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Cardiac torsion and electromagnetic fields: The cardiac bioinformation hypothesis

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Summary Although in physiology the heart is often referred to as a simple piston pump, there are in fact two additional features that are integral to cardiac physiology and function. First, the heart as it contracts in systole, also rotates and produces torsion due to the structure of the myocardium. Second, the heart produces a significant electromagnetic field with each contraction due to the coordinated depolarization of myocytes producing a current flow. Unlike the electrocardiogram, the magnetic field is not limited to volume conduction and extends outside the body. The therapeutic potential for interaction of this cardioelectromagnetic field both within and outside the body is largely unexplored.

It is our hypothesis that the heart functions as a generator of bioinformation that is central to normative functioning of body. The source of this bioinformation is based on: (1) vortex blood flow in the left ventricle; (2) a cardiac electromagnetic field and both; (3) heart sounds; and (4) pulse pressure which produce frequency and amplitude information. Thus, there is a multidimensional role for the heart in physiology and biopsychosocial dynamics.

Recognition of these cardiac properties may result in significant implications for new therapies for cardiovascular disease based on increasing cardiac energy efficiency (coherence) and bioinformation from the cardioelectromagnetic field. Research studies to test this hypothesis are suggested.

Introduction

In addition to its resemblance to a simple piston pump, the heart exhibits two other properties that we hypothesize are important. First, the heart as it contracts in systole also rotates producing torsion, which was recognized by both Artistotle and Harvey [1]. Second, the heart produces a significant electromagnetic field with each contraction due to the coordinated depolarization of myocytes producing a current flow. This electrical activity can be detected throughout the body due to volume conduction of the current. The magnetic field however, is not limited to volume conduction and extends outside the body. The role of interacting magnetic field effects outside the body is largely unexplored. It is our hypothesis that the heart functions as a generator of bioinformation that is central to normative

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functioning of body. This bioinformation is derived from the vortex pumping action of the heart and the cardioelectromagnetic field.

This hypothesis will be examined from the aspect of the anatomical and experimental studies of cardiac muscle structure that produce torsion and vortex blood flow during normal contraction. Then, we address the cardiac magnetic field both in terms of measurement techniques and its clinical applications to date. By providing a unifying hypothesis, we draw attention to the multidimensional role of the heart that will stimulate additional research and expand our therapeutic strategies in cardiovascular disease to include modalities that impact the cardioelectromagnetic field and cardiac coherence.

Cardiac rotation during pumping

The analogy of the heart action to a piston pump is well described. Thus, cardiac function is most commonly expressed as an ejection fraction. At this most basic level, the physiologic purpose of cardiac pumping is to provide the energy to circulate metabolites throughout the body. The focus of current diagnostic evaluations and therapies is limited to maintaining cardiac pump function and does not address the additional rotational component of cardiac contraction.

Cardiac muscle structure with its multilayer design results in an obligatory pattern of rotation during cardiac contraction. The twisting motion of the heart is a function of the layers of cardiac muscle fibers, which are obliquely oriented in three major layers [2]. Buckberg has written extensively about the helical muscle structure of the heart which has a circumferential basal loop that then becomes an oblique double helix forming the apical loop [3] as shown in Fig. 1.

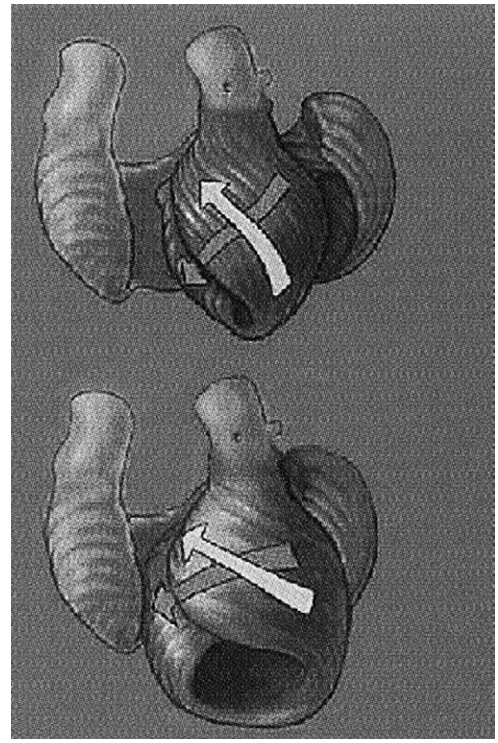

Figure 1 The fiber orientation of the basal and apical loops is shown for the normal heart (top) and the failing heart (bottom). Note that the circumferential basal loop is not changed, but that the 60° oblique fiber angle in the normal heart is made more transverse in heart failure. The apical loop in the failing heart develops a more basal loop configuration (from Buckberg GD, Coghlan HC, Torrent-Guasp F. The structure and function of the helical heart and its buttress wrapping. V. Anatomic and physiologic considerations in the healthy and failing heart. *Semin Thorac Cardiovasc Surg*. 2001;13:358—85. Reprinted with permission of WB Saunders.).

This fiber band orientation has a functional counterpart in the contraction sequence within the myocardium. Thus, when the normal heart beats there is sequential torsion, or twisting, to shorten the slope and make the long axis more longitudinal, while simultaneously thickening the muscles to compress the intraventricular contents. This four part motion can result in a 30% increase in ejection fraction [4]. The magnitude and direction of cardiac rotation has been examined in heart transplant patients. Postoperative imaging of radiopaque markers showed that during ventricular ejection there was counterclockwise twisting about the left ventricular long axis (viewed from apex to base) [5]. Since most anatomic structural designs are uniquely related to function is it interesting to speculate on the purpose of this rotational cardiac contraction component. Torsional deformation probably does not contribute significantly to kinetic energy stored for cardiac ejection [6]. An alternative hypothesis might be that torsional deformation contributes to the formation of vortex blood flow in the heart as discussed below.

A vortex flow can be described as a fluid structure that possesses circular or swirling motion that involves three dimensional flow information [6]. The cardiac blood pool undergoes vortex formation as part of the directional change required for the blood entering the left ventricle from the atrium to exit through the aortic valve. Kim et al. [6] confirmed the presence of diastolic vortex formation in the human left ventricle using magnetic resonance velocity mapping. In this study, the motion of the anterior mitral leaflet promoted the development of a ventricular vortex flow that was directed in an anterior and counterclockwise motion during diastole. Kilner et al. [7] also recorded flow images with large-scale flow features and major changes in the direction of blood flow within the heart that recurred repeatedly through successive beats. The authors propose that the relatively coherent swirling of the blood might avoid excessive dissipation of energy by limiting flow separation and instability. These two studies clearly show that the cardiac blood pool forms a vortex related to valve leaflet motion.

The magnitude and direction of ventricular torsion are not constant and depend on a combination of local ventricular geometry, fiber architecture, compressibility, contractility, wall thickness and an inverse relationship to LV cavity volume [8]. The healthy heart responds with auto-adjustments of contractility, compliance and structure to create flow patterns and interrelations appropriate to this morphodynamic heart action. These flow patterns in turn could transmit information on the energetic status of the heart to the rest of the body via the circulatory system. The anatomy of the aortic valve and aorta contribute to the continuation of the cardiac vortex flow pattern in the extracardiac circulation [9]. The helical nature of the aorta as it bends around the pulmonary artery may also favor rotary flow [10,11].

The cardioelectromagnetic field

The cardioelectromagnetic field is the second main component of our hypothesis that the heart produces multidimensional bioinformation. The heart produces a magnetic field in the body due to the organized electrical depolarization and repolarization of cardiac myocytes. The electric currents in the human body produce time-varying vector oriented magnetic signals. These can now be measured with SQUID technology (superconducting quantum interference devices). The heart produces the largest magnetic field in the body at $50{,}000 \times 10^{-15}$ T (tesla) compared to the brain signal of only a few 10^{-15} T [12]. The magnetocardiogram measured by the SQUID records the magnetic field induced by the same bioelectric currents that generate the electrocardiogram and provides further information about heart function beyond the standard electrocardiogram (ECG) [13]. The magnetocardiogram simultaneously provides three types of information: arrhythmia localization from electrophysiological data, metabolic data on viability, and a spatial-temporal correlation between the ischemic and arrhythmogenic areas [14].

Cardiac bioinformation theory

It is our hypothesis that the heart functions as a generator of bioinformation that is central to normal functioning of body. Russek and Schwartz [15] provide a general description of these concepts linked to biological systems with special reference to the heart. They point out that the heart generates patterns of energy including electrical, magnetic, sound, pressure, temperature and electrostatic energies. Furthermore, these heart based signals occur with different temporal patterns and frequencies. This allows one to speculate on the role of carrier waves or harmonics as a unifying principle and reference pattern compared to patterns of bioinformation from non-cardiac sources. These specific units of information become more difficult to interpret when there is more disturbance of the underlying reference wave [16] as shown schematically in Fig. 2.

Our hypothesis of cardiac bioinformation includes four aspects of cardiac energy; cardiac torsion (myocardial rotation and vortex flow

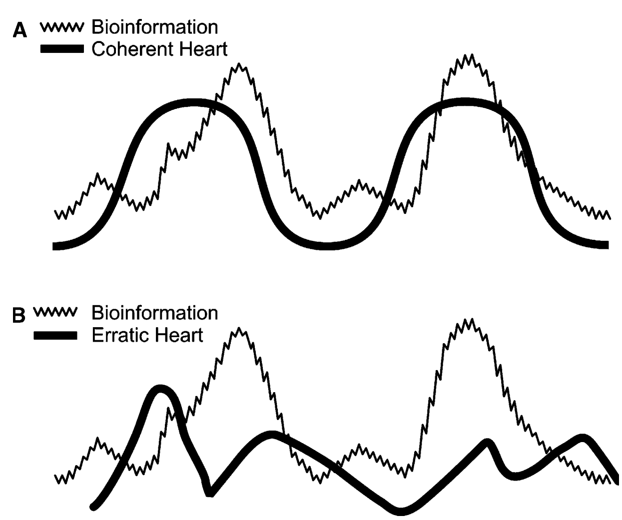

Figure 2 Heart based signals as a reference wave. (A) Coherent cardiac heart rate variability and contraction provides a uniform functional reference signal for interpreting the magnitude and frequency information of other non-cardiac bioinformation signals. (B) The same non-cardiac bioinformation signals lose definition without the stability of the underlying cardiac energy pattern.

patterns), cardioelectromagnetic fields, heart sounds, and pulsatile flow patterns. The interactive features of these four aspects of cardiac energy are now discussed with reference to our hypothesis that the heart is a source of multidimensional bioinformation.

Cardiac torsion

Our previous discussion details how the heart follows a helical contraction pattern resulting in torsion that is affected by subclinical changes in cardiac function. We also postulate that torsion as a function of cardiac physiology contributes information to the cardiac magnetic field by changing the electrical potential of cardiac myocytes thus changing the cardioelectromagnetic field.

Cardiac electromagnetic fields

The heart is the single largest bioelectrical source in the body and produces surface potentials significantly larger than those produced by nerve and skeletal muscle [17]. We postulate that the cardiac magnetic field, due to its size, is an important component of the bioenergetic field that impacts both the internal organization of the human body as well as the interaction between two or more humans and other living organisms. Studies evaluating the interaction of the electromagnetic field in this way use the ECG as a surrogate marker of the cardioelectromagnetic field. Other measurements of electrical activity in the body such as the electroencephalogram (EEG) have to subtract out the ECG signal, which is considered an artifact. Analysis of the process for subtracting the ECG artifact from the EEG reveals two subtle but important points that support an interactive effect between the magnetic fields throughout the body [18]. First, the subtraction method does not remove the entire ECG signal from the EEG because of interactive effects between the two magnetic fields. Second, the R spike shows a different topological pattern from different locations of the brain as influenced by the electromagnetic activity of the brain.

Heart sounds

Everyone is familiar with the two component sounds of the heartbeat. These sounds come primarily from the sequential closing of the mitral and aortic valves. The heart sounds are so ubiquitous that they are almost ignored when, in fact, they provide a continuum of sound and vibrational energy for the whole body throughout the entire lifespan. The biggest vibration (measured by seismograph) occurs with the ejection of blood from the left ventricle [16]. The pulse pressure wave of blood traveling down the aorta with each heartbeat is reflected back from the aortic bifurcation at the iliac junction. This reflected wavefront forms an interference pattern. According to Bentov [16], the heart and aorta together form a resonant system where the length of the aorta is equal to 1/2 wavelength when the system is in resonance. The heart rhythm can be changed by changing our respiratory rate as in meditation [19]. Conditions, where the heart beat coincides with the wave pattern of blood being reflected back from the iliac bifurcation creates a resonance at about seven times a second with an amplitude almost three times the normal signal. An important characteristic of resonant systems is that they are sustained with a minimum amount of energy. This concept is expanded in the section on cardiac coherence effects discussed below.

Pulsatile flow patterns

Heart pulsations have amplitude (pulse pressure) and rhythm that interact with rheologic blood flow properties such as viscosity, turbulence, and the shape of cellular elements. Every cell endowed with a vascular supply is provided with information from the timing, amplitude and direction of these blood flow signals. The rotational and energetic contraction patterns of the heart also affect the quality of pulse pressure presented to the aorta and vascular systems. Clinical studies have shown that the pulsatility of the ascending aorta is a strong predictive factor for restenosis after coronary angioplasty [20]. Changes in reflected pulse waves and vascular compliance serve to augment diastolic pressure to the coronaries [21].

Conclusion

In summary, cardiac contraction generates a vortex flow as well as volumetric pumping. In addition, the cohesive electrical activity of the cardiac muscle creates an electromagnetic field with every heartbeat. Thus, there is a multidimensional role for the heart in physiology and biopsychosocial dynamics. Based on this hypothesis, we must broaden our areas of research and therapeutics in order to completely understand the significance of cardiac function in health and disease.

Implications of this hypothesis

Cardiac coherence — a unifying mechanism for generating optimal bioinformation

The beating heart produces electromagnetic, acoustic, and pulsatile signals that provide an information field for the entire body. The cardiac field effects are bi-directional because they extend outside the body. There is a field effect generated by the heart and there are outside field effects from other electromagnetic systems that impact upon this same heart. Heart rhythms can be linked to other basic rhythmic physiologic activity such as the breath cycle, the blood pressure and EEG in a process called cardiac coherence [22]. For purposes of discussion let us expand the term cardiac coherence to represent the common linkage point between the information field the heart generates and the information field to which it is exposed.

It is likely that increased cardiac coherence will have a direct effect on cardiac contractility and overall left ventricular function. The cardiac contraction pattern is responsive to a variety of physiologic signals. After the initial electrical stimulation, the cardiac muscle, like skeletal muscle, can adjust its energy cost to the prevailing mechanical constraints such as filling pressure, afterload, and perhaps, coordinated muscle geometry [23]. Furthermore, we know that cardiac ischemia has significant effects on the dynamics of cardiac apex rotation due to changes in the transmural muscle balance [24]. Conversely, improving the torsion or rotational parameters of the heart may have a beneficial effect of cardiac contraction in the presence of ischemia or hibernating myocardium. All of these observations support a role for changes in cardiac torsion and the electromagnetic field as an indicator of the overall status of heart energetics that in turn may be transmitted throughout the circulatory system.

Cardiac coherence may have an important interface with a variety of complex biological systems. Multidisciplinary fields such as psychoneuroimmunology point to the interconnectedness of physiologic processes that are not localized to specific organs. For example, inflammation is not always a response to a specific microbial or viral agent but it also seems to be a ubiquitous condition related to biochemical processes of fatty acid metabolism and oxygen radical formation. Much of genomic research is focused on finding heterozygous alleles or polymorphisms that may predispose to certain diseases. Yet, the actual incidence of disease varies based on unique individual adaptations and the interaction of environmental factors such as diet and chemical exposures. The cardioelectromagnetic field may be another factor that contributes to the interconnectedness of biologic systems and influences such diverse mechanisms as regulatory proteins, receptor binding, and cellular metabolism. The systemic changes that result might include reduced inflammation, improved circulatory efficiency, and improved cellular responsiveness.

Therapeutic implications

There are limitations to our current therapies for heart disease. It is well known that a certain percentage of cardiac events cannot be explained by traditional risk factors [25]. Equally, puzzling is our inability to predict the timing of events or of the location of the cardiac culprit lesion for a heart attack based on stenosis severity. There are several examples where the pharmaceutical approach to treating cardiovascular disease has been unsuccessful. We have been unable to find an inotropic stimulant that improves cardiac function without increasing mortality [26] and antiarrhythmics have also resulted in increased mortality even though the index arrhythmia was better controlled [27]. The therapeutic strategy to antagonize activated neurohormonal systems may have adverse effects as well as advantageous ones [28]. Pharmaceuticals are reaching the limit of therapeutic potential due to the complexity of drug interactions that can detract from the intended benefit of the intervention [29]. All of these observations suggest that it may be time to shift our research to adjunctive non-pharmacologic therapies of cardiovascular disease. Our hypothesis provides a framework for emphasizing non-pharmacologic therapeutic options in at least three areas related to heart disease: flexible biological systems, cardiac coherence to augment contractility, and optimizing the cardioelectromagnetic field.

The interaction between cardiac contraction, electromagnetic field effects and circulatory bioinformation suggests that the heart is part of a complex flexible biologic system that is designed to register sensitive changes in biochemical and energetic field effects. The current goal of cardiac risk reduction focuses on reaching specific static target levels for blood pressure, glycemia, and cholesterol by adding artificial constraints and receptor antagonists. Our hypothesis supports a new view of normal cardiac function that must include components of flexibility and responsiveness to the variety of homeostatic challenges that confront us throughout the day. In this view, the problem is not only the elevated levels of blood pressure and cholesterol but the fact that these levels are fixed and do not vary. Several examples in the clinical literature already support this viewpoint that therapeutic benefits are derived from flexible and responsive systems. There are circadian and other time-based variations in the incidence of adverse vascular events such as myocardial infarction, stroke, and sudden death [30,31]. A flexible system allows a range of responses to daily fluctuations in biochemical processes. Recent studies show a major role for responsiveness of the autonomic nervous system in cardiovascular health. A decrease in heart rate variability (HRV) carries a poor prognosis both in heart failure and in ischemic heart disease, as well as being a predictor of arrhythmic cardiac death and myocardial infarction [32,33].

Several of the current cardiovascular therapies are designed to increase coherent cardiac contraction as a mechanism to increase cardiac function. For example, one of the purposes of angiotensin converting enzyme inhibitor therapy post myocardial infarction is to reduce ventricular remodeling which decreases cardiac function primarily due to contraction asynergy. A relatively new therapeutic intervention is biventricular pacing. Biventricular pacing restores a more coordinated contraction pattern that has been shown to significantly improve ventricular function [34]. Our hypothesis predicts that energetic modalities that enhance the cardiac coherence and thus the cardioelectromagnetic field could also improve the therapeutic response of our standard interventions.

The cardioelectromagnetic field is the third area that may be a new therapeutic option as a result of our hypothesis. The cardioelectromagnetic field reflects the directional currents of organized cellular contraction in the myocardium. Interventions that increase the coherence of cardiac contraction would therefore be expected to increase the cardiac magnetic field as discussed above. Mind-body activities such as meditation, deeper rhythmic breathing, Qi gong, and heart focused stress reduction techniques might also increase the cardioelectromagnetic field. Meditation has been shown effective in reducing blood pressure and reducing chest pain in patients with coronary artery disease [35,36]. Part of this effect may be due to changes in the breathing pattern. The use of magnetic fields for therapeutic purposes is not without precedence. Electric and electromagnetic fields have been used for bone fracture healing since the early 1970s [37]. Our hypothesis provides the framework for initiating more complete studies in the therapeutic role of the cardioelectromagnetic field.

Future research directions

Future studies need to evaluate the effect of not only the volumetric pumping, but also the electromagnetic field of the heart and the information patterns carried by the blood, such as sound vibrations, pulse pressure, temperature, and viscosity. One such study would be to evaluate the effect of changes in cardiac torsion or contraction patterns and its effect on vortex blood flow. For example, biventricular pacemaker settings could be changed experimentally to modify contraction patterns and quantified by harmonic echocardiographic imaging [38] and then the vortex blood flow patterns evaluated by repeating the imaging studies referenced above.

Research related to our hypothesis needs to address the question of whether meditation and mind-body techniques can change the cardioelectromagnetic field. Cardio-pulmonary function is related to energy delivery based on changes in HRV and respiration [39]. Mind-body relaxation techniques and meditation can be used to modulate the breath and heart rate such that a resonance occurs and the interference pattern is minimized to optimize this cardiac energy delivery. SQUID technology can be used to perform current density reconstructions in vector fields specific to a given volume element or surface element for precise measurements of cardiomagnetics [40]. In clinical research applications it may be more appropriate to use intermediary markers of overall health patterns such as inflammation and HRV as outcomes. For example, exercise training, breathing exercises, and meditation can all be shown to increase HRV [41,42]. These studies will need to be multidisciplinary in nature and draw heavily on prior work in the field of mind-body medicine for techniques designed to increase the cardiac coherence. The ultimate goal remains the same; the reduction of traditional cardiac outcome events and the reduction of morbidity from cardiovascular disease.

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