II. Electrical Properties of Meridians

With an overview of the electrodermal screening test

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The electrical properties of acupuncture points have been studied extensively [1-3]. It has been shown that more than 90% of skin points of particularly high conductivity coincide with traditional acupuncture points [4-6]. An important outgrowth of these discoveries was the development of the electrodermal screening device (EDSD), test (EDST), and system (EDSS). Research in the energetic properties of the skin has continued, including the successful imaging of meridian and acupuncture point activity [7] and imaging of various human biological energetic properties, including infrared thermal, radiothermal, acoustothermal, electric, and magnetic radiation and chemiluminesence [8].

In early studies, the stratum corneum and epidermis as a whole are generally described using a frequency independent RC-parallel circuit. Deep tissue, or dermis, is understood to be a pure resistance (Fig. 1). Further advances in the model included skin and interface potentials in considering the electrolyte effect [9], which in turn brings about ionic motion in response to the applied voltage [10,11], but the model remained essentially the same. The old model contains only passive elements, which can not adequately describe the activity of living organisms. It does not include a response mechanism of the measured meridian, and therefore can only elucidate responses where meridian function is not a major aspect. Beginning in 1988, I tried to construct a new model based on a systematic conceptualization that included the active elements found in living organisms. The result was a model that can generate possible response currents that qualitatively and quantitatively match all known clinical data.

Body's Response to Small DC Stimulation

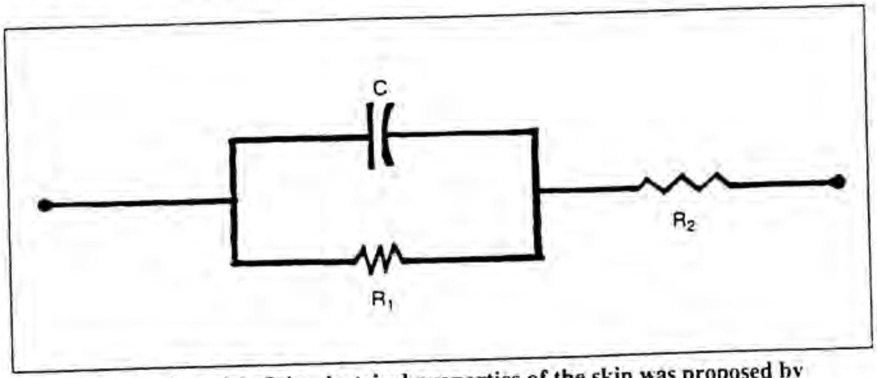
The old model fails to adequately describe measured phenomena because it is based on two restricted assumptions: 1) that a living organism can be modeled using only passive elements, and 2) that the electrical current passes only through skin and not through other tissues. Both traditional meridian theory and my experience suggest just the opposite, that active responses are involved and that the current passes through many parts of the body. In reality, a weak electrical DC stimulus evokes three mechanisms in the body: electric conduction, dielectric polarization, and self-regulation by an organic defense system. The first two are physical and the third is biological.

The moment that a direct current of about one volt is applied to two electrodes attached to the skin, such as during the EDST, electrons and ions propelled by the circuit begin to move through the body. The mobility of electrons is influenced by cellular metabolism and the concentration of charged particles suspended in body fluid. The net effect can be described using a resistance function of time. A constant, swift change takes place from the moment the circuit is closed till it reaches a final, steady state. From the point of view of statistical physics, the resistance function would be:

$$R(t) = R_n/[1-(1+t/\tau_1)\exp(-t/\tau_1)] \quad (1)$$

where R_n is the final resistance of the circuit (including both the device and the patient), after the circuit is closed for a time longer than τ_1. τ_1 is the relaxation time of electrons in the circuit. Experimental data show that τ_1 is always less than 50 ms.

In addition to electrical conduction, the cells will be polarized by the force of applied voltage, *E*, as shown in Fig. 2. The charge on the cellular membrane will cause displacement in such a way as to produce an opposing field. There is a slight separation between the positive and negative charges, causing a small electric dipole in each cell. All dipoles are aligned along the force lines of external voltage, *E*. This alignment results in dielectric polarization potential *V*(*t*), which acts



1. This standard model of the electrical properties of the skin was proposed by Rosendal in the 1940s. In this model, stratum corneum combined with epidermis is represented by a capacitor, C, and a resistor, R_1, in parallel connection. The dermis is simply denoted by a resistor, R_2.

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against voltage *E*.

The motion of cellular charges is over-damped due to the high viscosity of cytoplasm and the relative deformation of the cellular state caused by polarization. There also exists polarized long molecules suspending in body fluid, although these do not dominate the process. The net potential, *V(t)*, is actually the sum of all types of polarization. The behavior of dipolar alignment can be expressed by the equation of motion of a driven over-damped oscillator:

$$\ddot{P}_j(t)+2\beta_j\dot{P}_j(t)+\omega^2{}_jP_j(t)=H_j(E) \quad (2)$$

where $P_j(t)$ is the moment, β_j the damping effect, and the characteristic frequency of the type *j* dipoles. $H_j(E)$ is the action of external voltage *E* applied on $P_j(t)$. If the initial conditions were $P_j(0)=0$ and $\dot{P}_j(0)=0$, the complete solution of $P_j(t)$ is:

$$P_j(t)=(H_j/\omega_j^2)[1-Z_j\exp(-t/\tau_{2j})+(Z_j-1)\exp(-t/\tau_{3j})] \quad (3)$$

In the above, Z_j is a constant and τ_{2j} and τ_{3j} are the two relaxation times for an over-damped oscillator. τ_{2j} and τ_{3j} are related to β_j and ω_j:

$$\tau_{2j}\equiv 1/\left[\beta_j-(\beta_j^2-\omega_j^2)^{1/2}\right]$$
$$\tau_{3j}\equiv 1/\left[\beta_j+(\beta_j^2-\omega_j^2)^{1/2}\right] \quad (4)$$

And it is now possible to define :

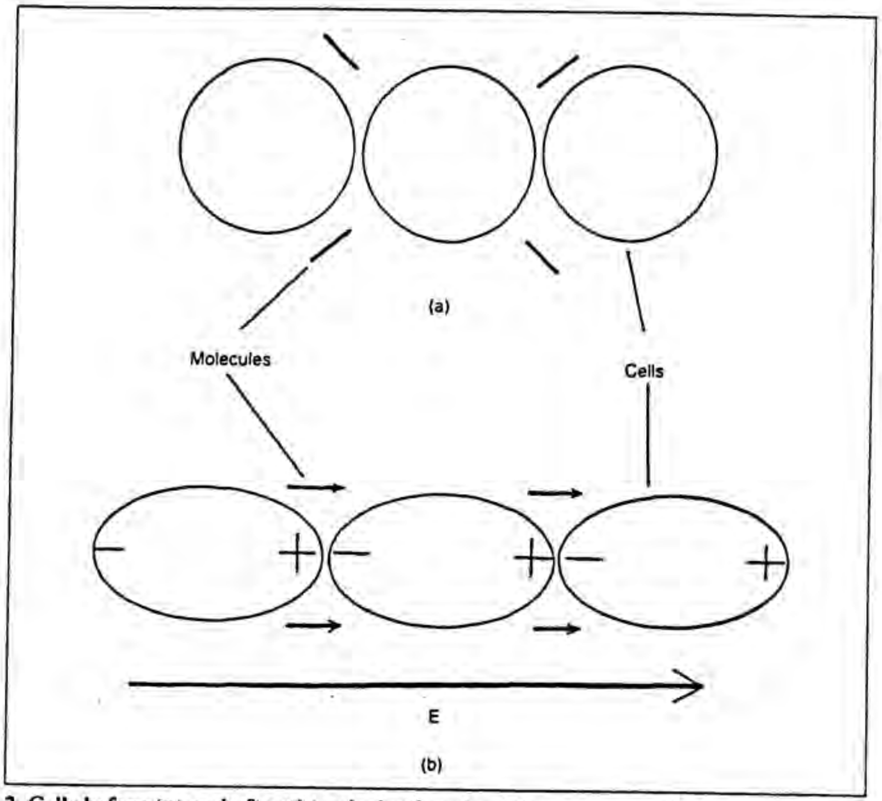
$$Z_j\equiv\tau_{2j}/(\tau_{2j}-\tau_{3j}) \quad (5)$$

If N_j were the number of type *j* dipoles per unit volume and *D* the separation distance of the two electrodes, then the potential difference *V(t)* induced by dielectric polarization is:

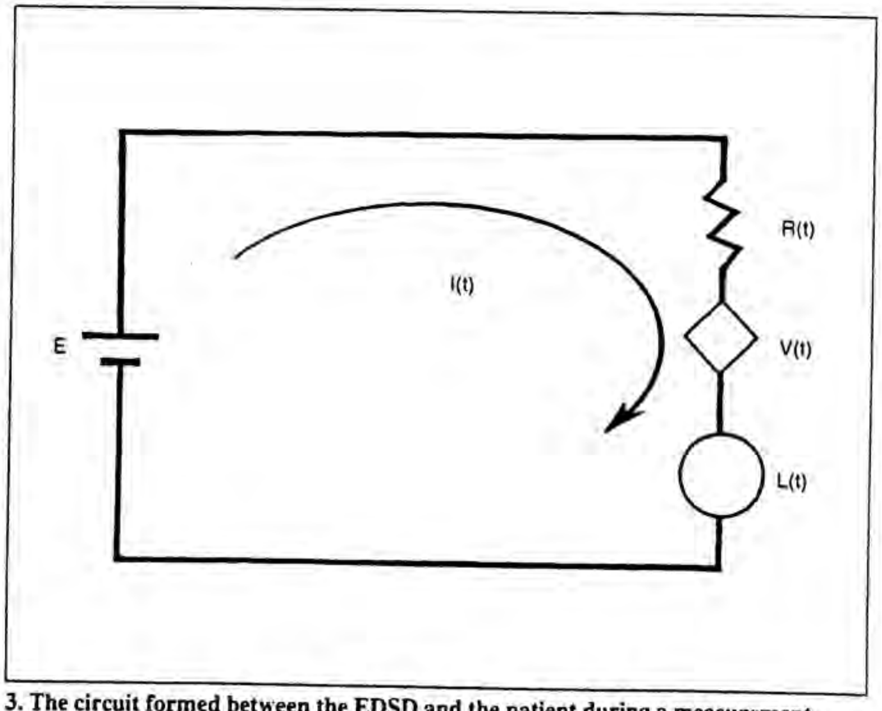
$$V(t)=\sum_j N_jP_j(t)D/\varepsilon_0 = \sum_j V_{oj}[1-Z_j\exp(-t/\tau_{2j})+(Z_j-1)\exp(-t/\tau_{3j})] \quad (6)$$

In the above, ε_o is the permittivity of free space, and V_{oj} is the final polarization potential of type *j* dipoles as time *t* tends to infinity. The summation includes all types of dipoles.

Every living organism has a strong immune system to protect itself from disturbance at all times. Naturally, polarization induced by an external voltage will provoke the cellular immune system. The immune system responds with an oppos-



2. Cells before (a) and after (b) polarization. Applying an external DC voltage, E, will induce a charge displacement of the cellular membrane, or a small electric dipole inside each cell, which causes all cells in the circuit temporarily to be elliptically deformed. The long molecules suspended in body fluid are also polarized and aligned along the applying direction of *E*. The induced dipole moments of both cells and molecules between the electrodes thus produces a polarization potential, *V(t)*, which opposes the voltage *E*.



3. The circuit formed between the EDSD and the patient during a measurement. *R(t)* is the resistance, and *V(t)* is the polarization potential induced by the applied voltage, *E*. The self-regulating function of the cells results in an electromotive force (emf) called life potential, *L(t)*, which acts against *V(t)*.

ing behavior, a net electric energy gradient or electromotive force (emf), which is brought about by complicated processes taking place inside the cells. These processes covert chemical energy (stored within the cells in the form of bio-mass) into electrical energy. Because this function is peculiar to living organisms and is not found in inanimate objects, I refer to it as life potential $L(t)$.

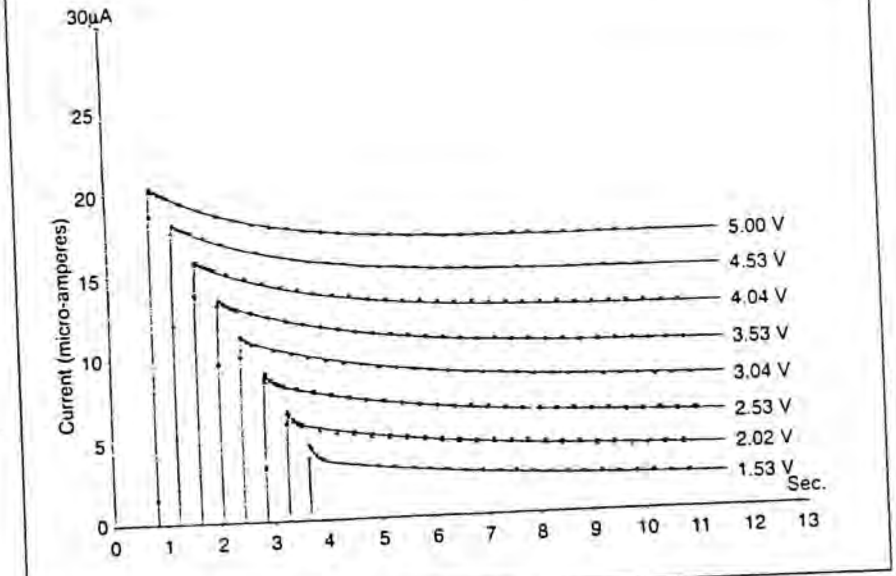
With the above considerations, the effective circuit for electrodermal screening test, including both the device and the patient being measured, can be depicted as in Fig. 3. The current passing through the human body would therefore be:

$$I(t) = [E + L(t) - V(t)] / R(t) \qquad (7)$$

In experiments it is only possible to get the net balance between life and polarization potentials. They can not be obtained separately. Balance potential $B(t)$ is the difference between life potential $L(t)$ and polarization potential $V(t)$. Therefore, Eq. 7 becomes:

$$I(t) = [E + B(t)] / R(t) \qquad (8)$$

In healthy people, the life potential $L(t)$ behaves similarly to polarization potential $V(t)$. It is thus possible to compute current $I(t)$. We have done this repeatedly and compared the observed data with a curve based on theoretical computations made with Eq. 8 (Fig. 4). I personally have taken over 10,000 readings in the last 6 years, and every curve I have seen can be analyzed in this fashion.



4. The small symbols are examples of typical experimental data (human response currents) for various strengths of applied voltage, E (from 1.5 to 5 V). The lines represent values created using the formula developed to describe this phenomena (Eq. 8). Note that the experimental data and theoretical values are in excellent agreement.

The above theoretical discussion is true for all skin areas, but there are also implications specific to EDST readings, particularly Eqs. 6 and 7. The first reading in the EDST curve, generally the highest point on the curve, is the peak value of the response current, which is inversely related to the electric resistance of the measured point. Voll developed standard interpretations for clinical EDSD readings which are discussed briefly in the preceding article by Julia Tsuei. Curve behavior after the peak is an expression of the competition between life potential and polarization potential. A representation of the five standard curve types and their interpretation using values from Eq. 7 are found in Fig. 5.

The figure does include an example of a reading drop, but possible variations in the drop are not depicted. Three variations are commonly observed: steep drop, gradual drop, and uneven drop. A steep slope generally corresponds to acute disease, while a gradual sloping may indicate chronic conditions, such as cancer. If a gradual drop is found, it is crucial that the measurement be taken until the dropping stops, so that the complete amount of the drop can be noted. An uneven, wavy slope is probably due to either unsteady functioning of life potential or electro-chemical reactions taking place within the body during the measurement.

Theoretical Properties Specific to Meridians

We then continued this line of theoretical research in the hope of understanding properties specific to meridians. It would have been possible to continue the process of fitting mathematical formulas to experimental curves, but this would have been an extremely difficult process involving eight parameters. The decision was made to proceed with a further evolution of the equation analysis based on two indicators, one to show conductance (I_p) and one to show net polarization (FD). Preliminary research shows that results attained by continuing the process of fitting curves would have yielded very similar results.

Relaxation time, τ_1, of resistance function $R(t)$ is usually less than 50 ms, while the relaxation times of balance function $B(t)$ is always several seconds. The response current reaches its peak value, I_p, much earlier than the reaction of the balance function. One could say that the human body functions as a resistor during the first 50 ms following the closing of the circuit and then as a semi-dielectric. The peak current., can be expressed as:

$$I_p = E / R_o \qquad (9)$$

R_o is the final resistance. It is clear from Eq. 9 that the magnitude of I_p is an equivalent measurement of conductance.

After the circuit is closed for a time much longer than τ_1 resistance $R(t)$ will reach its final constant value R_o, and balance potential $B(t)$ will reach a value very close its asymptotic value, B_o. Hence the final current I_f becomes:

$$I_f = [E + B_o] / R_o \qquad (10)$$

It is now possible to introduce a new indicator, called fractional drop (FD):

$$FD \equiv [I_p - I_f] / I_p = -B_o / E \qquad (11)$$

B_o which can be measured using the FD value, is the final balance of the measured meridian under the application of the external voltage.

The phenomenon behind the FD (Eq. 11) and Voll's ID is the same. The only difference is the mathematical expression. Strictly speaking, the ID is expressed as:

$$ID \equiv I_p - I_f = -B_o / R_o \qquad (12)$$

Note that there are two inter-dependent

variables in Eq. 12, so it is much more difficult to resolve the equation, possibly resulting in misinterpretation of the reading. For this reason, I prefer FD as an expression of the polarization phenomenon.

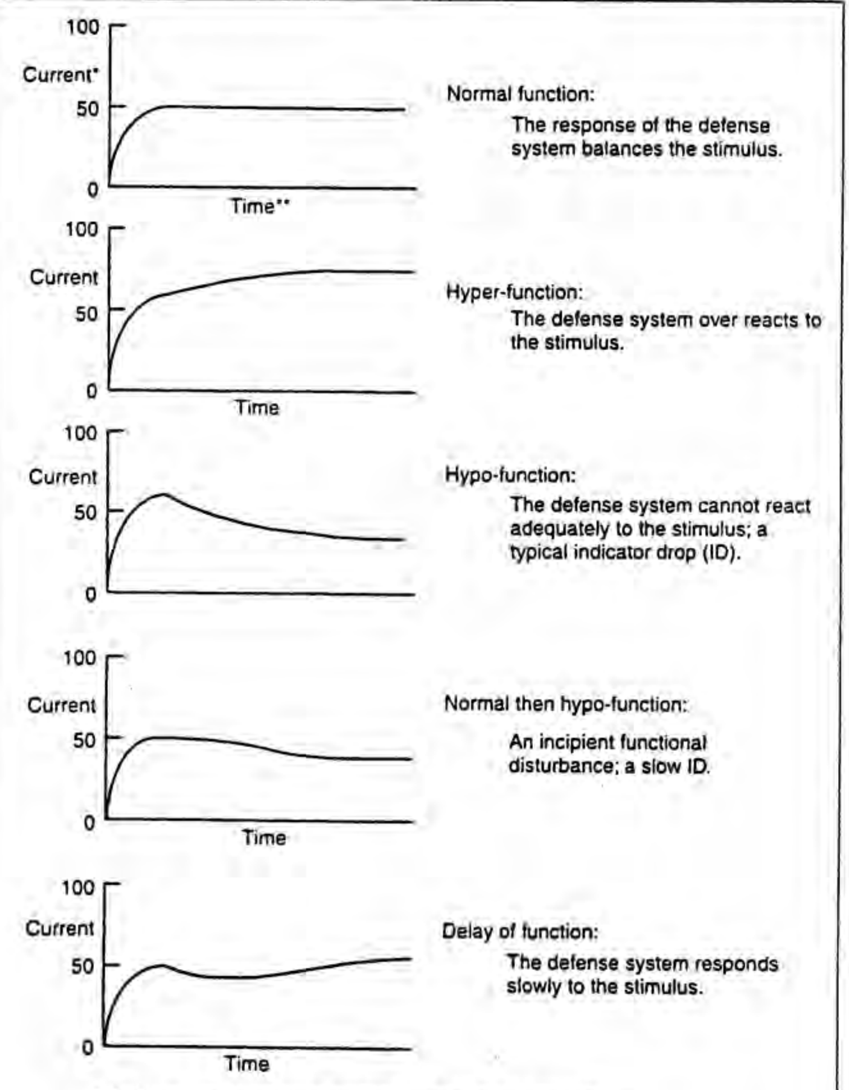
Clinical Measurement of Meridian Properties

We have completed two small studies to test the above theoretical formulations, one in 1991 of arm points on the large intestine meridian [12], and one in 1993 of arm points on the pericardium meridian [13]. The following is a description of the pericardium meridian study, though the same methods were used in both. All data quoted below are from the pericardium meridian study.

In the pericardium meridian study, there were 30 volunteers: 19 males and 11 females, ages 19 to 30, average age 25.06. Electrodes were affixed over two genuine acupuncture points ("Chiu-tsa" HE3 and "Nei-kuan" HE6) and two non-meridian points located 1 cm away from the two above mentioned points (Fig. 6). Points were located using both traditional methods and by measuring skin conductance. Applied voltage, E, in this case 1.5V, was turned on and off from a distance to avoid any direct or indirect contact between the technician and the subject. After each measurement, the electrodes were shorted in order to erase the resulting polarization around them. The time interval between any two successive measurements was at least 20 s, so as to avoid any carry over effect. Both pairs of points were measured 20 times on each subject, switching current direction so that we had 10 readings in each direction. The current direction and order in which the various pairs of points were tested was determined randomly. The data were recorded and analyzed using a computer. Wilcoxon signed rank test was used to discriminate the properties of meridian-point and control-point groups. The paired-t test was used to determine preferential direction.

Both meridians demonstrated higher conductivity than the non-meridian skin areas ($P<0.001$, Table 1), which is in agreement with work of Nakatani [14], Niboyet [3], and Reichmanis, et al., [7]. This finding means that meridians are good paths for electric current, because less energy dissipates flowing through meridians than when flowing through neighboring (non-meridian) tissues. Analysis of the FD shows that less polarization occurs along meridians ($P<0.05$, Table 1). The effect of this property is that meridians have a smaller dielectric constant than neighboring tissue. Because of this, electromagnetic waves move faster through meridians than through non-meridian tissue. It is the combination of these two characteristics, higher conductivity with lower polarizability, that makes the meridian system an efficient bio-information communication network. [6]

We then organized the data according to the direction of energy flow and did further analysis (Table 2). Less resistance results in higher conductance, so the preferential direction of conductance would be the direction of less resistance. The preferential direction of conductance along the pericardium meridian is from the finger toward the body ($P<0.005$). Electric current moving along the pericardium meridian toward the body will encounter less resistance and attenuate less. Polarization in meridians is a different facet, which must be analyzed separately. The lower the polarization, the faster electromagnetic waves will be able to move, so the preferential direction of electromagnetic wave propagation (EMWP) is the direction in which there is less polarization. The preferential direction of EMWP on the pericardium meridian is from the body to the finger. ($P<0.001$) Moving in this direction, there would be less delay in bio-information carried by EMWP [15]. To our surprise, this is the one major area where the two studies differed. On the large intestine meridian, the



* 0-100 represents the meter reading (i.e., relative conductance).

**Total measurement time is usually under 15 s, but in some cases might be as long as 2 min.

5. Five examples of typical readings taken with the EDSD.

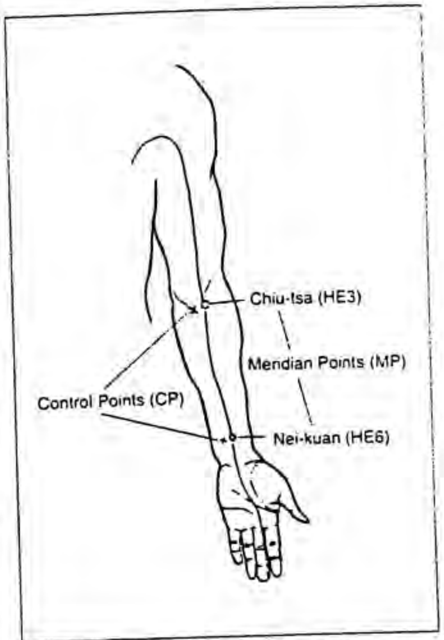
Table 1: From a study of the electrical properties of pericardium meridian points on the left arm: point type analysis.

	toward the body			toward the finger		
Point Type	meridian	control	P value	meridian	control	P value
Avg. I_p*	1.60±1.37	0.41±0.54	P<0.001	1.52±1.27	0.40±0.52	P<0.001
FD*	9.51±10.01	3.99±14.10	P<0.05	-8.10±21.41	2.76±13.05	P<0.05

Table 2: From a study of the electrical properties of pericardium meridian points on the left arm: direction of current analysis.

	meridian points			control points		
Current Direction	toward the body	toward the finger	P value	toward the body	toward the finger	P value
Avg. I_p*	1.60±1.37	1.52±1.27	P<0.005	0.41±0.53	0.40±0.52	P<0.05
FD*	9.51±10.01	-8.10±21.41	P<0.001	3.99±14.10	2.76±13.05	N.S.

*I_p in µA, FD in percent, representing the degree of polarization



6. Line represents the pericardium meridian. Specific measurement points included both meridian points (circles) and control points (crosses).

preferential direction of both conductance and EMWP is from the finger to the body.

The phenomenon of preferential direction in meridians, as observed in our studies, agrees completely with rules of chi circulation in traditional Chinese medicine, including those expressed in the *The Yellow Emperor's Classic of Medicine* (ca. 100 B.C.E., also reffered to as the Neijing). The Neijing describes two types of chi: meridian chi (MC) and subtle nutritious chi (SNC) [16]. The MC in all of the twelve regular meridians is said to flow from the distal points inward toward the body. SNC can flow in either direction. If the meridian runs along the outside of the arms or the inside of the legs, the SNC flows inward toward the body. If the meridian runs along the inside of the arms or the outside of the legs, then the SNC flows outward toward the distal points (Fig. 7). SNC flow directions correspond with the preferential direction of EMWP. The preferential directions of leg meridians, also in agreement with the Neijing, were observed in another study in 1991 [unpublished]. Rosendal observed this phenomenon in the form of differences in DC anodic and cathodic skin conduction, though he incorrectly interpreted the phenomenon as the result of an electrolyte enhancement diffusion process in the stratum corneum [17].

Role of the Meridian System in Biological Development

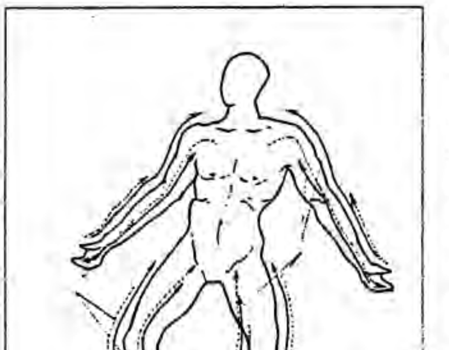
A fertilized egg first splits into two cells, but these two cells are still physiologically dependent on each other. They are members of an integrated, though relatively simple, living system. They must maintain an extremely high level of integration in order to develop into a human fetus, an extremely complicated living system. To maintain integration between the two cells of a new embryo, both cells must constantly exchange matter, energy, and information. If this is not done, the two cells will develop separately, and either the embryo will die or twins will be born. The communication of matter includes the movement of ions, resulting in an electric current flowing between them through the cellular membrane gap junctions [18]. This pathway must be of lower resistance or higher conductance. The types of energy used in embryonic biocommunication include heat, electromagnetic waves, and electrical potential energy. All of these are transferred back and forth between the two cells at extremely fast speeds, assuring the integration of the larger organism, the embryo.

To be as simple and efficient as possible, living organisms channel current and energy waves along the same path. Therefore, one can assume that the various types of information-carrying media in the early embryo travel along the same meridian running between the two cells. Because the circulation, nervous, and hormone systems have not yet developed, this first meridian is the primary route for biological communication and control within the system. The first meridian actively brings about integration of the embryo by controlling cellular generation.

When the two cells split into four cells, the meridian connecting them must become more complicated in order to integrate the four, and thus a meridian system begins to develop. The more the cells split, the more complicated the meridian system becomes. At a certain stage, the organism becomes so large that cellular communication by way of the primitive meridian system is inadequate for continued physiological development. Gradually, many functions of the early meridian system are executed, instead, by differentiated tissues (the early circulation, nervous, and hormonal systems). Naturally, these tissues, which are developing in order to replace various meridian functions, are often located in the same areas and along the same paths as the meridian system. This has been observed in anatomic studies of acupuncture points or meridians [19].

By the second trimester, the circulation and hormone systems have assumed responsible for the transportation of matter, and the nervous system for most electrical signal communication. But throughout the life of the organism, the meridian system continues to execute its primitive function of cellular integration, and it is never totally replaced by differentiated tissues and organs. The meridian system and the regulative physiological systems supplement and compliment one another, thus guaranteeing perfect physiological functioning. None of them can be damaged without affecting the others. In a histological comparison, the meridians are more primary and flexible than the differentiated systems, and can adjust more quickly to external forces. Differentiated tissues, such as blood vessels and nerve fibers, are more rigid due to their pipe-like structure.

Though the meridian system itself does not have a definite physiological structure, it creates and maintains structure, a role it plays for the entire life of an organism. This role was made clear in the proceeding example of embryo development. However, how does this function express itself in the mature organism? One of the most important functions of the mature meridian system is the control of cellular regeneration. An example of this is the electrical properties discovered by Becker to be active during limb regeneration in salamanders [20]. Though limb regeneration is not possible for humans, the body is capable of healing processes. One such process, the repair of biological structures by the generation of cellular mass, is controlled primarily by the human meridian system. We have found that preferential meridian direction is reversed in some cases of disease, which is similar to the reversal of magnetic polarity that Becker observed in salamander leg stumps during the regeneration process.



7. Directions of flow of two types of chi described in the Neijing (The Yellow Emperor's Classic of Medicine). According to the Neijing, meridian chi (solid lines) flows along all of the twelve regular meridians, from distal points toward the body. Subtle nutritious chi (broken lines) flows in the same direction, along meridians located on the outside of the arms and the inside of the legs. The direction of flow of subtle nutritious chi is the opposite (body to distal) in meridians that are located along the inside of the arms or outside of the legs. Our experiments suggest that the direction of meridian chi corresponds to the preferential direction of conductance, while the direction of subtle nutritious chi corresponds with the preferential direction of electro-magnetic wave propagation.

Conclusion

A model of electrical properties of the skin had been the accepted scientific standard for decades. But this model was based entirely on mechanistic principles and failed to explain many biological phenomena, particularly those relating to acupuncture points and meridians. I have developed a model which, unlike the standard model, includes an active biological response and the fact that the electricity passes though different types of tissue, not just skin. This model not only explains much of acupuncture phenomena, in general, but can also be used to explain all possible EDST readings.

We followed the studies of electrodermal properties with studies of qualities specific to meridians. We discovered that meridians have higher conductance, faster EMWP, and patterns of preferential direction. Because of these factures, the meridian system acts as a particularly good network for the communication of bio-information and thus plays an essential role in biological function. It is very interesting that much of what we have learned through our studies (in which the most modern equipment and methodologies were used) is in agreement with meridian theory dating from 100 B.C.E. and earlier.

Acknowledgments

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