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Ultraweak Electromagnetic Fields and Sub-Atomic Dynamics – A Possible Subset of Signal-Transduction and -Storage Mechanisms in the Cardiovascular System (Non-Linearity, Small-Scale Fluctuations and Predictive Aspects)

R. Gasser, S. Gasser, C. Hecking

Ultraweak electromagnetic fields, charges and fluxes constitute a basic principle of life (here intentionally termed “animated matter”). Influencing these minimal charges and fluxes locally through ultraweak fields/radiation/photon emission elicited by external sources at given wave lengths, bandwidths and field strength may constitute an important therapeutic tool in the future. The multitude of possible mediators in this context may, however, also explain the difficulty in assessing direct cause and effect chains – in other words, summary vectors may bring about very heterogeneous responses in different subjects. However, the latter may be well expressed in heart rate variability and, using non-linear algorithms, these may be decoded one day and served as an important and highly sensitive diagnostic tool. Heart rate spectral analysis and DFA of HRV constitute a powerful non-invasive tool for quantifying autonomic nervous system activity and responsiveness yielding important information about sino-atrial response to autonomic input as a biophysical surrogate for complex autonomous signal proceeding and interaction. Routine application of DFA in high resolution HRV to clinical cardiovascular medicine needs further investigation. Nevertheless, it is likely to become an important procedure in cardiovascular risk stratification in the years to come. While, on the one hand, the main focus of magnetic resonance techniques has been directed to imaging and diagnostic purposes up to now, one may anticipate that, on the other hand, deeper understanding of electromagnetic/quantum physical properties of animated matter (biological and biophysical processes) would inevitably lead to the therapeutic use of defined electromagnetic- and radio-waves: Such exposure to calculable, locally induced currents may cause elicitation of specific, predictable biochemical and biophysical reactions in deeper layers of the tissue. Or, in more simple terms, understanding the coherent wave structure of the quantum physical alterations within defined time segments during biochemical/biophysical cellular reactions, one may be able to influence those directly using waves (electromagnetic/radio/photons) instead of matter (chemicals). *J Clin Basic Cardiol 2003; 6: 87–92.*

Key words: cardiac, non-linearity, signal-transduction

During the recent years it has become evident that all biological systems produce electromagnetic waves and ultraweak photon emission and, less surprisingly, show sensitive and variable responses throughout the whole spectral range. The frequencies range between the order of a few Hertz and reach as far as radio waves ($h\nu < kT$), the UV region ($h\nu \geq kT$) and above. These emissions can give rise to sensitive reactions within organisms at various spectral intervals. One can collect predictable emissions and measure equally predictable responses to such fields and photon emissions. In animals, including insects, such signals are used for communication, coordination of movement (flight – eg keeping align flocks of birds), orientation, navigation, growth, circadian rhythms, etc. Similarly, plants coordinate growth and their direction, biophysical and biochemical processes as well as mitosis and many other mechanisms via such ultraweak emissions and responses to the latter.

In the cardiovascular system, electrochemical and electrophysical processes play a decisive role in electromechanical control of the heartbeat as well as in the response of the vascular system to external and internal factors. While cellular electrophysiology (transmembrane ion-movements and ion-channel electrophysiology) appears likewise very simple, the understanding of kinetobaric, photochemical, thermodynamic and fractal aspects of ultraweak electromagnetic fields and photon emission on the sub-cellular level has appeared to be reserved for a handful of scientists as yet. However, this may change in the light of the emerging importance of diag-

nostic and therapeutic use of these phenomena (eg magnetic resonance tomography in cardiovascular diagnostics or the application fractal scaling, detrended fluctuation analysis on heart rate variability data or inter-bacterial communication currently investigated as quorum sensing).

Weak and Ultraweak Electromagnetic Fields in Biological Systems

Electrical Fields in Biological Systems

Alternating as well as stationary weak and ultraweak electrical fields constitute the basic biophysical concept on which the living cell is functioning [1]. Cellular electrophysiology has, in large extent, investigated these phenomena. In particular, transmembrane resting charges (Nernstian equation)

$$EMF = E_o + 2,303 \frac{RT}{nF} \times \log a_i$$

built up by ion-pumps/transmembrane ion-channels and their rectifying properties as well as alternating transmembrane ion-currents (Goldman equation). Furthermore, liquid junction potentials produce an electromotive force (EMF), which, for example, in a solution with another interfering ion would be [2]:

$$EMF = E_o + 2,303 \frac{RT}{nF} \times [\log a_i + K_{ij}(a_j)^{n_i/n_j}].$$

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However, it should be noted that, in solutions with higher ionic strength, the ionic activity will be:

$$a_i = \gamma_i c_i$$

but, already here we find a direct thermodynamic dependence of the ion-activity in a solution (eg cytoplasm). Therefore, the mean activity-coefficient for a dissolved electrolyte can be calculated using the Debye-Hueckle theory [3, 4] which derives from the Poisson equation (the latter describes the spheric-symmetric electrochemical situation as a property of the relation between the solvent and the electrolyte) and from the Boltzman equation, which describes (here in simplified terms just to ease the understanding) the ion-distribution and the electric energy of ions. In terms of the concentrations of all ionic moieties present, the Debye-Hueckel interface-equation may be described as

$$\log \gamma \pm = \frac{A (Z_1 \times Z_2) I}{1 + B \times a \times I} + C \times I$$

It should be mentioned that long acting Coulomb forces will be influenced by short interactions between ions and solvent. In summary, meaning that, at the interface between two liquids, which contain different concentrations of ions, a liquid junction potential is created, one can easily understand that in any biological system, ie, living organism, where countless membranes separate different saline solutions, where proteins carry charges and lipids bind certain charged molecules, a plethora of low electric fields and fluxes exist. The most important ones for the cardiovascular system entail the action potential and its transduction as well as autonomous neuronal electric activity which effects heart rate variability.

Influencing these minimal charges and fluxes locally through ultraweak fields/radiation/photon emission elicited by external sources at given wave lengths, bandwidths and field strength may constitute an additional therapeutic tool in the future.

Dielectrical Polarisation

Furthermore, the body of every animal species shows a mosaic like surface map of areas with different charge pattern. Changes in these pattern are brought about by electrically/ionic active secretion and/or by environmental parameters. Organic body surfaces also exhibit semiconductor properties. Dielectrical polarisation is detectable in all parts of the body [5].

Electrical fields emanating from living organisms ("animated matter") are measured either by radioactively treated potential probes or by field mills which record the electrostatic induction charges of the field. Charges on membranes can be measured with conventional microelectrodes or specific ion-selective microelectrodes [6] (see also Fig. 1). Electromagnetic charge is, for example, of fundamental importance for flying animals like insects and birds for navigation and orientation, using the interaction between electromagnetic geological and atmospheric fields and their own field.

In heart, the effects of such interactions are under investigation, however, specific pattern of morbidity and mortality such as circadian distributions of myocardial infarction rates or the association of malignant arrhythmias/sudden cardiac death with season, climate, weather and magnetic fields gives rise to such implications [7, 8]. When considering an influence of electrical fields on the human heart, these could be mediated by various phenomena such as diathermy, displacement currents, electrophoresis and electro-osmosis, micro-vibrations, piezo-resonances, local charge accumulation, control of mechanoreceptors, Josephson effects on membranes, coherence principles with resonance in the α -dispersion range and others.

The multitude of such possible mediators may explain the difficulty in assessing direct cause and effect chains – in other words, summary vectors may bring about very heterogenous responses in different subjects. However, the latter may be well expressed in heart rate variability and, using non-linear algorithms, these may be decoded one day and serve as an important and highly sensitive diagnostic tool (see below).

Strong, Weak and Ultraweak Magnetic Fields

If one considers, however, aspects of the electric field strength and the electromotive force, as reiterated above, it has to be mentioned that movement of charges usually generates an additional force K_m , that can be defined as a magnetic field. That can be described as

$$\vec{K} = \vec{K}_e + \vec{K}_m = q \times \vec{E}(r,t) + q \times \frac{\vec{v}}{c} \times \vec{B}(r,t)$$

where $\vec{B}(r,t)$ is the known magnetic induction, $\vec{K}$ the force on a known charge q moving at a particular velocity v over the absolute velocity of light c . Magnetic induction, however, has no source, whereas electrical fields originate from charges ($\text{div } B = 0$) and B is induced by moving charges and may as well exert forces on moving charges themselves – specifically on circular atomic currents, hence being

$$\vec{B}(\vec{r}) = \frac{1}{c} \int \vec{j}(\vec{r}') \times \frac{(\vec{r} - \vec{r}')}{|\vec{r} - \vec{r}'|} dv'$$

where $\vec{j}(\vec{r}')$ is the current density and the most simple description of magnetic interactions would be

$$\vec{m} = \frac{1}{2c} \int \vec{r} \times \vec{j}(\vec{r}') dv'$$

where $\vec{m}$ is the magnetic moment in analogy to the electric dipole moment. Then, the density of magnetic moment

$\frac{1}{2c}(\vec{r} \times \vec{j})$ is, because of $\vec{B}(\vec{r}) = \frac{1}{c} \int \vec{j}(\vec{r}') \times \frac{(\vec{r} - \vec{r}')}{|\vec{r} - \vec{r}'|} dv'$, a measure of

the specific magnetisation occurring at the position of $\vec{r}'$. If $\vec{B}(\vec{r})$ is weakened, diamagnetic substances occur at the position. Practically all organic and inorganic substances (except free

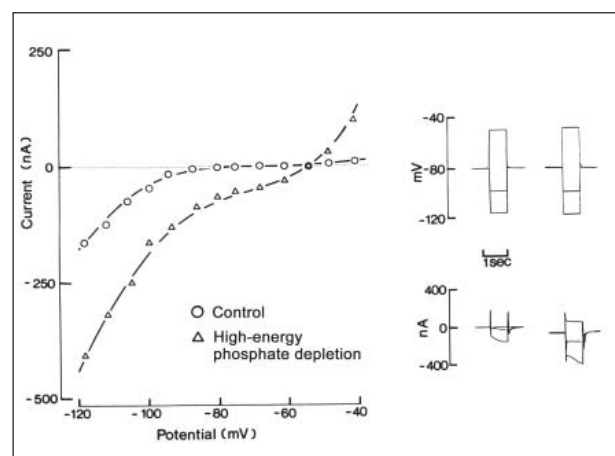


Figure 1. Ischaemia-induced increase of open-probability of voltage gated ATP-dependent K-channels during high-energy phosphate depletion verified using luciferin-luciferase technique. Slope-conductance of isochronal current-voltage relationship of a voltage-clamped sheep Purkinje strand from own experiments. The experiment indicates high energy phosphate dependence of gating properties of certain subjects of transmembrane channels. Modified after [6].

radicals and some transition elements) are diamagnetic. In this setting, each electron behaves at the Larmour frequency

$$\omega = \frac{e \times B}{2c \times M'}$$

hence giving rise to

$$|\vec{m}_D| = \left| \frac{e^2 \times B}{4c^2 \times M} \times r^2 \right|$$

where r represents the mean orbital radius and $\vec{m}_D$ represents an additional magnetic moment. The magnetic moments no longer compensate for each other but weaken the applied field taking up energy. This effect is, however, attenuated, hence magnetic fields, unlike electric fields, are able to penetrate deeply into organisms. On the other hand, some salts, transition elements, oxygen and free radicals are paramagnetic dipoles. These tend to strengthen the applied field and the radiation of an alternating magnetic field of an adequate frequency

$$v = \frac{\Delta U}{h} = \frac{\Delta m \times B}{h}$$

then leading to the stimulation of states with energetically unfavourable orientation in nuclear magnetic resonance spectroscopy [9]. Already very early authors have alluded to the fact that resonance stimulation of the nuclei and/or electrons of paramagnetic states like spin waves could underlie the biological effects caused by magnetic fields: in 1964, Barnothy already listed numerous such effects on biological systems [10–15]. Various effects are also seen in the cardiovascular system, eg, the aortic flow, the conduction system and the ECG and may also play a role in public health and diagnosis of ischaemic heart disease [10–15].

For example, different magnetic fields are applied during the sequences of magnetic resonance imaging. Measurements use an initial strong magnetic field up to several Tesla followed by rapidly switched magnetic field gradients followed by radio frequency fields. Such an imaging procedure causes interactions between these electromagnetic fields and the body, possibly causing heating and tissue damage, on the other hand switched magnetic field gradients can stimulate electrically excitable tissue and can also be sensorically perceived. At so called hot spots, current densities at extremely high frequency J_{AM} can be calculated as

$$J_{Am}(t) = \sum_{i=1}^n \left(\frac{a_i \times J_{Am,i} \times \cos(\omega_i t + \varphi_i)}{\sum_{k=0}^n |a_k|} \right) + \sum_{j=1}^n \left(\frac{b_j \times J_{Am,j} \times \sin(\omega_j t + \varphi_j)}{\sum_{k=0}^n |b_k|} \right)$$

Using a Fourier series-expansion of typical gradient wave forms (calculating the eddy currents [16]) one can study how, for example, different wave-forms of the switched gradient field influence strength and direction of induced currents.

While, on the one hand, the main focus of such techniques has been directed to imaging and diagnostic purposes up to now, one may anticipate that, on the other hand, deeper understanding of electromagnetic/quantum physical properties of animated matter (biological and biophysical processes) would inevitably lead to the therapeutic use of defined electromagnetic- and radio-waves: Such exposure to calculable, locally induced currents may cause elicitation of specific, predictable biochemical and biophysical reactions in deeper layers of the tissue. Or, in more simple terms, understanding the coherent wave structure of the quantum physical alterations within defined time segments during biochemical/biophysical cellular reactions, one may be able to influence those directly using waves (electromagnetic/radio/photons) instead of matter (chemicals) [17, 18]. However, during the recent

years, important work has been published which contributes to this understanding.

Hypothetical Concepts of Quantum-Control of Biological Systems

In 1983, Pitkänen defended a remarkable thesis [19], attributed as “Topological Geometrodynamics” as an attempt to unify fundamental interactions by assuming that physical space-times can be regarded as submanifolds of a certain 8-dimensional space, which itself is a product of the Minkowski space future light cone and a 4-dimensional complex projective space CP_2 . In this theory, Pitkänen obtains a generalization of the string model by replacing 1-dimensional strings with 3-dimensional surfaces. In other words, he attempts to construct a Poincare invariant theory of gravitation (Poincare’s group acts by imbedding space rather than on space-time surface). The Pitkänen theory reveals a radical generalization of the concept of space-time applicable to various fields of physics and biology. Topological Geometrodynamics predicts how biological formations appear as macroscopic quantum systems.

In this context, ionic flow equilibrium in many-sheeted space-time provides a rather concrete view about biocontrol and coordination, thus explaining several unclear findings of cellular biology and biophysics. In this context, one should refer to the experimental work of Ling and others who challenge the classical theory of transmembrane ion movement. Ling has demonstrated that the ionic concentrations of a metabolically deprived cell are not changed at all and questions the assumed mechanisms of ion-channels and ionic pumps [20]. However, my own work, extensively related to transmembrane ion transport in metabolically deprived cardiac cells and vascular smooth muscles, is in disagreement with Ling’s observations [6, 21–23]. Using luciferin-luciferase as a marker for metabolic depletion, we have clearly evidenced increased transmembrane outward current through ATP-dependent K-channels even in early myocardial ischaemia [6]. Figure 1 shows slope-conductance of ischaemia-induced increase of open-probability of voltage gated ATP-dependent K-channels from a set of own experiments. The curve shows the isochronal current-voltage relationship of a voltage-clamped sheep Purkinje strand.

The work of Sachs, Qin and others, based on patch-clamp technique, shows that the quantal ionic currents through cell membranes remain essentially undisturbed when the membrane is replaced by a silicon membrane or by a cell membrane purified from channel proteins [24–26]. I will like to remark that practically all transmembrane conductances are heavily dependent on voltage and modified by certain proteins or ions. Figure 2, for example, shows results of own experiments, where the slope conductance of a Purkinje strand increases when extra-cellular Mg is reduced. The isochronal current-voltage relationship changes and the outward current increases at depolarised potentials, whereas the presence of 0.3 mM barium decreases the slope conductance to the same values regardless of the presence and absence of Mg_0 , which argues for a complex response of transmembrane ionchannels to various molecular, atomic and subatomic influences. The observations of Sachs and Qin, however, gave rise to other speculative models for transmembrane ion channels taking quantum physical properties of small currents into account: Pitkänen [27], for example, regards the homeostasis of the cell and its exterior as an ionic flow equilibrium based in the multi-sheeted spacetime. In his view, ionic super currents flowing from superconducting,

controlling spacetime sheets flow to controlled atomic spacetime sheets and back. These currents are ohmic at the atomic spacetime sheets. Thus, extremely small ionic densities and super currents at cellular spacetime sheets can control ionic currents and also higher ionic densities at atomic spacetime sheets. Immense savings in metabolic energy would be achieved, if the ohmic currents at the atomic spacetime sheets flow through the cell membrane region containing the strong electric field along the superconducting cell membrane spacetime sheet (rather than atomic spacetime sheets) as a non-dissipative supercurrent. Superconducting spacetime sheets thus are supposed to contain a plan of the biosystem coded to ion densities and magnetic quantum numbers characterizing the super currents. Electromagnetic fields inherently affect these super currents.

The model of Pitkänen [27], however, relies crucially on the liquid crystal property of animated matter, making ohmic current circuitry possible at the atomic spacetime sheets as a part of the many-sheeted control circuitry. However, our own observations of complex reactions of ionchannels to other ions and the dependence of specific channels (K_{ATP} -channels) on cellular energetic levels (c.f. high energy-phosphate depletion [6]) are not necessarily in contrast to Pitkänen's theoretical quantum physical concept of ionchannels, on the contrary, especially ionic, atomic and subatomic effects upon ionchannels re-iterate the vision of many-sheeted control circuitry, however, on a possibly more complex level than suspected by Pitkänen.

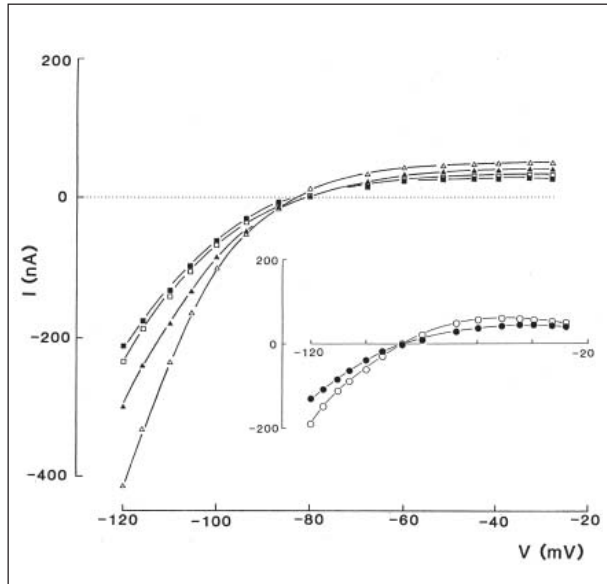


Figure 2. Results from own voltage-clamp experiment using isolated cardiac sheep Purkinje strands, where the slope conductance increases when extra-cellular Mg (Mg_o) is reduced. The isochronal current-voltage relationship under control conditions (filled triangles) changes after reducing Mg_o to near zero (open triangles) and the outward current increases at depolarised potentials. The presence of 0.3 mM barium decreases the slope conductance to the same values regardless of the presence (closed squares) and absence of Mg_o (open squares). Inset: open circles: Ba_o -sensitivity of current-voltage relationship in the absence of Mg_o , ie, the difference between Mg_o sensitive current and Barium-inhibited current-voltage relationship at near 0 Mg_o ; filled circles: Mg_o -sensitive current-voltage relationship, ie, difference between control and the current-voltage relationship at Mg_o near 0 mM. It can be seen clearly that changing concentrations of extracellular divalent cation concentrations affect transmembrane conductance through voltage gated ion channels.

Predictions Derived from Non-Linearity in Cardiovascular Medicine

In cardiology, one could postulate in this context a general system theory for self-organization of fluctuations which would give the following model predictions. Space-time integration of small-scale fluctuations can, as outlined above, give rise to an overall logarithmic spiral trajectory with the quasi-periodic Penrose tiling pattern for the internal structure. The logarithmic spiral trajectory can also be resolved as a hierarchical eddy continuum with progressive increase in phase. Embedded in the eddy continuum one may find dominant wavebands, the bandwidth inherently increasing with period length. Furthermore, dominant peak periodicities are functions of the golden mean and elicit cycle associated biological rhythms [28–30]. Since cumulative integration of enclosed small scale fluctuations results in large scale fluctuations, the eddy energy spectrum follows inverse power law form of statistical normal distribution according to the “Central Limit Theorem”. The square of the eddy amplitude or the variance represents the probabilities. Such a result, that additive amplitudes of eddies, when squared, represent probability densities, is observed in the subatomic dynamics of quantum systems such as the electron or photon.

The dynamics of spacetime fractal fluctuation pattern formation, therefore, follows quantumlike mechanical laws, consistent with El Naschie's concept of cantor fractal characteristics for quantum systems [31]. Important advances can also be seen in quantum-physical aspects of biophysics and in recording and storage capacity of massive datasets of continuously fluctuating, non-linear, non-stationary and non-equilibrium-like signals. While these techniques and advanced understanding of biophysics in its non-linearity have progressed immensely, tools to analyse fluctuating data still often assume linearity, stationarity and equilibrium-like conditions. Only very recently, it has been understood, that such complex datasets may contain further information about the patient's condition and his prognosis (eg, sudden cardiac death, severity of heart failure etc.). However, such background leak information becomes extractable from physiological time series: In particular, the absence of characteristic temporal or spacial scales, which constitutes the salient characteristic of fractal behavior, indicates information concerning the adaptability of response – in other words: a “global fitness” parameter (c.f. Figure 3 and adjacent figurelegend).

Mathematically, a fractal process entails both self-similarity and fractional dimensionality. For self-similar processes, fluctuations grow exponentially, hence, a large observation window time series is unbounded. In this context, fractal scaling analysis and detrended fluctuation analysis (DFA) have been established as a powerful decoding tool. The clinical utility of DFA has been documented in several studies: Mäkikallio and colleagues, for example, demonstrated that DFA of HRV may predict subsequent ventricular tachycardia after myocardial infarction [32, 33] and also can predict mortality of patients with heart failure [34].

Predictions can also be made, concerning vascular causes of death, progression of coronary artery disease and arrhythmic death. It has been shown clearly, that new analysis methods based on non-linear dynamics may be more powerful in terms risk stratification [35]. Furthermore, real-time analysis of HRV in critically ill patients provides additional information about patient status, effects of intervention and prognosis [36]. In summary, heart rate spectral analysis and DFA of HRV constitute a powerful non-invasive tool for quantifying autonomic nervous system activity and responsiveness yielding important information about sino-atrial response to auto-

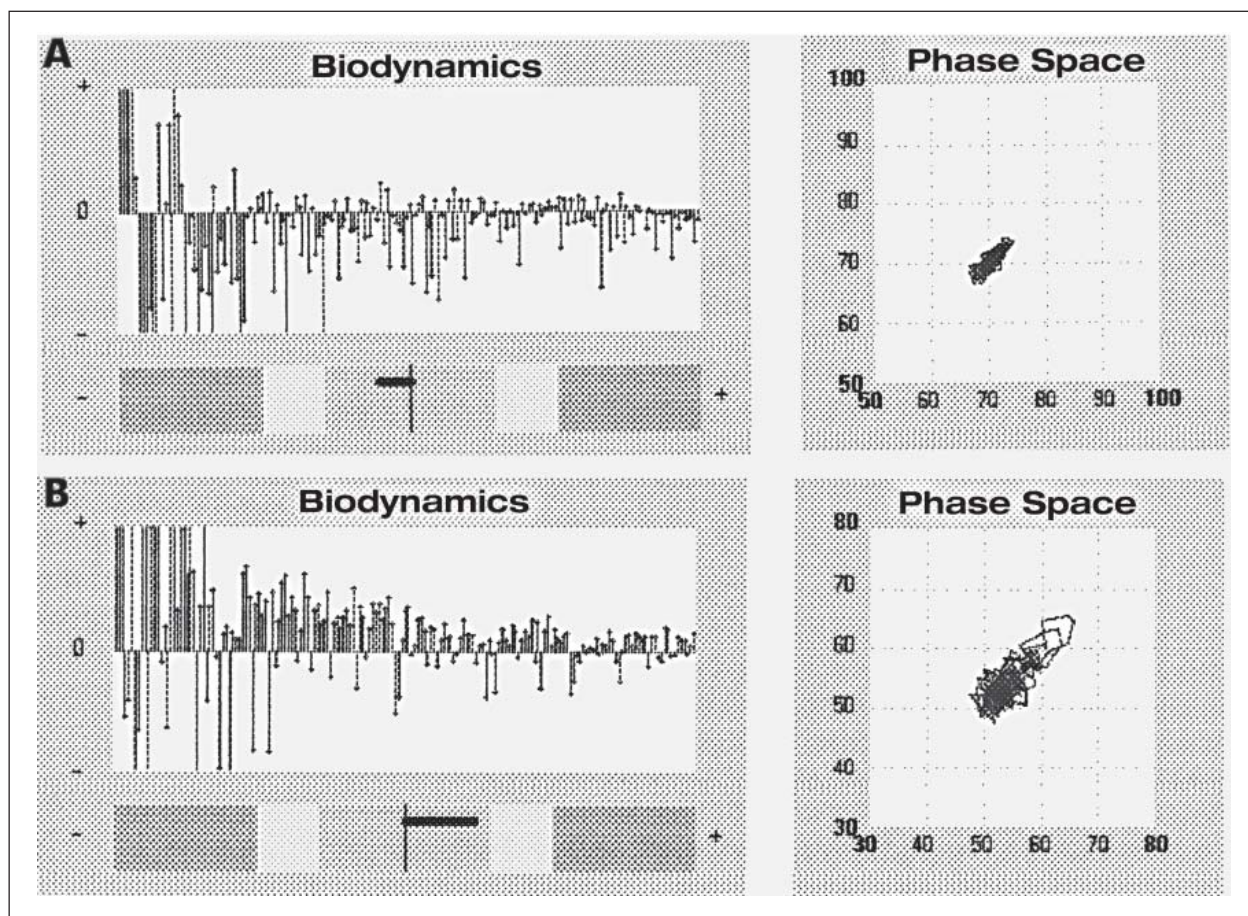


Figure 3. Phase space and biodynamics using an high resolution HRV system (Pro-Quant-System®, surface and development by Senekowitsch et al.) in a patient with metabolic syndrome (hyperlipidaemia, overweight and hypertension). **A:** before and **B:** two months after transdermal and transalveolar application of “energetically” activated ions from purified Dead Sea-salt using a specific moist chamber (Vita Salin Vital Kabine®) initially developed for wellness purposes. The inset “Biodynamics” represents a graphical description of real heart rate variability values sampled over a mean time frame using the Lyapunov-exponent, which describes the exponential convergence, neutrality or divergence of close matched phase space (right inset) characteristics. The phase space represents a graphical concept which can display effects of different trajectories. Heart rate variability expressed in this way is extremely sensitive to various trajectories since it represents the terminal product of autonomous response to minimal trajectory effects. In other words: it is likely that minimal effects of alternating space-time sheet flow on controlled atomic space could produce visible and calculable effects in the phase space visualised using the Lyapunov-exponent. In more practical terms: In this patient, the exposure to “energetically” activated Dead Sea-salts improved the mathematical “global fitness” parameter, increasing the phase space – subjectively, the patient felt “generally better”.

nomic input as a biophysical surrogate for complex autonomous signal proceeding and interaction [37, 38]. Routine application of DFA in high resolution HRV to clinical cardiovascular medicine needs further investigation. Nevertheless, it is likely to become an important procedure in cardiovascular risk stratification in the years to come.

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