Editorial: The Publishing Process
R.J. LanzaFame, M.D.

Treatment of Medial and Lateral Epicondylitis—Tennis and Golfer’s Elbow—with Low Level Laser Therapy: A Multicenter Double Blind, Placebo-Controlled Clinical Study on 324 Patients
Z. Simunovic, M.D., F.M.H., T. Trobonjaca, M.D., and Z. Trobonjaca, M.D.

Intrapulpal Temperature during Preparation with the Er:YAG Laser Compared to the Conventional Burr: An in Vitro Study

Import of Radiation Phenomena of Electrons and Therapeutic Low-Level Laser in Regard to the Mitochondrial Energy Transfer
L. Wilden, M.D., and R. Karthein, Ph.D.

Morphological and Atomic Analytical Changes after CO₂ Laser Irradiation Emitted at 9.3 μm on Human Dental Hard Tissues

Design and Development of an Electro-Optic Measurement System for 3-D Topographic Surveys: Application to Skin Nevus Lesions

Surgical Cleansing of Varicose Ulcers of the Leg Using a CO₂ Laser with Rotating Mirror Scanner
O. Marangoni, M.D., and M. Melato, M.D.

U.S. Corporate News

185

187

190

193

Instructions for Authors can be found in the back of the issue.
Import of Radiation Phenomena of Electrons and Therapeutic Low-Level Laser in Regard to the Mitochondrial Energy Transfer

LUTZ WILDEN, M.D.,¹ and RAINER KARTHEIN, Ph.D.²

ABSTRACT

Objective: The authors describe a consistent theoretical model of the cellular energy transfer (respiratory chain) by taking into consideration the radiation phenomena of electrons and therapeutic low level laser. Summary Background Data: Biochemical models of the cellular energy transfer regard the classical corpuscular aspect of electrons as the responsible energy carriers, thereby ignoring the wave-particle dualism of the electrons and the import of radiation energy in this process. Methods: The authors show the influence of radiation phenomena on the cellular energy transfer, explaining consistently some of the intermediate steps of this complex process. Results: Because of the inherent wave-particle dualism of the electrons, it is appropriate to regard radiation phenomena to explain the cellular energy transfer. The classical biochemical models use only the particle part of the electrons as energy carriers. The connection between energy transport by radiation and the order in structures may be understood if, for instance, structurally bound energy is released during the dissolution of structures (oxidation of foodstuffs) or is again manifested (final reduction of oxygen to water). With a attention to the energy values relevant for the respiratory chain, the import of electromagnetic radiation of characteristic ranges of wavelengths on the cellular energy transfer becomes evident. Depending on its wavelength, electromagnetic radiation in the form of light can stimulate macromolecules and can initiate conformation changes in proteins or can transfer energy to electrons. Low level laser from the red and the near infrared region corresponds well with the characteristic energy and absorption levels of the relevant components of the respiratory chain. This laser stimulation vitalizes the cell by increasing the mitochondrial ATP(adenosine-tri-phosphate)-production. Conclusions: With regard to radiation phenomena and its enhanced electron flow in the cellular energy transfer (respiratory chain), it is possible to explain the experimentally found increase of ATP-production by means of low-level laser light on a cellular level. Intense research for this biosstimulative effect is still necessary.

INTRODUCTION

Every living cell needs energy. The energy necessary for the complex functions of the cell comes from nutrients absorbed by the organism. In its primary form, however, the chemical energy of the nutritive compounds is not directly usable for the cell, but must be first converted biochemically into a cellulyarly usable form. The most important form of use in cells is the highly energetic ATP system. The cellular energy transfer takes place in the mitochondria and, therefore, these organelles have a key function for the eucaryotic cell. Biochemical models of the energy transfer describe the energy transporting electrons as responsible for the intermediate steps of this conversion. It begins, via the citric acid cycle, with the generation of high-energy electrons, which subsequently lose their initial energy in the electron transport chain of the inner mitochondrial membrane (respiratory chain) and disappear again as soon as oxygen (O₂) is reduced to water (H₂O). According to the classical corpuscular idea of electrons, the transfer of energy originating from foodstuffs to cellular energy in the mitochon-

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drial structures of the inner membrane is a flow process of high-energy electrons (electron flow). Several processes in this assumed flow of electrons can be explained only insufficiently with regard to the particle idea of electrons. Furthermore, the energy transport has been consistently explained only recently.

WHAT CHARACTERIZES AN ELECTRON?

Electrons belong to the elementary particles (leptons) and are therefore a constituent part of the fundamentals of which all matter is made. The corpuscular model qualities (mass, charge) of electrons discovered by J. J. Thomson still hold today. This furnished a basic explanation of the structure of matter. Thirty years later, his son, G. P. Thomson, demonstrated the wave-particle dualism of electrons by means of electron interferences that occurred during the transmission of polycrystalline metal foils. The wave-particle dualism is described by the Einstein—de Broglie relations for the wavelength and frequency of corpuscular radiation.¹ These relations represent the connection between the particle and wave qualities of both electrons and other objects such as photons (the quantum units of electromagnetic energy) without hurting the classical corpuscular mechanics. The striking proof of the wave-particle dualism of photons arises from the fact that electrons are energetically stimulated by electromagnetic rays. Furthermore, electromagnetic radiation can transfer its energy to electrons. It is possible to apply the wave as well as the particle concept to describe atomic processes involving electrons and electromagnetic radiation. The wave and particle qualities of electrons are complementary. Their diffusion is characterized primarily by their wave qualities, their interaction with atomic systems by their particle qualities. These physical facts were taken into consideration in the following examination of the mitochondrial energy transfer.

THE CLASSIC MODEL OF THE MITOCHONDRIAL ENERGY TRANSFER

In biochemistry the electron transport linked with mitochondrial energy transfer is defined by the particle idea of the electron. The function of electrons in the mitochondrial energy transfer system is to operate the real power plant of the mitochondria as energy carriers. That is oxidative phosphorylation, which produces ATP. The oxidative phosphorylation can work only in connection with an electron donor and an electron acceptor. The most important electron donors in this regard are the nicotinamide adenine dinucleotide (NADH/NAD⁺) and the flavin adenine dinucleotide (FADH₂/FAD) systems. The catabolism of foodstuffs in the citric acid cycle generates high-energy electrons that pass via NADH and FADH₂ to the respiratory chain. These electrons flow in the system of ATP-producing oxidative phosphorylation and lose their energy in doing so. Finally, they reduce molecular oxygen (O₂) to water (H₂O). This mitochondrial electron flow is described biochemically as a hydrodynamic, electrochemical, and biomechanical model.

The hydrodynamic model

The hydrodynamic model illustrates the aspect of the mitochondrial electron flow by means of defined potential levels, where electrons are either picked up or delivered. In this connection, the cellular electron flow can be compared to a watercourse with several waterfalls, like an artificial garden. The waterfalls owe their existence to several water reservoirs, which are linked to each other and situated at different heights. The height of these water reservoirs corresponds with the oxidation-reduction potential (redox-potential) of the involved redox pairs (donator/acceptor). However, not every waterfall (electron flow) must be connected to a power station and an energy conversion system (oxidative phosphorylation). If, however, there are such transfer systems in the electron flow, nature tries to establish as many intermediate steps as possible in the whole system. These intermediate steps are comparable to cascades in the watercourse.

The electrochemical model

The electrochemical model explains the mitochondrial energy transfer and electron flow as follows. The energy, which is released during the transfer of electrons from a high-energy to a low-energy state, is used to operate proton pumps as part of an elaborate electron-transport process in the mitochondrial membrane. The mechanism is basically analogous to an electric cell driving a current through a set of electric motors. However, in biologic systems, electrons are carried between one site and another not by conducting wires, but by diffusible molecules (electron carriers) that can pick up electrons at one location (donator) and deliver them to another (acceptor).

The biomechanical model

The corpuscular-based concept of cellular flow demands the realization of a complex electron-transporting biomechanism that, at the present time, cannot be explained consistently. Mitochondrial electron-transport starts with the generation of high-energy electrons in the citrate cycle. In the course of four oxidation-reduction reactions, three electron-pairs are transferred to the oxidized form of NAD⁺, while one pair becomes the oxidized form of FAD. These electron acceptors, which, in their reduced forms (NADH/FADH₂), are highly energetic, are regenerated again when they deliver their electrons to the respiratory chain in the inner mitochondrial membrane. Reduced NADH gives its electrons to membrane-bound proteins of the respiratory chain due to random collisions. Reduced FADH₂, because of sitting on the inner membrane, hands its electrons directly to the respiratory chain. In the course of this transfer, the electrons lose their energy due to the high redox potential with regard to molecular oxygen (O₂). This energy is used cellulary to install a proton gradient so that this energy will be transferred by means of the oxidative phosphorylation to produce ATP. In aerobic organisms, this process is the main source of ATP. The features of this process are characterized by:

1) Oxidative phosphorylation takes place in the respiratory chain that is located on the inner mitochondrial membrane and is one of its integral parts. The NADH reduced by means of the extramitochondrial glycolysis cannot penetrate the mitochondrial membrane and the same applies to energy suppliers such as pyruvate and fatty acids. The mitochondrial membrane is a structural obstacle to transportation. This is why NADH, the main source of electrons, depends on the help of membrane-transport systems (shuttles) to get into the mitochondria. As far
as quantity is concerned, the malate-aspartate shuttle (malate cycle) is the most important transport system of the cytoplasmic NADH.4

2) The arrangement of the respiratory chain contains numerous electron carriers such as cytochromes and flavins. The transfer of electrons from NADH or FADH2 to O2 by means of these electron carriers consists of several intermediate steps. In addition to this, proton pumps generate a membrane potential (proton-motor force) in the mitochondrial matrix. According to the particle concept of electron flow, the high-energy electrons flow through the respiratory chain via a set of electron carriers (flavins, iron-sulphur complexes, chinones, and cytochromes) until they finally reduce O2 to water. With the exception of the chinones, these electron carriers are prosthetic groups of proteins. The reaction centers of these proteins are almost exclusively equipped with reactive transition metals such as iron and copper. The model of electron transport shows that the electrons flow mainly from one metal to another by means of rotation and translation of the electron carriers.2 The electrons are thus brought down to the lowest energy level, oxygen, and emit their energy. But, although each NADH donates two electrons, each O2 molecule must receive four electrons to produce water. This is why a corpuscular conception of electron flow quantitatively demands the existence of different electron-collecting and dispersing points along the electron-transport chain, where these differences in the number of electrons are compensated for.3

3) The driving force of oxidative phosphorylation in the model is the membrane potential of the inner mitochondrial membrane and the electron transfer potential of 1, 14 V, which is created between the NADH/FADH2 and O2. The free energy of the oxidation of NADH via O2 amounts to 220 kJ/mol. The electron-transfer feeds three oxidative phosphorylation units until the electrons are finally delivered to O2. Therefore, most of the energy released can be converted into a storage form instead of being lost to the environment as heat. The model explains this with an indirect method of reaction, where hydrogen atoms are separated first into protons and electrons (creation of hybrid ions, hydrogen atoms with additional electrons and H+). At several steps along the way, protons and electrons are recombined transiently, but only when the electrons reach the end of this electron-transport chain are the protons permanently returned to neutralize the negative charges created by the final addition of electrons to the oxygen molecule.3

THE MODEL OF THE MITOCHONDRIAL ELECTRON FLOW WITH REGARD TO RADIATION PHENOMENA

In the prevailing classical particle idea of electrons, the energy-transfer from nutritive molecules such as pyruvate to the molecular mitochondrial structures of the respiratory chain is described as a flow of high-energy electrons. But, as has already been noted, there are no consistent explanations for some intermediate steps involved in this electron flow. These include the transport and diffusion of electrons and the interaction between electrons and other components of the mitochondrial energy transfer. Furthermore, the question of the coordination in this process taking part on all levels is answered insufficiently with the random principle. According to the molecular particle concept of biochemistry, the intermediate steps of energy-transfer are regarded as chaotic occurrences without any synergetic precision.3 For example, NADH emits its electrons to the respiratory chain in the course of random collisions. The particle concept describes this as a well-aimed vibratory and rotary motion of the components up to quantum mechanical tunneling of electrons through molecular barriers.6 One reason for this could be the correspondence between the observed rapidity of electron transfer and the frequency of random collisions between diffusible electron carriers and the enzyme complexes (rate: each complex donates and receives an electron approximately once every 5–20 milliseconds). This assumed randomness of collisions is linked with the observation, however, that there is no need to postulate a structurally ordered chain of electron-transfer proteins in the lipid bilayer, and that the ordered transfer of electrons is due entirely to the specificity of functional interactions among the components of the respiratory chain.3

FROM THE PARTICLE ASPECT TO RADIATION PHENOMENA

Because radiation phenomena, in consequence of wave-particle duality, belong to the fundamental nature of electrons, the electron flow linked with the mitochondrial energy transfer can also be described as a radiation process. Contrary to the abovementioned chaotic randomness in the classical particle concept, functional movements and changes in the cell take place in a highly ordered way.7 The cellular order and the whole human organism could not exist otherwise. Order principles only work if high-structured processes are dependent on long-range interactions between the components involved. These interactions have a greater radius of action than that of chemical forces, for example of chemical bonds. This makes it necessary to leave the exclusively molecular point of view and turn to the radiation aspect of matter.5 Therefore, the classical particle concept of the mitochondrial electron flow can be regarded, theoretically, as a wave. The connection between energy transport in the space (radiation) and order (molecular structure) reveals itself when, in structural form, bound energy is released during the breakdown of structures and, if circumstances are reversed, is structurally bound again. This explains some of the abovementioned aspects of mitochondrial energy transfer that so far, cannot be explained consistently.

THE IMPORT OF ELECTROMAGNETIC RADIATION

Chemical reactions are made basically of splittings or combinations of the reaction partners. Cellular examples of this are the oxidation of foodstuffs in the citric acid cycle and the ATP-production in the respiratory chain. To cause a chemical reaction in a cell, the involved partners need to receive enough energy of motion to meet. Usually, at least one of the reactant partners must be stimulated—at least for a short time—to change its electric charge distribution before new units can be formed.5 These essential regulations in the team-work of the components are triggered off by electromagnetic radiation phe-
TABLE 1. COMPARISON BETWEEN THE CHARACTERISTIC ENERGY RANGES OF CHEMICAL BONDS AND THE ENERGY OF ELECTROMAGNETIC RADIATION (PHOTONS) EXPRESSED IN WAVELENGTH

<table>
<thead>
<tr>
<th>Chemical Bond</th>
<th>Energy of Bond (Joule) (characteristic ranges)</th>
<th>Energy of Electromagnetic Radiation in wavelength (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Van-der-Waals-bond</td>
<td>ca. $6.4 \cdot 10^{-21}$ — $1.3 \cdot 10^{-20}$</td>
<td>31100 — 15300 (Infrared)</td>
</tr>
<tr>
<td>Hydrogen bond</td>
<td>ca. $2.1 \cdot 10^{-19}$ — $4.8 \cdot 10^{-19}$</td>
<td>950 — 410 (Infrared, Visible light)</td>
</tr>
<tr>
<td>Ionic bond</td>
<td>ca. $3.2 \cdot 10^{-19}$ — $6.4 \cdot 10^{-19}$</td>
<td>620 — 310 (Visible light, UV-A)</td>
</tr>
<tr>
<td>Covalent bond</td>
<td>ca. $3.5 \cdot 10^{-19}$ — $1.2 \cdot 10^{-18}$</td>
<td>560 — 160 (Visible light, UV-A, -B, -C)</td>
</tr>
</tbody>
</table>

nomena. In other words, the presence or absence of radiation of a special frequency, wavelength, intensity, diffusion, or polarization in the cell is the deciding factor for whether or not reactions take place. We discuss below the import of electromagnetic radiation on the systems and components involved in mitochondrial energy transfer. The basis for this view is the energy range that plays a role for energy carriers of mitochondrial energy transfer. This cellular energy range can, for example, be shown by means of the following components, which are primarily involved in energy transfer.

1) The starting point of the examination is the bond energies of different kinds of chemical bonds in the cellular catabolism of nutrients in the citric acid cycle. Table 1 shows typical energy ranges for the bond energies of chemical bonds (van der Waals, hydrogen, covalent, and ionic bonds). These energies can also be expressed in units of wavelengths of electromagnetic radiation. To present chemical bond energies as energies of electromagnetic radiation, the following fundamental formula by Einstein is used. Electromagnetic radiation of the wavelength $\lambda$ is inversely proportional to the energy $E$ of the electromagnetic radiation:

$$E = h \cdot c / \lambda \ (J)$$

with $E =$ energy of electromagnetic radiation in Joule (J), $h =$ Planck constant ($= 6.6256 \cdot 10^{-34}$ J·s), $c =$ velocity of light ($= 2.9979 \cdot 10^8$ m/s) and $\lambda =$ wavelength of electromagnetic radiation in meters (m).

To illustrate the energy values shown in Table 1, the wavelength of the range of electromagnetic radiation that is visible to the human eye measures ca. 400—800 nm. The energies of the chemical bonds mentioned above correspond, more or less, to the energy range of visible light. Some part reach into the near infrared and ultraviolet (UV-A, UV-B, and UV-C) range of electromagnetic radiation. For example, the energies of hydrogen bonds are nearly the same as the wavelengths of the low energetic range of visible light and reach from yellow over red to the near-infrared.

2) As shown above, the chemical energy of the different kinds of bonds is first released during the breakdown of bonds in the cellular metabolism and then converted into celluly usable energy by corresponding molecular structures of the mitochondria. These molecular structures consist of the electron-donor and acceptor systems and, in addition to this, of the components of the respiratory chain. The characteristic energy ranges that apply to these systems can also be specified. One corresponding functional structure on the molecular side of the energy transfer is the nicotinamide adenine dinucleotide system (NADH/NAD+). Its photoabsorption (UV-visible) spectrum is shown in Fig. 1. The FADH2/FAD system, which in the corpuscular model of the electron transfer also yields as a donator of high-energy electrons, shows a photoabsorption behaviour similar to that of NADH/NAD+ (Fig. 1, inset).

Due to its physical origin (electronic configuration, specific molecular orbital structure), the photo(UV-visible)absorption spectrum is a characteristic fingerprint of the systems in question. Absorption maxima (absorption bands) of the spectrum mark the range where the observed system resonates and absorbs the most energy in the form of electromagnetic radiation (visible light). What happens with the absorbed energy depends on the physical nature of the specific systems and their own original electronic structure. Whether energy is released or not is dependent on factors such as relaxation, fluorescence, heat conversion, or dynamic changes in the system. In comparison

![FIG. 1. Photo (UV-visible) absorption spectra of the NAD+/NADH-system (inlet:FADH2-system).](image-url)
Radiation Phenomena in Mitochondrial Energy Transfer

Table 2. Characteristic Ranges of Absorption Bands of Components Involved in the Mitochondrial Respiratory Chain (Wavelength in nm)\(^2\)

<table>
<thead>
<tr>
<th>Component</th>
<th>Soret-band</th>
<th>(\beta)-band</th>
<th>(\alpha)-band</th>
</tr>
</thead>
<tbody>
<tr>
<td>NADH/NAD</td>
<td>300–340</td>
<td>470–490</td>
<td>580–630</td>
</tr>
<tr>
<td>Flavoproteins</td>
<td>350–490</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ubichinon Q</td>
<td>270–410</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cytochrome b</td>
<td></td>
<td>450–465</td>
<td>520–530</td>
</tr>
<tr>
<td>Cytochrome (C_1)</td>
<td></td>
<td>370–380</td>
<td>530</td>
</tr>
<tr>
<td>Cytochrome c</td>
<td></td>
<td>410–415</td>
<td>521–528</td>
</tr>
<tr>
<td>Cytochrome a</td>
<td></td>
<td>420–450</td>
<td>520–540</td>
</tr>
<tr>
<td>Cu A</td>
<td></td>
<td></td>
<td>830</td>
</tr>
<tr>
<td>Cu B</td>
<td></td>
<td></td>
<td>760</td>
</tr>
<tr>
<td>Cytochrome (a_3)</td>
<td></td>
<td></td>
<td>520–540</td>
</tr>
</tbody>
</table>

The chemical bond energies (expressed in wavelengths of electromagnetic radiation) that are released in the citric acid cycle from covalent carbon bonds and hydrogen bonds correspond well to the absorption bands of the NADH/NAD\(^+\) and FADH\(_2\)/FAD systems (compare Fig. 1 and Table 1).

3) Another energy range to be examined more closely arises from the key structures in the respiratory chain, the electron carriers. These electron carriers are primarily metal proteins with iron-sulphur centers, heme groups, and copper atoms as prosthetic groups. The best known are the flavins and heme components. The three main enzyme complexes of the respiratory chain with such metal proteins are the NADH dehydrogenase complex, the cytochrome \(b_1\) complex, and the cytochrome oxidase complex (cytochrome \(a_3\)). In general, each electron carrier has an absorption spectrum and reactivity that is distinct enough to allow its behavior to be traced even in crude mixtures.\(^3\) They absorb electromagnetic radiation in the range of visible light and change

FIG. 2. Comparison of the energy ranges between the chemical bonds, the components involved in the mitochondrial respiratory chain, and the electromagnetic radiation of low level laser shown as energy (wavelength) of electromagnetic radiation.
their absorption bands (color) when they are oxidized or reduced. Table 2 shows some of the essential electron carriers and the range of their absorption bands. For example, flavins constitute an astonishing class of green and yellow pigments that derive from riboflavin or vitamin B₂, while hemes (iron-porphyrines) combine with proteins to form a whole range of colored molecules with hues from blood red to pea green. The position of the absorption bands can vary depending on the coordination of the prosthetic groups in the holoprotein.

As mentioned above, these components of the respiratory chain are clearly distinguishable by means of their absorption spectra. The shortwave absorption bands in the region of 280 nm (UV range of the electromagnetic radiation) are derived from amino acids of the proteins tryptophan and tyrosine. The longer wave absorption region originates primarily from the prosthetic (metal) group of the particular electron carrier (for example, Soret, α-, β-bands of heme). These energy ranges correspond well with both the energies of released chemical bonds (see Table 1) and the photoabsorption spectra of the electron-donor and acceptor systems (see Fig. 1). Therefore, electromagnetic radiation entering in the mitochondrial respiratory chain can be absorbed directly by the electron carriers through their so-called antenna pigments. The effective radiation scale (expressed in frequency or wavelength) extends from UV over the visible region to infrared (IR).

Furthermore, the oxidative phosphorylation is enabled by the close link between electron carriers and protein molecules. These proteins control the electrons through the respiratory chain, so that they can pass from one enzyme complex to another in the right order and effectively. This electron control occurs by allosteric rearrangements in the proteins involved. Both the control system and the provision of energy for such dynamic conformation changes in proteins or vibratory motions in macromolecules can be explained with the aid of radiation phenomena. The import of radiation phenomena in the context of the mitochondrial energy transfer and electron flow, enables understanding of the process of the energy finally released from the catabolism and its absorption by the structures of the inner mitochondrial membrane. Following an explanation of the import of electromagnetic radiation in the form of light on the mitochondrial energy transfer. Depending on its wavelength, light (photons as quanta) can, for instance, stimulate macromolecules to change the geometry of molecules as well as to transfer energy to electrons. As a matter of fact, light has a directly stimulating effect on cellular structures, as has been shown by several experiments. On this cellular level there still remains much research to be done concerning the biostimulatory effect of electromagnetic radiation (e.g., in the region of visible, natural solar light). The relevant issues in this research arise from the location of cellular stimulation points and from the explanation of the directly stimulating effect of electromagnetic radiation in connection with the components of the respiratory chain.

LOW LEVEL LASER LIGHT

The stimulative effect of electromagnetic radiation in the form of low level laser light in medicine is already used today. It is known that the effect of low level laser light does not derive from heat. Variations of the energy of electromagnetic radiation show that the effect of laser light is limited to certain spectral regions. The wavelength (energy range) between 600-700 nm (red region) seems to be especially effective. Low level laser light from the red region and the near-infrared region corresponds definitely with the characteristic energy and absorption levels relevant for the respiratory chain. This indicates the stimulation center of low level laser light in this way that the electromagnetic energy stimulates the components of the so-called antenna pigments of the respiratory chain and therefore vitalizes the cell by increasing mitochondrial ATP production. This kind of stimulation can be interpreted as a biological resonance effect. Therefore, the components of these antenna pigments are resonators of different sizes and forms, which resonate with a specific stimulation that means energy of radiation. They are capable of transferring the stimulation functionally for various regulation processes in the cell. The energy range of these processes and components of the cell involved in the mitochondrial respiratory chain, is shown in Figure 2.

One characteristic energy range is represented by the chemical bonds that are released by the cellular catabolism. On the other hand, the absorption bands of the components of the mitochondrial respiratory chain (particularly the electron carriers with their antenna pigments) are in a comparable energy range (see Fig. 1 and Table 2). Both of these relevant energy ranges correspond remarkably well to the energy range of the electromagnetic radiation of low level laser light used therapeutically.

CONCLUSION

In the mitochondria, the chemical energy contained in foodstuffs is converted into a cellularly usable form. Biochemical models of this energy transfer regard electrons as energy carriers responsible for the different transfer processes. After being gained in the citric acid cycle, high energy electrons effectively pass the electron transport chain (respiratory chain) by delivering their initial energy to the cellular energy transfer and finally reduce oxygen to water. The classical particle idea of electrons describes the mitochondrial energy transfer as a flow process of high energy electrons (electron flow). Intermediate steps in this model of electron flow are inconsistent with the particular idea of electrons. Because of the inherent wave-particle duality of the electrons, it is necessary to use radiation phenomena to explain mitochondrial energy transfer. The connection between energy transport by radiation and order in structural form may be understood if, for instance, structurally bound energy is released during the dissolution of structures (oxidation of foodstuffs) or is again manifested (reduction of oxygen to water). Regarding the energy values relevant for the respiratory chain, the import of electromagnetic radiation of characteristic ranges of wavelengths on the mitochondrial energy transfer becomes evident. Depending on its wavelength, electromagnetic radiation in the form of light can stimulate macromolecules, initiate conformation changes in proteins, and transfer energy to electrons. Therefore, with regard to radiation phenomena in the mitochondrial energy transfer and its enhanced electron flow in the respiratory chain, it is possible to explain the experimentally found increase of ATP-production by means of low-level laser
light on a cellular level. Furthermore, it must be emphasized that the theoretical model mentioned above and the biostimulative effect of radiation phenomena require continued research.

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