ATP Synthesis in Myosin Heads by Endogenous UV

Thomas Prevenslik
QED Radiations, Berlin, Germany

Abstract

In muscle contraction, mitochondria provide an efficient but limited conversion of glucose to ATP that otherwise proceeds by the inefficient glycolysis of pyruvate and fatty acids. Historically, ATP synthesis in mitochondria followed hydrolysis driven by chemiosmotic hydrogen ion gradients across the inner membrane. However, ATP synthesis in mitochondria may instead proceed by dehydration reactions powered by exogenous UV produced from the size dependent mitochondrial features, a process that may be extended to each of the many heads on the myosin filament thereby increasing ATP synthesis without the need for pyruvate and fatty acids. Exogenous UV is a consequence of the Planck law of quantum mechanics that denies atoms in nanoscale myosin heads the heat capacity to conserve heat by a change in temperature. In this regard, the simple QED theory of nanoscale heat transfer allows heat conservation by creating standing EM waves inside the myosin heads. Unlike electronic quantum states, simple QED is based on size dependent quantum states defined by the dimensions of the nanostructure over which the EM waves stand. Myosin heads are shown to not only provide an electrostatic basis to muscle contraction, but in muscles supersede mitochondria in ATP synthesis.

Introduction

In 1969, Huxley [1] proposed muscle contraction occurs by relative sliding between actin and myosin filaments based on ATP hydrolysis by chemiosmosis. However, the mechanism underlying muscle contraction by filament sliding to this day remains a mystery prompting the following brief historical review of ATP synthesis as a background to this paper.

In the 1960's, the origin of life captivated biological research. Mitchell [2] proposed ATP synthesis in mitochondria by hydrolysis following chemiosmosis driven by the flow of H+ ions across the inner membrane. Chemiosmosis occurs by assuming a sequential chain of complex redox reactions with electron transfer from donors to acceptors assisted by enzymes. In contrast, Sagan et al. [3] proposed life on the early Earth began by dehydration reactions under intense solar UV radiation and experimentally showed ATP was formed from ADP + Pi under UV radiation. However, ATP by hydrolysis and not UV dehydration was embodied in the sliding-filament model [1] of muscle contraction. To this day, muscle contraction by ATP hydrolysis is thought initiated by a conformation [4] of myosin heads with ADP + Pi attaching to actin to perform the power stroke. Upon binding with another ATP, the head detaches from actin in recovery by another conformation change, the sliding process repeating in the manner of a ratchet.

In 2018, myosin head movement in hydrated myosin filaments, coupled with ATP hydrolysis was shown [5] that absent actin filaments, myosin heads fluctuate around a definite neutral position; whereas, upon binding to ATP, the myosin heads somehow acquire a "charged-up" state and perform a power stroke while releasing ADP and Pi. Binding with another ATP returns the myosin heads to the neutral or non - "charged-up" position suggesting the "charged-up" myosin heads decide their direction of movement without being guided by actin filaments.

Although having a long history like the ratchet mechanism of muscle sliding, the mechanism that creates the "charged-up" myosin heads is still not clear. As early as 1974, a complex of the myosin head and bound ATP was proposed [6] hydrolyzed by chemiosmosis into a "charged" intermediate state having a great tendency to bind to actin filaments. In 1985, the myosin heads having a strong affinity to ATP were thought [5] somehow raised to an activated intermediate form by binding to an actin filament. The activated complex, myosin-ATP-actin, thought to undergo ATP hydrolysis and to produce ADP + Pi. In the ATP hydrolysis, solitons were proposed [7] to underly the "charged" intermediate state in the sequence of events [6] in which the myosin head attaches to actin, swivels and propels the thin filament past the thick filament prior to detaching from the actin molecule and returning to the neutral position. But in solitons, ATP hydrolysis requires the temperature dependence of the phonons which cannot occur because the Planck law precludes temperature changes at the nanoscale embodied in this paper.

Beyond the fact that the cross-bridges lack the ability to produce contractile force, criticism [8] of ratchetting by sequential attachment and detachment occurred by discrete forces instead of the smooth force measured during muscle contraction. Consistent with a smooth force, the myosin heads were assumed [8] to act like individual electric dipoles activated by ATP to electrostatically attract the actin filaments. An earlier electrostatic mechanism [9] was the release of positive Ca2+ ions from actin that attracted the negatively charged myosin filament, the Ca2+ ions controlling the sliding filament muscle by binding to the actin filaments producing a shift in the position of tropomyosin that regulates the ratchet attachment-detachment cycle. Otherwise, myosin and actin filaments repel each other as both are naturally charged negative.

Contrarily, myosin head binding to actin filaments was found [10] to take place to the same extent irrespective of Ca2+ ions providing the KCl solution was at low ionic strength. On this basis, It was concluded [11] the strong actin-myosin linkages may be nothing more than a strong electrostatic attractive force between myosin heads and actin filaments, e.g., positively charged amino acid residues [12] in myosin attract the negatively charged N-terminal peptide of actin to create the "charged-up" state.

In 2019, ATP synthesis in mitochondria was proposed [13] to proceed by UV enhanced dehydration consistent with the Sagan et al. [2] proposal for the origin of life on the early Earth being driven by solar UV. Later, solar UV vanished on Earth with the formation of ozone. With UV decreasing, survival would have necessitated mitochondria evolve structural features to produce an endogenous source of UV. Perhaps, the structural feature to continue ATP synthesis was EM radiation standing at UV wavelengths in the fold formed between adjacent cristae is shown in Fig. 1.

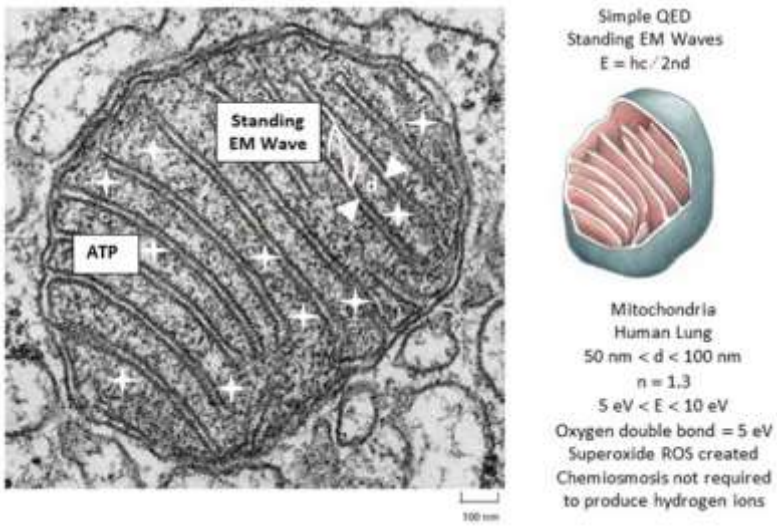

Figure 1. ATP synthesis by standing UV waves between cristae

Unlike chemiosmosis, simple QED does not depend on the H+ gradient and sequential redox reactions to produce ATP by hydrolysis. ATP synthesis by UV dehydration is direct:

$$ADP + Pi + UV \rightarrow ATP$$

However, UV as the source of ATP synthesis may appear undesirable as DNA is damaged. But mitochondria most likely evolved DNA repair [14] mechanisms even sacrificing ATP produced. Perhaps, Nature took advantage of the simplicity of UV enhanced ATP hydration synthesis to sustain life at the expense of some ATP.

Simple QED in UV enhanced mitochondria was extended [15] to the myosin heads. By simple QED, the "charged-up" state was superseded by endogenous EUV created inside myosin heads that by the photoelectric effect produced the positive charge in electrostatic muscle contraction. Only the myosin heads charge positive - the myosin and actin filaments [9] carry their natural negative charge. Also, the Z-disk is naturally charged negative, but along with attached actin filaments may be briefly positively charged by neuron action potentials. Fig. 2 shows muscle contraction occurs as all positive charged myosin heads are attracted to both actin filaments and the nearest charged Z-disk. Contact of heads with actin is inconsequential as attraction to Z-disks provides the axial contraction force. Upon contact of the myosin heads with the actin at the Z-disk, the positive charges are neutralized and muscle contraction ceases. Muscle relaxation occurs by Coulomb repulsion of negatively charged myosin and Z-disks.

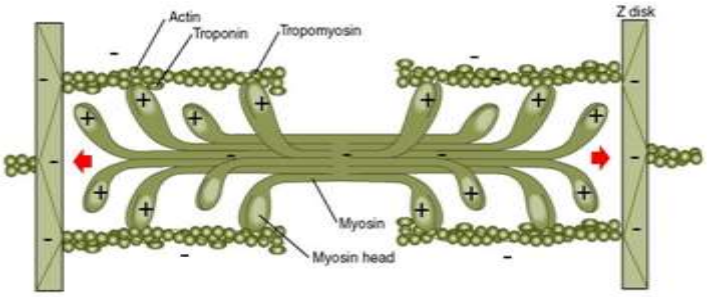

Figure 2. Endogenous EUV induced Muscle Contraction

Unlike the ratchet mechanism based on ATP hydrolysis by chemiosmosis, electrostatic muscle contraction is based on ATP synthesis by UV enhanced dehydration [15]. Simple QED creates endogenous EUV in the myosin heads that upon fluorescing down to UV levels creates positive charge by the photoelectric effect. But if so, the UV may also synthesize ATP by dehydration reactions to supplement, if not replace the mitochondria as the source of ATP in muscle contraction.

PURPOSE

To propose the myosin heads not only produce positive charge in electrostatic muscle contraction, but also provide a source of ATP synthesis. Indeed, the ATP suppled to muscles from mitochondria cannot be efficient because the mitochondria are not local to each of the many myosin heads on a myosin filament. It is likely Nature recognized this and provided each myosin head with a means to synthesize ATP. Dehydration ATP synthesis is preferred as only a source of UV is required as hydrolysis requires a membrane and hydrogen ion gradients. The heat necessary to produce the UV is the thermal surroundings of the myosin head. Any ATP produced by the myosin head is assumed to increase the temperature of thermal surroundings and not the myosin head directly. The Sliding-filament model adapted for endogenous EUV in myosin heads absent actin filaments and Z-disks is shown in Fig. 3.

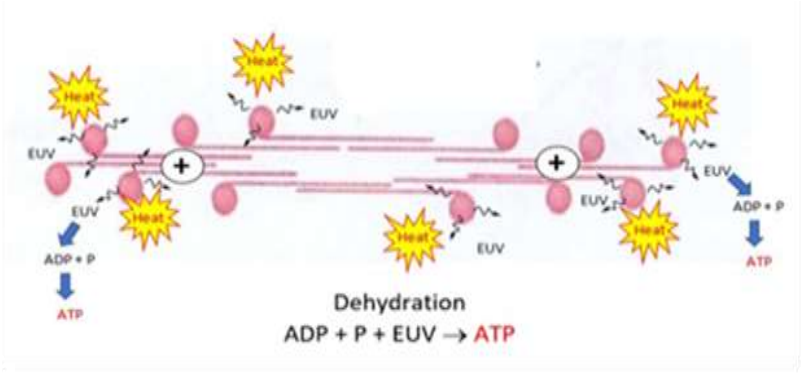

Figure 3. EUV from Thermal Heat producing ATP and Muscle Contraction

In Fig. 3, the myosin heads locally absorb heat Q from the thermal surroundings which includes the ATP synthesized from ADP + Pi. Mitochondrial ATP not local to the myosin heads cannot contribute to local heating of myosin heads and are not considered. On a relative basis, the heat released from ATP binding is a small fraction of that in the temperature of thermal surroundings.

ANALYSIS

Endogenous EUV created in myosin heads depends on simple QED - a method of analysis applicable to nanoscale heat transfer. Simple QED is not the complex light and matter interaction based on virtual photons advanced by Feynman and others that cannot be directly confirmed experimentally. Instead, simple QED based on real photons is immediately understood by the Planck law of quantum mechanics that requires the heat capacity of constituent atoms in nanoscale structures to vanish under EM confinement. In contrast, classical physics always assumes the atom has heat capacity and produces an increase in temperature upon the absorption of heat. Simple QED differs as the nanostructure conserves heat by the creation of standing EM radiation inside and across the diameter d of a nanoparticle (NP) illustrated in Fig. 4.

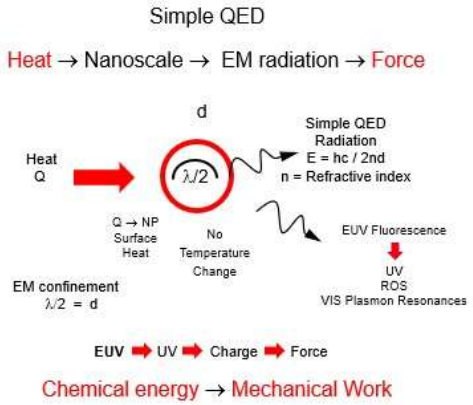

Figure 4. Simple QED conversion of Heat Q to EM radiation

The heat Q into the NP is transferred from blood or tissue as a thermal bath. Because NPs have high surface-to-volume ratios, the heat Q is almost totally absorbed in the NP surface. The NP temperature cannot conserve the surface heat by an increase in temperature, and instead a standing EM wave is created inside and across the diameter d of the NP having half-wavelength $\lambda/2 = d$. Correcting the velocity of light c for the refractive index n of the NP gives the time $\tau = 2d/(c/n)$ for 1 cycle. Hence, the wave frequency $c/\lambda = 1/\tau = c/2nd$ gives $\lambda = 2nd$. In the EUV, the refractive indices $n \sim 1$ and the wavelength $\lambda \sim 2d$. However, the myosin head is not spherical, but pear-like in shape [16] as shown in Fig. 5.

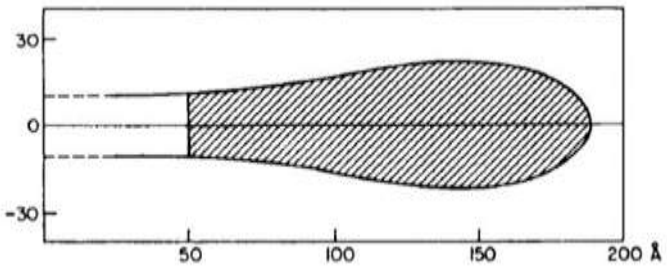

Figure 5. Myosin head shape

The myosin head is highly asymmetric with a length of 165 Å, width of 65 Å, and thickness of approximately 40 Å. The volume is 142,000 Å ^{3}.

Simple QED may create standing EM radiation in all directions, but Fermat's principle of minimum time suggests EM radiation is produced across the minimum dimension. Hence, the myosin head thickness governs and $\lambda \sim 80$ Å = 8 nm. Hence, the EUV energy E = 155 eV >> ionization potential of hydrogen, oxygen, and carbon atoms in the myosin molecule. Clearly, positive charge of at least 1 electron is created provided energy is available to create at least one 155 eV photon.

However, the EUV energy for muscle contraction must be created from the thermal environment limited to body temperature of 37 °C = 310 °K. Quantum mechanics based on discrete electronic energy levels precludes the creation of EUV photons from thermal energy at 310 °K and requires EM radiation equal or greater than 155 eV. However, simple QED is a size dependent quantum state independent of discrete electron levels which is filled with EM radiation having energy equal to the thermal kT energy which normally occurs when the myosin head is immersed in a 310 °K thermal bath. Otherwise, energy conservation is violated.

Classically, upon immersing the myosin heat in the thermal bath, the thermal energy U is,

$$U = \frac{3}{2} kT\, N$$

where, k = Boltzmann's constant, N = number of atoms, and T = absolute temperature.

The myosin head contains W/MW moles of myosin, where W = weight of myosin head and MW = molecular weight. The weight W = ρV, where ρ = density and V = volume of the myosin head. In the myosin head, the number of myosin molecules N_m = W·Av/MW, where Av = Avagadro's number. For $\rho = 1.083 \times 10^6$ g/m^3 and V = 142x10^{-27}m^3, W = 1.54x 10^{-19} g. With myosin [17] having MW ~ 20000 Da, $N_m \sim 4.6$ molecules. For myosin having 208 atoms/molecule, the number of atoms in the myosin head N = 964. Hence, the available thermal energy U = 38.6 eV < 155 eV and EM energy cannot be conserved across the thickness of the myosin head. However, EM waves standing across the 16.5 nm length of the myosin head only require E = 37.6 eV < 38.6 eV. Although marginal, at least one EUV photon at 37.6 eV created from thermal surroundings is likely available to allow every myosin head a single positive charge necessary for muscle contraction.

But is the single EUV photon created promptly?

Consider the heat Q from the thermal surroundings to create the EUV photon and ignore the heat from ATP binding. The change in surface temperature ΔT under the instantaneous creation of a EUV photon with a pulse of energy E from the thermal surroundings is given [18] by,

$$\Delta T = \frac{1.2H}{\beta\sqrt{\pi}}\left[\sqrt{t + \Delta t} - \sqrt{t}\right]$$

where, t = time, Δt = pulse duration, H = E /Δt and E = hc/2nd, β = thermal effusivity, $\beta = \sqrt{K\rho C}$ where K, ρ, and C are thermal conductivity, density, and specific heat. Combining,

$$\Delta T = \frac{1.2}{\pi d^2 K}\left(\frac{E}{\Delta t}\right)\sqrt{\frac{\alpha}{\pi}}\left[\sqrt{t + \Delta t} - \sqrt{t}\right]$$

Instead of the pear-like myosin head, a spherical NP diameter d ~ 20 nm is selected. Here, α = thermal diffusivity, α = K/ρC. The Planck energy E = 37.6 eV of the EUV photon is assumed spread over the spherical surface area πd^2. For n = 1, the EUV photon is created in time Δt = 2d / (c /n) = 0.13 fs. Hence, the EUV heat Q = E/Δt ~ 46 mW. Taking α = 1.24 x10^{-7} m^2/s and K = 0.52 W/m-°K, the surface temperature promptly decreasing ΔT ~ 120 °K, a change in temperature that rapidly recovers in < 1 ps as shown in Fig. 6.

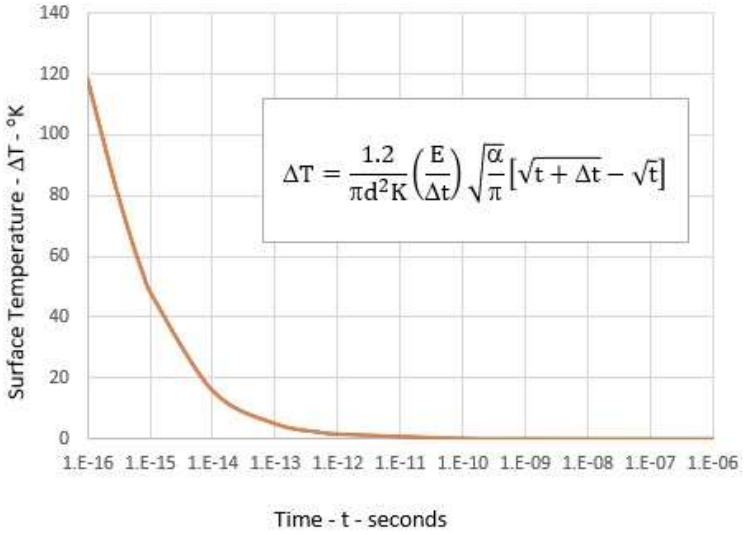

Figure 6. Myosin head surface temperature in creating EUV photon

What this means is EUV creation in the myosin heads do not depend on the heat of ATP binding. The single EUV photon is created from the thermal surroundings alone. Moreover, single ATP binding to the myosin head only releases 0.304 eV - far less than the 37.6 eV required to create the EUV photon. Many ATP heat releases provide the thermal energy in the muscle surroundings.

In muscle contraction by endogenous UV, the Coulomb attractive force F in terms of the distance X between a positive q charged head and negative charged surroundings is,

$$F = \frac{q^2}{4\pi\varepsilon_o \varepsilon X^2}$$

where, ε_o is the permittivity, and ε the relative permittivity of the medium. The relative permittivity of water $\varepsilon \sim 80$ is not applicable. In low KCl concentrations the relative permittivity ~ 4.7. In the early analysis [1] of the cross-bridge, the F = 2 pN force was found at X = 8 nm. The charge q is,

$$q = X\sqrt{4\pi\varepsilon_o \varepsilon F}$$

Hence, the head has q = 1.6 e electron charges - a single positive charge occurring at X = 4.9 nm.

What this means is the myosin head was charged by at least 1 EUV photon which is consistent with this paper. In general, the electrostatic force F occurs between many positive myosin heads attracted to α-actin at the Z-disk. In simplification, the average of many positive charges is taken to be located at X shown in Fig. 7.

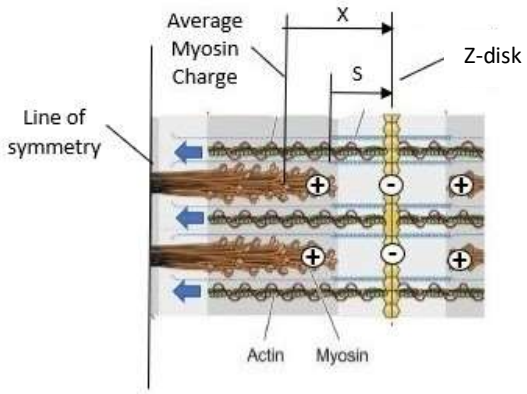

Figure 7. Average electrostatic charge

Once again, taking the electrostatic force F = 2 pN and assuming the average distance X = 500 nm, the positive charge q ~ 100 electron charges or 100 singly charged myosin heads assuming simple QED creates at least one single positive q charge. Since about 150 myosin heads are available in a half-sarcomere, 100 heads are required to produce the 2 pN contraction force.

CONCLUSIONS

Myosin heads undergo ATP synthesis by UV enhanced dehydration during times of muscle relaxation providing heat to maintain the temperature of the thermal surroundings. But during demands of muscle exertion, the myosin heads produce EUV radiation that fluoresces down to UV levels and creates positive charge by the photoelectric effect to contract the muscle.

ATP synthesis in the cross-bridge ratchetting mechanism of the sliding-filament model is superseded by UV enhanced ATP hydration synthesis induced by electrostatic muscle contraction from positive charged myosin heads, the charge created by the photoelectric effect from endogenous EUV conserving heat from the thermal surroundings.

Muscle contraction by electrostatic attraction from positive charged myosin heads and the negative charged Z-disks supersedes contraction in the sliding-filament model by cross-bridges.

Myosin heads not bound to negative charged actin filaments carry positive charge. But contact by Coulomb attraction neutralizes positive charged myosin heads. Upon loss of contact, myosin heads now free promptly regain positive charge in < 1 ps.

Heat in the thermal surroundings creates the EUV photons inside the myosin head to allow photoelectric charging. A single ATP binding to a myosin head releases 0.304 eV, but a EUV photon standing across the length of the myosin head requires 37.6 eV. Heat from the thermal surroundings powers muscle contraction and not ATP binding, although ATP binding contributes to thermal heating.

Like myosin heads, ATP synthesis in mitochondria is produced by endogenous UV instead of hydrolysis by chemiosmosis from a H+ ion gradient through the membrane wall. EUV enhanced ATP synthesis by dehydration in the myosin heads produces ATP directly in the muscle without need for mitochondria.

References

1. Huxley HE. (1969) The mechanism of muscular contraction. Science 164: 1356–1366

2. Mitchell P. (1961) Coupling of phosphorylation to electron and hydrogen transfer by a chemiosmotic type of mechanism. Nature 191: 144–148.

3. Ponnamperuma C., Sagan C, Mariner R. (1963). Synthesis of Adenosine Triphosphate under possible primitive Earth conditions. Nature 199: 222-226.

4. Lymn RW, Taylor, EW. (1971) Mechanism of adenosine triphosphate hydrolysis by actomyosin. Biochemistry 10: 4617–4624.

5. Sugi H, Akimotoa T, Chaen S. Basic properties of ATP-induced myosin head movement in hydrated myosin filaments, studied using the gas environmental chamber. Micron; 2018; 113:48–60.

6. Murray JM, Weber A. The Cooperative Action of Muscle Proteins. Sci. Amer.; 1974; 230:58-71.

7. Yomosa S. Solitary excitations in muscle proteins. Phys. Rev. A; 1985; 32:1752-1758.

8. Iwazumi T, Noble M. (1989) An electrostatic mechanism of muscular contraction. Int J Cardiol 24: 267-275.

9. Ingels NP, Thompson NP. (1966) An electrokinematic theory of muscle contraction. Nature 211: 1032-1035.

10. Sugi H, et al. (2013) Enhancement of Force Generated by Individual Myosin Heads in Skinned Rabbit Psoas Muscle Fibers at Low Ionic Strength. PLOS ONE 8: e63658.

11. Sugi H, Chaen S, Kobayashi T, Abe T (2013) Evidence that actin-myosin cycling in muscle may not pass through rigor configuration. Biophys J 104 Supple 1: 305–306a.

12. Va´rkuki BH, Yang Z, Kintses B, Erde´lyi P, Ba´rdos-Nagy I et al. (2012) A novel actin binding site of myosin required for effective muscle contraction. Nature Struct Mol Biol 19: 299–306.

13. Prevenslik T. (2019) ATP by Endogenous UV Radiation. See 10th Targeting Mitochondria Conference, October 27-29, Berlin at nanoqed.org, 2019.

14. Beyer, R. E. (1959). The Effect of Ultraviolet Light on Mitochondria. I. Inactivation and Protection of Oxidative Phosphorylation during Far-Ultraviolet Irradiation. Archives Biochemistry and Biophysics. 79, 269-274.

15. Prevenslik T. (2019) Electrostatic Muscle Contraction. See www.nanoqed.org, 2019.

16. Rayment I, et al. (1993). Three-Dimensional Structure of Myosin Subfragment-1: A Molecular Motor. Science 261: 51-58.

17. Warrick HM, Spudich JA. (1987) Myosin Structure and Function in Cell Motility. Ann. Rev. Cell Bioi. 3: 379-421.

18. Carslaw, H. S, and J. C Yeager. (1959) Conduction of Heat in Solids, 2 nd. Ed. Oxford Univ. Press.