra-weak photon emission in biological systems. *Journal of Photochemistry and Photobiology B: Biology*, 139, 11–23. <https://doi.org/10.1016/j.jphotobiol.2014.02.008>
- [3] Vahalová, P., & Cifra, M. (2023). Biological autoluminescence as a perturbation-free method for monitoring oxidation in biosystems. *Progress in Biophysics and Molecular Biology*, 177, 80–108. <https://doi.org/10.1016/j.pbiomolbio.2022.10.009>
- [4] Rahnama, M., Tuszyński, J. A., Bókkon, I., Cifra, M., Sardar, P., & Salari, V. (2011). Emission of mitochondrial biophotons and their effect on electrical activity of membrane via microtubules. *Journal of Integrative Neuroscience*, 10(1), 65–88. <https://doi.org/10.1142/S0219635211002622>
- [5] Pónya, Z., & Somfalvi-Tóth, K. (2022). Modelling biophoton emission kinetics based on the initial intensity value in *Helianthus annuus* plants exposed to different types of stress. *Scientific Reports*, 12(1), 2317. <https://doi.org/10.1038/s41598-022-06323-3>
- [6] Tsuchida, K., Iwasa, T., & Kobayashi, M. (2019). Imaging of ultraweak photon emission for evaluating the oxidative stress of human skin. *Journal of Photochemistry and Photobiology B: Biology*, 198, 111562. <https://doi.org/10.1016/j.jphotobiol.2019.111562>
- [7] Tsuchida, K., Sakiyama, N., Ogura, Y., & Kobayashi, M. (2023). Skin lightness affects ultraviolet A-induced oxidative stress: Evaluation using ultraweak photon emission

- measurement. *Experimental Dermatology*, 32(2), 146–153. <https://doi.org/10.1111/exd.14690>
- [8] Mould, R. R., Kalampouka, I., Thomas, E. L., Guy, G. W., Nunn, A. V. W., & Bell, J. D. (2023). Non-chemical signalling between mitochondria. *Frontiers in Physiology*, 14, 1268075. <https://doi.org/10.3389/fphys.2023.1268075>
- [9] Alberto, N., Domingues, M. F., Cennamo, N., & Borriello, A. (2025). Photonics for bioapplications: Sensors and technology. *Biosensors*, 15(7), 416. <https://doi.org/10.3390/bios15070416>
- [10] Shahbaz, M., Butt, M. A., & Piramidowicz, R. (2023). A concise review of the progress in photonic sensing devices. *Photonics*, 10(6), 698. <https://doi.org/10.3390/photonics10060698>
- [11] Poplová, M., Prasad, A., Van Wijk, E., Pospíšil, P., & Cifra, M. (2023). Biological auto(chemi)luminescence imaging of oxidative processes in human skin. *Analytical Chemistry*, 95(40), 14853–14860. <https://doi.org/10.1021/acs.analchem.3c01566>
- [12] Paolis, L. D., Francini, R., Davoli, I., de Matteis, F., Scordo, A., Clozza, A., . . . , & Benfatto, M. (2024). Biophotons: A hard problem. *Applied Sciences*, 14(13), 5496. <https://doi.org/10.3390/app14135496>
- [13] Benfatto, M., Pace, E., Davoli, I., Francini, R., de Matteis, F., Scordo, A., . . . , & Grigolini, P. (2023). Biophotons: New experimental data and analysis. *Entropy*, 25(10), 1431. <https://doi.org/10.3390/e25101431>
- [14] Benfatto, M., Pace, E., Curceanu, C., Scordo, A., Clozza, A., Davoli, I., . . . , & Grigolini, P. (2021). Biophotons and emergence of quantum coherence—A diffusion entropy analysis. *Entropy*, 23(5), 554. <https://doi.org/10.3390/e23050554>
- [15] Michaelian, K., & Cano Mateo, R. E. (2022). A photon force and flow for dissipative structuring: Application to pigments, plants and ecosystems. *Entropy*, 24(1), 76. <https://doi.org/10.3390/e24010076>
- [16] Michaelian, K. (2024). The pigment world: Life's origins as photon-dissipating pigments. *Life*, 14(7), 912. <https://doi.org/10.3390/life14070912>
- [17] Pietro, W. J., & Mermut, O. (2022). A SiPM-enabled portable delayed fluorescence photon counting device: Climatic plant stress biosensing. *Biosensors*, 12(10), 817. <https://doi.org/10.3390/bios12100817>
- [18] Prasad, A., Gouripreddi, P., Devireddy, H. R. N., Ovsii, A., Rachakonda, D. P., Wijk, R. V., & Pospíšil, P. (2020). Spectral distribution of ultra-weak photon emission as a response to wounding in plants: An in vivo study. *Biology*, 9(6), 139. <https://doi.org/10.3390/biology9060139>
- [19] van Wijk, R., van Wijk, E. P. A., Pang, J., Yang, M., Yan, Y., & Han, J. (2020). Integrating ultra-weak photon emission analysis in mitochondrial research. *Frontiers in Physiology*, 11, 717. <https://doi.org/10.3389/fphys.2020.00717>
- [20] Zapata, F., Pastor-Ruiz, V., Ortega-Ojeda, F., Montalvo, G., & García-Ruiz, C. (2021). Increment of spontaneous human biophoton emission caused by anger emotional states. *Proof of concept. Microchemical Journal*, 169, 106558. <https://doi.org/10.1016/j.microc.2021.106558>
- [21] Casey, H., DiBerardino, I., Bonzanni, M., Rouleau, N., & Murugan, N. J. (2025). Exploring ultraweak photon emissions as optical markers of brain activity. *iScience*, 28(3), 112019. <https://doi.org/10.1016/j.isci.2025.112019>
- [22] Sprengel, M. L., Teo, L., Allen, S., Ijssennagger, N., Hammerschlag, R., Dyer, N. L., & Crawford, C. (2025). Biofield therapies clinical research landscape: A scoping review and interactive evidence map. *Journal of Integrative and Complementary Medicine*, 31(5), 406–430. <https://doi.org/10.1089/jicm.2024.0773>
- [23] Sá, R., Quitério, R. J., & Pignataro Neto, G. (2026). Efficacy of biofield therapies in alleviating pain and reducing symptoms associated with mental disorders: A systematic review and meta-analysis. *OBM Integrative and Complementary Medicine*, 11(2), 021. <https://doi.org/10.21926/obm.icm.2602021>
- [24] Kent, J. B., Li, J., & Li, X. J. (2020). Quantifying biofield therapy through biophoton emission in a cellular model. *Journal of Scientific Exploration*, 34(3), 434–454. <https://doi.org/10.31275/20201691>
- [25] Rubik, B., & Jabs, H. (2017). Effects of intention, energy healing, and mind-body states on biophoton emission. *Cosmos and History: The Journal of Natural and Social Philosophy*, 13(2), 227–247.
- [26] Haraguchi, S., Kotake, J., Chen, W., Parkhomtchouk, D. V., Zhang, T., & Yamamoto, M. (2001). Biophoton change by mental concentration. *Journal of International Society of Life Information Science*, 19(2), 373–380. https://doi.org/10.18936/islis.19.2_373
- [27] Pospíšil, P., & Prasad, A. (2026). Biofield in neural communication: A review and conceptual framework. *Progress in Biophysics and Molecular Biology*, 200, 31–40. <https://doi.org/10.1016/j.pbiomolbio.2026.02.005>
- [28] Sá, R., & Pignataro Neto, G. (2025). Advancing biophysics in energy-based clinical interventions: A narrative review. *EXPLORE*, 21(4), 103198. <https://doi.org/10.1016/j.explore.2025.103198>
- [29] Hammerschlag, R., Levin, M., McCraty, R., Bat, N., Ives, J. A., Lutgendorf, S. K., & Oschman, J. L. (2015). Biofield physiology: A framework for an emerging discipline. *Global Advances in Health and Medicine*, 4(1_suppl), 35–41. <https://doi.org/10.7453/gahmj.2015.015.suppl>
- [30] Sá, R. (2026). Coherent photonic biofields: Revisiting Fritz-Albert Popp's hypothesis. *BioSystems*, 267, 105880. <https://doi.org/10.1016/j.biosystems.2026.105880>
- [31] Liebert, A., & Kiat, H. (2021). The history of light therapy in hospital physiotherapy and medicine with emphasis on Australia: Evolution into novel areas of practice. *Physiotherapy Theory and Practice*, 37(3), 389–400. <https://doi.org/10.1080/09593985.2021.1887060>
- [32] Liebert, A., Capon, W., Pang, V., Vila, D., Bicknell, B., McLachlan, C., & Kiat, H. (2023). Photophysical mechanisms of photobiomodulation therapy as precision medicine. *Biomedicine*, 11(2), 237. <https://doi.org/10.3390/biomedicine11020237>
- [33] Berni, M., Brancato, A. M., Torriani, C., Bina, V., Annunziata, S., Cornella, E., . . . , & Pasta, G. (2023). The role of low-level laser therapy in bone healing: Systematic review. *International Journal of Molecular Sciences*, 24(8), 7094. <https://doi.org/10.3390/ijms24087094>
- [34] Peng, L., Fu, C., Wang, L., Zhang, Q., Liang, Z., He, C., & Wei, Q. (2021). The effect of pulsed electromagnetic fields on angiogenesis. *Bioelectromagnetics*, 42(3), 250–258. <https://doi.org/10.1002/bem.22330>
- [35] Ghoshchi, S. P., Petroni, M. L., Piras, A., Marcora, S. M., & Raffi, M. (2024). Pulsed electromagnetic field (PEMF) stimulation as an adjunct to exercise: A brief review. *Frontiers in*

- Sports and Active Living*, 6, 1471087. <https://doi.org/10.3389/fspor.2024.1471087>
- [36] Lee, C.-G., Park, C., Hwang, S., Hong, J.-E., Jo, M., Eom, M., ..., & Rhee, K.-J. (2022). Pulsed electromagnetic field (PEMF) treatment reduces lipopolysaccharide-induced septic shock in mice. *International Journal of Molecular Sciences*, 23(10), 5661. <https://doi.org/10.3390/ijms23105661>
- [37] Zheng, Y., Mei, L., Li, S., Ma, T., Xia, B., Hao, Y., ..., & Huang, J. (2022). Pulsed electromagnetic field alleviates intervertebral disc degeneration by activating Sirt1-autophagy signaling network. *Frontiers in Bioengineering and Biotechnology*, 10, 853872. <https://doi.org/10.3389/fbioe.2022.853872>
- [38] Hackel, J. G., Paci, J. M., Gupta, S., Maravelas, D. A., North, T. J., & Paunescu, A. (2025). Evaluating noninvasive pulsed electromagnetic field therapy for joint and soft tissue pain management: A prospective, multi-center, randomized clinical trial. *Pain and Therapy*, 14(2), 723–735. <https://doi.org/10.1007/s40122-025-00711-z>
- [39] Liu, J., Zhou, J., Huang, X., Yin, L., Zhou, L., Liao, Y., ..., & Sun, Z. (2024). Protective effects of pulsed electromagnetic field therapy attenuates autophagy and apoptosis in osteoporotic osteoarthritis model rats by activating PPAR γ . *Electromagnetic Biology and Medicine*, 43(1-2), 61–70. <https://doi.org/10.1080/15368378.2024.2314108>
- [40] Calìogna, L., Medetti, M., Bina, V., Brancato, A. M., Castelli, A., Jannelli, E., ..., & Pasta, G. (2021). Pulsed electromagnetic fields in bone healing: Molecular pathways and clinical applications. *International Journal of Molecular Sciences*, 22(14), 7403. <https://doi.org/10.3390/ijms22147403>
- [41] Linnemann, C., Sahin, F., Chen, Y., Falldorf, K., Ronniger, M., Histing, T., ..., & Nussler, A. K. (2023). Net formation was reduced via exposure to extremely low-frequency pulsed electromagnetic fields. *International Journal of Molecular Sciences*, 24(19), 14629. <https://doi.org/10.3390/ijms241914629>
- [42] Huang, M., Li, P., Chen, F., Cai, Z., Yang, S., Zheng, X., & Li, W. (2023). Is extremely low frequency pulsed electromagnetic fields applicable to gliomas? A literature review of the underlying mechanisms and application of extremely low frequency pulsed electromagnetic fields. *Cancer Medicine*, 12(3), 2187–2198. <https://doi.org/10.1002/cam4.5112>
- [43] Talagas, M., Lebonvallet, N., Berthod, F., & Misery, L. (2020). Lifting the veil on the keratinocyte contribution to cutaneous nociception. *Protein & Cell*, 11(4), 239–250. <https://doi.org/10.1007/s13238-019-00683-9>
- [44] García-Mesa, Y., Cuendias, P., Alonso-Guervós, M., García-Piqueras, J., Martín-Biedma, B., Cobo, T., ..., & Vega, J. A. (2024). Immunohistochemical detection of PIEZO1 and PIEZO2 in human digital Meissner's corpuscles. *Annals of Anatomy - Anatomischer Anzeiger*, 252, 152200. <https://doi.org/10.1016/j.aanat.2023.152200>
- [45] Shaner, S., Savelyeva, A., Kvartuh, A., Jedrusik, N., Matter, L., Leal, J., & Asplund, M. (2023). Bioelectronic microfluidic wound healing: A platform for investigating direct current stimulation of injured cell collectives. *Lab on a Chip*, 23(6), 1531–1546. <https://doi.org/10.1039/D2LC01045C>
- [46] Zhao, X., Yang, M., Wang, Y., Pang, J., Wijk, E. V., Liu, Y., ..., & Han, J. (2017). Spectrum of spontaneous photon emission as a promising biophysical indicator for breast cancer research. *Scientific Reports*, 7(1), 13083. <https://doi.org/10.1038/s41598-017-13516-8>
- [47] Dutta, R., & Bagchi, B. (2017). Environment-assisted quantum coherence in photosynthetic complex. *The Journal of Physical Chemistry Letters*, 8(22), 5566–5572. <https://doi.org/10.1021/acs.jpclett.7b02480>
- [48] Yan, X., Shen, H., Jiang, H., Zhang, C., Hu, D., Wang, J., & Wu, X. (2006). External Qi of Yan Xin Qigong differentially regulates the Akt and extracellular signal-regulated kinase pathways and is cytotoxic to cancer cells but not to normal cells. *The International Journal of Biochemistry & Cell Biology*, 38(12), 2102–2113. <https://doi.org/10.1016/j.biocel.2006.06.002>
- [49] Gronowicz, G., Secor, E. R., Jr., Flynn, J. R., Jellison, E. R., & Kuhn, L. T. (2015). Therapeutic touch has significant effects on mouse breast cancer metastasis and immune responses but not primary tumor size. *Evidence-Based Complementary and Alternative Medicine*, 2015, 1–10. <https://doi.org/10.1155/2015/926565>
- [50] Yang, P., Wei, D., Chakraborty, S., Nguyen, P., Cusimano, A., Deng, D., ..., & Cohen, L. (2026). The preclinical effects and mechanisms of biofield therapy on pancreatic cancer cell growth and metastasis. *Cancer Medicine*, 15(4), e71726. <https://doi.org/10.1002/cam4.71726>
- [51] Igamberdiev, A. U. (2012). Biomechanical and coherent phenomena in morphogenetic relaxation processes. *Biosystems*, 109(3), 336–345. <https://doi.org/10.1016/j.biosystems.2012.05.006>
- [52] Pietruszka, M. (2025). Field-induced coherence and Fröhlich condensation in hydrated DNA. *BioSystems*, 256, 105564. <https://doi.org/10.1016/j.biosystems.2025.105564>
- [53] Lin, F., Baldessari, F., Gyenge, C. C., Sato, T., Chambers, R. D., Santiago, J. G., & Butcher, E. C. (2008). Lymphocyte electrotaxis in vitro and in vivo. *The Journal of Immunology*, 181(4), 2465–2471. <https://doi.org/10.4049/jimmunol.181.4.2465>
- [54] Sun, Y., Reid, B., Ferreira, F., Luxardi, G., Ma, L., Lokken, K. L., ..., & Zhao, M. (2019). Infection-generated electric field in gut epithelium drives bidirectional migration of macrophages. *PLOS Biology*, 17(4), e3000044. <https://doi.org/10.1371/journal.pbio.3000044>
- [55] Brown, M. J., & Loew, L. M. (1994). Electric field-directed fibroblast locomotion involves cell surface molecular reorganization and is calcium independent. *The Journal of Cell Biology*, 127(1), 117–128. <https://doi.org/10.1083/jcb.127.1.117>
- [56] Lutgendorf, S. K., Mullen-Houser, E., Russell, D., DeGeest, K., Jacobson, G., Hart, L., ..., & Lubaroff, D. M. (2010). Preservation of immune function in cervical cancer patients during chemoradiation using a novel integrative approach. *Brain, Behavior, and Immunity*, 24(8), 1231–1240. <https://doi.org/10.1016/j.bbi.2010.06.014>
- [57] Yang, J.-M., Lee, C., Yi, S.-H., Yang, J.-S., & Soh, K.-S. (2004). Biophoton emission and blood flow in the human hand. *Journal of International Society of Life Information Science*, 22(2), 344–348. https://doi.org/10.18936/islis.22.2_344
- [58] Minami, E., Usui, T., & Kokubo, H. (2014). Relationship between age and healing power: A study using a bio-sensor for non-contact healing. *Journal of International Society of Life Information Science*, 32(1), 49–55. https://doi.org/10.18936/islis.32.1_49
- [59] Kotake, J., Haraguchi, S., Parkhomtchouk, D. V., & Yamamoto, M. (2002). Change of biophoton emission by

- mental concentration Part II. Trial detection of healing effect by biophoton change. *Journal of International Society of Life Information Science*, 20(1), 132–147. https://doi.org/10.18936/islis.20.1_132
- [60] Wijk, E. P. A. V., & Wijk, R. V. (2005). Multi-site recording and spectral analysis of spontaneous photon emission from human body. *Complementary Medicine Research*, 12(2), 96–106. <https://doi.org/10.1159/000083935>
- [61] Kobayashi, M., Kikuchi, D., & Okamura, H. (2009). Imaging of ultraweak spontaneous photon emission from human body displaying diurnal rhythm. *PLoS One*, 4(7), e6256. <https://doi.org/10.1371/journal.pone.0006256>
- [62] Nakamura, K., & Hiramatsu, M. (2005). Ultra-weak photon emission from human hand: Influence of temperature and oxygen concentration on emission. *Journal of Photochemistry and Photobiology B: Biology*, 80(2), 156–160. <https://doi.org/10.1016/j.jphotobiol.2005.02.005>
- [63] Ortega-Ojeda, F., Calcerrada, M., Ferrero, A., Campos, J., & Garcia-Ruiz, C. (2018). Measuring the human ultra-weak photon emission distribution using an electron-multiplying, charge-coupled device as a sensor. *Sensors*, 18(4), 1152. <https://doi.org/10.3390/s18041152>
- [64] Langer, J. J., & Langer, M. (2023). *Why are spontaneous bio photons observed only in living organisms? The key role of the proton current in ultra-weak photon emission*, bioRxiv. <https://doi.org/10.1101/2023.09.15.557955>
- [65] Langer, J. J., Frąckowiak, E., & Golczak, S. (2020). Electrically induced light emission from proton-conducting materials. Protonic light-emitting diodes. *Journal of Materials Chemistry C*, 8(3), 943–951. <https://doi.org/10.1039/C9TC05980F>
- [66] Mitome, N., Kubo, S., Ohta, S., Takashima, H., Shigefuji, Y., Niina, T., & Takada, S. (2022). Cooperation among c-subunits of FoF1-ATP synthase in rotation-coupled proton translocation. *eLife*, 11, e69096. <https://doi.org/10.7554/eLife.69096>
- [67] Kobayashi, M., Iwasa, T., & Tada, M. (2016). Polychromatic spectral pattern analysis of ultra-weak photon emissions from a human body. *Journal of Photochemistry and Photobiology B: Biology*, 159, 186–190. <https://doi.org/10.1016/j.jphotobiol.2016.03.037>
- [68] Tsuchida, K., & Kobayashi, M. (2020). Ultraviolet A irradiation induces ultraweak photon emission with characteristic spectral patterns from biomolecules present in human skin. *Scientific Reports*, 10(1), 21667. <https://doi.org/10.1038/s41598-020-78884-0>
- [69] Joines, W. T., Baumann, S. B., & Kruth, J. G. (2012). Electromagnetic emission from humans during focused intent. *Journal of Parapsychology*, 76(2), 275–294.
- [70] Hecht, S., Shlaer, S., & Pirenne, M. H. (1942). Energy, quanta, and vision. *Journal of General Physiology*, 25(6), 819–840. <https://doi.org/10.1085/jgp.25.6.819>
- [71] Nimpf, S., & Keays, D. A. (2022). Myths in magnetosensation. *iScience*, 25(6), 104454. <https://doi.org/10.1016/j.isci.2022.104454>
- [72] Shibata, T., Hattori, N., Nishijo, H., Kuroda, S., & Takakusaki, K. (2024). The origins of light-independent magnetoreception in humans. *Frontiers in Human Neuroscience*, 18, 1482872. <https://doi.org/10.3389/fnhum.2024.1482872>
- [73] Setchfield, K., Gorman, A., Simpson, A. H. R. W., Somekh, M. G., & Wright, A. J. (2024). Effect of skin color on optical properties and the implications for medical optical technologies: A review. *Journal of Biomedical Optics*, 29(1), 010901. <https://doi.org/10.1117/1.JBO.29.1.010901>
- [74] Cifra, M., & Pospíšil, P. (2014). Ultra-weak photon emission from biological samples: Definition, mechanisms, properties, detection and applications. *Journal of Photochemistry and Photobiology B: Biology*, 139, 2–10. <https://doi.org/10.1016/j.jphotobiol.2014.02.009>
- [75] Du, J., Deng, T., Cao, B., Wang, Z., Yang, M., & Han, J. (2023). The application and trend of ultra-weak photon emission in biology and medicine. *Frontiers in Chemistry*, 11, 1140128. <https://doi.org/10.3389/fchem.2023.1140128>
- [76] Lee, J. D., & Oh, M. J. M. (2023). Light-emitting diode (LED) and Arndt–Schultz curve. In J. D. Lee & M. J. M. Oh (Eds.), *Lasers in dermatology: Parameters and choice* (pp. 149–154). Springer. https://doi.org/10.1007/978-981-19-7568-4_14
- [77] Yang, P., Jiang, Y., Rhea, P. R., Conway, T. L., Chen, D., Gagea, M., . . . , & Cohen, L. (2019). Human biofield therapy and the growth of mouse lung carcinoma. *Integrative Cancer Therapies*, 18, 1534735419840797. <https://doi.org/10.1177/1534735419840797>
- [78] Yang, P., Rhea, P. R., Conway, T., Nookala, S., Hegde, V., Gagea, M., . . . , & Cohen, L. (2020). Human biofield therapy modulates tumor microenvironment and cancer stemness in mouse lung carcinoma. *Integrative Cancer Therapies*, 19, 1534735420940398. <https://doi.org/10.1177/1534735420940398>
- [79] Cohen, L., Delorme, A., Cusimano, A., Chakraborty, S., Nguyen, P., Deng, D., . . . , & Yang, P. (2024). Examining the effects of biofield therapy through simultaneous assessment of electrophysiological and cellular outcomes. *Scientific Reports*, 14(1), 29221. <https://doi.org/10.1038/s41598-024-79617-3>
- [80] Cai, Z. Z., Chen, Y., Wang, L., Teng, J., Chen, Y. M., Li, M. M., . . . , & Bai, X. M. (2021). A preliminary study of the effects from different sources of Qi on telomeres. *Biomedical Journal of Scientific & Technical Research*, 33(2), 25665–25671. <https://doi.org/10.26717/BJSTR.2021.33.005374>
- [81] Craddock, T. J. A., Friesen, D., Mane, J., Hameroff, S., & Tuszyński, J. A. (2014). The feasibility of coherent energy transfer in microtubules. *Journal of The Royal Society Interface*, 11(100), 20140677. <https://doi.org/10.1098/rsif.2014.0677>
- [82] Olaya-Castro, A., Nazir, A., & Fleming, G. R. (2012). Quantum-coherent energy transfer: Implications for biology and new energy technologies. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 370(1972), 3613–3617. <https://doi.org/10.1098/rsta.2012.0192>
- [83] Weingarten, D. H., LaCount, M. D., van de Lagemaat, J., Rumbles, G., Lusk, M. T., & Shaheen, S. E. (2017). Experimental demonstration of photon upconversion via cooperative energy pooling. *Nature Communications*, 8(1), 14808. <https://doi.org/10.1038/ncomms14808>
- [84] Li, K. H., Popp, F. A., Nagl, W., & Klima, H. (1983). Indications of optical coherence in biological systems and its possible significance. In H. Fröhlich & F. Kremer (Eds.), *Coherent excitations in biological systems* (pp. 117–122). Springer. https://doi.org/10.1007/978-3-642-69186-7_11
- [85] Sun, C., Li, X., & Guo, J. (2023). Relationship between photosystem activity and ultraweak luminescence excitation

- in *Cerasus humilis* leaves under salt stress. *Plant Physiology and Biochemistry*, 196, 1032–1045. <https://doi.org/10.1016/j.plaphy.2023.03.005>
- [86] Eller, M. S., Yaar, M., & Gilchrist, B. A. (1994). DNA damage and melanogenesis. *Nature*, 372(6505), 413–414. <https://doi.org/10.1038/372413a0>
- [87] Slominski, R. M., Raman, C., Jetten, A. M., & Slominski, A. T. (2025). Neuro-immuno-endocrinology of the skin: How environment regulates body homeostasis. *Nature Reviews Endocrinology*, 21(8), 495–509. <https://doi.org/10.1038/s41574-025-01107-x>
- [88] Slominski, A. T., Zmijewski, M. A., Plonka, P. M., Szaflarski, J. P., & Paus, R. (2018). How UV light touches the brain and endocrine system through skin, and why. *Endocrinology*, 159(5), 1992–2007. <https://doi.org/10.1210/en.2017-03230>
- [89] Woo, S.-H., Ranade, S., Weyer, A. D., Dubin, A. E., Baba, Y., Qiu, Z., ..., & ... (2014). Piezo2 is required for Merkel-cell mechanotransduction. *Nature*, 509(7502), 622–626. <https://doi.org/10.1038/nature13251>
- [90] Maksimovic, S., Nakatani, M., Baba, Y., Nelson, A. M., Marshall, K. L., Wellnitz, S. A., ..., & Lumpkin, E. A. (2014). Epidermal Merkel cells are mechanosensory cells that tune mammalian touch receptors. *Nature*, 509(7502), 617–621. <https://doi.org/10.1038/nature13250>
- [91] Cenaj, O., Allison, D. H. R., Imam, R., Zeck, B., Drohan, L. M., Chiriboga, L., ..., & Theise, N. D. (2021). Evidence for continuity of interstitial spaces across tissue and organ boundaries in humans. *Communications Biology*, 4(1), 436. <https://doi.org/10.1038/s42003-021-01962-0>
- [92] Soh, K.-S. (2004). Qi as biophotonic information flux of DNA in the Bonghan system. *Journal of International Society of Life Information Science*, 22(2), 287–293. https://doi.org/10.18936/islis.22.2_287
- [93] Soh, K.-S. (2009). Bonghan circulatory system as an extension of acupuncture meridians. *Journal of Acupuncture and Meridian Studies*, 2(2), 93–106. [https://doi.org/10.1016/S2005-2901\(09\)60041-8](https://doi.org/10.1016/S2005-2901(09)60041-8)
- [94] Stefanov, M., Potroz, M., Kim, J., Lim, J., Cha, R., & Nam, M.-H. (2013). The primo vascular system as a new anatomical system. *Journal of Acupuncture and Meridian Studies*, 6(6), 331–338. <https://doi.org/10.1016/j.jams.2013.10.001>
- [95] Stefanov, M. (2022). Primo vascular system: Before the past, bizarre present and peek after the future. *Journal of Acupuncture and Meridian Studies*, 15(1), 61–73. <https://doi.org/10.51507/j.jams.2022.15.1.61>
- [96] Nevoit, G., Poderiene, K., Potyazhenko, M., Mintser, O., Jarusevicius, G., & Vainoras, A. (2025). The concept of biophotonic signaling in the human body and brain: Rationale, problems and directions. *Frontiers in Systems Neuroscience*, 19, 1597329. <https://doi.org/10.3389/fnsys.2025.1597329>
- [97] Ho, M.-W. (2012). Super-conducting liquid crystalline water aligned with collagen fibres in the fascia as acupuncture meridians of traditional Chinese medicine. *Forum on Immunopathological Diseases and Therapeutics*, 3(3–4), 221–236. <https://doi.org/10.1615/ForumImmunDisTher.2013.007869>
- [98] Bordoni, B., Marelli, F., Morabito, B., & Sacconi, B. (2018). Emission of biophotons and adjustable sounds by the fascial system: Review and reflections for manual therapy. *Journal of Evidence-Based Integrative Medicine*, 23, 2515690X17750750. <https://doi.org/10.1177/2515690X17750750>
- [99] Guimberteau, J. C., Sawaya, E. T., & Armstrong, C. (2025). New perspectives on the organization of living tissue and the ongoing connective tissue/fascia nomenclature debate, as revealed by intra-tissue endoscopy that provides real-time images during surgical procedures. *Life*, 15(5), 791. <https://doi.org/10.3390/life15050791>
- [100] Pfeuty, B. (2024). Free-energy transduction mechanisms shape the flux space of metabolic networks. *Biophysical Journal*, 123(20), 3600–3611. <https://doi.org/10.1016/j.bpj.2024.09.012>
- [101] Babcock, N. S., Montes-Cabrera, G., Oberhofer, K. E., Chergui, M., Celardo, G. L., & Kurian, P. (2024). Ultra-violet superradiance from mega-networks of tryptophan in biological architectures. *The Journal of Physical Chemistry B*, 128(17), 4035–4046. <https://doi.org/10.1021/acs.jpcc.3c07936>
- [102] Bókkon, I., Salári, V., Tuszynski, J. A., & Antal, I. (2010). Estimation of the number of biophotons involved in the visual perception of a single-object image: Biophoton intensity can be considerably higher inside cells than outside. *Journal of Photochemistry and Photobiology B: Biology*, 100(3), 160–166. <https://doi.org/10.1016/j.jphotobiol.2010.06.001>
- [103] Amat, A., Rigau, J., Waynant, R. W., Ilev, I. K., & Anders, J. J. (2006). The electric field induced by light can explain cellular responses to electromagnetic energy: A hypothesis of mechanism. *Journal of Photochemistry and Photobiology B: Biology*, 82(2), 152–160. <https://doi.org/10.1016/j.jphotobiol.2005.10.001>
- [104] König, K. (2023). Multimodal multiphoton tomography with a compact femtosecond fiber laser. *Journal of Optics and Photonics Research*, 1(2), 51–58. <https://doi.org/10.47852/bonviewJOPR32021730>
- [105] Guimarães, P., Batista, A., Zieger, M., Kaatz, M., & Koenig, K. (2020). Artificial intelligence in multiphoton tomography: Atopic dermatitis diagnosis. *Scientific Reports*, 10(1), 7968. <https://doi.org/10.1038/s41598-020-64937-x>
- [106] Yakimov, B. P., Vlasova, I. I., Efremov, Y. M., Maksimov, E. G., Shirshin, E. A., Kagan, V. E., & Timashev, P. S. (2022). Detection of HOCl-driven degradation of the pericardium scaffolds by label-free multiphoton fluorescence lifetime imaging. *Scientific Reports*, 12(1), 10329. <https://doi.org/10.1038/s41598-022-14138-5>
- [107] Nguyen, L., Mess, C., Schneider, S. W., Huck, V., & Herberger, K. (2025). Multiphoton tomographic analysis of hyaluronic acid delivery: Comparison of carbon dioxide laser and 1927 nm thulium laser over time. *Lasers in Medical Science*, 40(1), 100. <https://doi.org/10.1007/s10103-025-04363-5>
- [108] Klemp, M., Meinke, M. C., Weinigel, M., Rőwert-Huber, H., König, K., Ulrich, M., ..., & Darvin, M. E. (2016). Comparison of morphologic criteria for actinic keratosis and squamous cell carcinoma using in vivo multiphoton tomography. *Experimental Dermatology*, 25(3), 218–222. <https://doi.org/10.1111/exd.12912>
- [109] Lange, I., Prinke, P., Klee, S., Piątek, Ł., Warzecha, M., König, K., & Haueisen, J. (2022). Feature-based differentiation of malignant melanomas, lesions and healthy skin in multiphoton tomography skin images. *Current Directions in Biomedical Engineering*, 8(2), 45–48. <https://doi.org/10.1515/cdbme-2022-1013>
- [110] Nguyen, L., Mess, C., Schneider, S. W., Huck, V., & Herberger, K. (2022). In vivo visualisation of tattoo particles

- using multiphoton tomography and fluorescence lifetime imaging. *Experimental Dermatology*, 31(11), 1712–1719. <https://doi.org/10.1111/exd.14646>
- [111] König, K., & König, A. (2025). Multiphoton tomography in cosmetic research. *Cosmetics*, 12(2), 44. <https://doi.org/10.3390/cosmetics12020044>
- [112] Jones, R. R., Hooper, D. C., Zhang, L., Wolverson, D., & Valev, V. K. (2019). Raman techniques: Fundamentals and frontiers. *Nanoscale Research Letters*, 14(1), 231. <https://doi.org/10.1186/s11671-019-3039-2>
- [113] Lynch, P. G., Das, A., Alam, S., Rich, C. C., & Frontiera, R. R. (2024). Mastering femtosecond stimulated Raman spectroscopy: A practical guide. *ACS Physical Chemistry Au*, 4(1), 1–18. <https://doi.org/10.1021/acspchemau.3c00031>
- [114] Krishnan Nambudiri, M. K., Sujadevi, V. G., Poornachandran, P., Murali Krishna, C., Kanno, T., & Noothalapati, H. (2024). Artificial intelligence-assisted stimulated Raman histology: New frontiers in vibrational tissue imaging. *Cancers*, 16(23), 3917. <https://doi.org/10.3390/cancers16233917>
- [115] Hughes, J. G., Tsikritsis, D., Bailie, A. E., Dondi, C., Dias, E., Fielding, H. H., ..., & Chisholm, D. R. (2026). Advanced multimodal imaging: FLIM, PLIM, and FluoRaman enabled by novel diarylacetylene probes. *The Analyst*, 151(2), 623–635. <https://doi.org/10.1039/D5AN00953G>
- [116] Darwin, M. E. (2023). Optical methods for non-invasive determination of skin penetration: Current trends, advances, possibilities, prospects, and translation into in vivo human studies. *Pharmaceutics*, 15(9), 2272. <https://doi.org/10.3390/pharmaceutics15092272>
- [117] Fan, J. J., Ou, Z.-Y., & Zhang, Z. (2024). Entangled photons enabled ultrafast stimulated Raman spectroscopy for molecular dynamics. *Light: Science & Applications*, 13(1), 163. <https://doi.org/10.1038/s41377-024-01492-4>
- [118] Gao, X., & Min, W. (2025). Quantum theory of stimulated Raman scattering microscopy. *Chemical Physics Reviews*, 6(2), 021306. <https://doi.org/10.1063/5.0248085>
- [119] Cloutier, E., Beaulieu, L., & Archambault, L. (2022). On the use of polychromatic cameras for high spatial resolution spectral dose measurements. *Physics in Medicine & Biology*, 67(11), 11NT01. <https://doi.org/10.1088/1361-6560/ac6b0e>
- [120] Wang, H., Li, Z., Xu, H., Liu, L., Zhang, W., Zheng, Y., ..., & Wang, L. (2025). Filter-less polychromatic recognition in one photosensitive oscillator via dual-perception feature decoupling. *Small*, 21(32), 2501335. <https://doi.org/10.1002/smll.202501335>
- [121] Xu, Y., Li, J., Bai, C., Liu, Y., & Wang, J. (2021). 5D-fusion sensing via interference illumination and polarization imaging. *Optics Letters*, 46(19), 4976–4979. <https://doi.org/10.1364/OL.438384>
- [122] Sá, R. (2026). Biophotonic signaling in energetic biocommunication: A conceptual framework and experimental strategy for validating weak optical interactions in biofields. *Optica Open*. <https://doi.org/10.1364/opticaopen.30734750>

How to Cite: Sá, R. (2026). Biophotonic Signaling in Energetic Biocommunication: A Conceptual Framework and Experimental Strategy for Validating Weak Optical Interactions in Biofields. *Journal of Optics and Photonics Research*. <https://doi.org/10.47852/bonviewJOPR62028840>