Electrical Energy Generator in Dermal Connective Tissues and Equivalent Circuit of Epidermis and Dermis

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Translator: Toshiaki Harada

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   (1) AMI Data of Rheumatic Patient
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I) Abstract

When a rectangular voltage (3VDC / 512 μ sec duration) having rising-edge frequency components of about 5MHz is applied across electrodes pasted at two positions on human skin by means of a current amplifier developed by Kinoshita and Motoyama, electric current flows initially through dermal connective tissues by capacitive conduction at the epidermal basement membrane. (This initial current is defined as BP = dermal current before polarization of capacitance “C”). As the capacitance “C” is charged fully, the current driven by external voltage becomes limited to that which flows in the epidermis due to the build-up of polarization voltage. (This current is defined as AP = epidermal current after the polarization of the capacitance “C”). At this stage the current is seen to fluctuate within 5~10% of its magnitude. This means that the capacitance at basement membrane is not a perfect insulator but is a leaky capacitor.

Above experiment indicate that the equivalent electric circuit of epidermis and dermis can be represented as follows:

Fig.1: Circuit Diagram

R1= Resistance in dermis, R2= Resistance in epidermis, C1= Capacitance at epidermal basement membrane (total electric charge stored in this capacitor “C” is denoted by IQ), R3 is the resistance which allows the leakage current.
Above findings were reported in earlier publications, e.g.,


During the last several years further experiments to measure electrical potential between two points on the skin, by means of special insulated needles inserted to the depth of dermis, were performed by a differential amplifier developed by Kinoshita and Motoyama. As the result, it was found that, in the dermis, there exist mechanisms for DC and AC electromotive forces as well as the capacitance and resistance. Furthermore, a kind of electric current was found to propagate at slow speed of 5~20cm/sec along the acupuncture meridians in a certain fixed direction.

Based on these experimental results an equivalent circuit for the epidermis/dermis was formulated. Circuit parameters representing epidermal resistance, dermal resistance and capacitance of epidermal basement membrane and that within the dermis were determined from the measured parameters of AMI (an electronic instrument devised by Motoyama and developed by Motoyama and Kinoshita, to measure the impedance of resistive and capacitive responses of epidermis and dermis, the current and time constant of its exponential decrease and the total electric charge built up by the capacitance.) DC and AC voltage sources detected as the electromotive forces by the above differential amplifier were also incorporated in the equivalent circuit. Thus, a simulation by the electrical equipment circuit has been done. An
electronic equivalent circuit comprised of circuit components with values thus determined was subjected to the AMI measurement. Values of BP, AP and IQ thereby obtained were found to be nearly identical to those of actual AMI measurement performed on human skin. These experimental results provide evidence to the contention that the electrical circuit represented by the epidermis/dermis equivalent circuit actually exists inside the epidermis/dermis structure.

In particular, it is to be noted that above experimental results suggest the existence of DC & AC electromotive forces as well as the existence of electrical energy propagation, although at slow speed, to various body tissues and organs by way of dermal connective tissues4.

**KEYWORDS:** electrical equivalent circuit in the skin, electromotive force in the dermis, connective tissue – meridians, chi-energy, yin-yang

**II) Objectives**

1. Study the mechanism of electrical potential generator within dermal connective tissues.
2. Verify that the electrical energy is transmitted to tissues of internal organs via (acupuncture) meridians, the existence and functionality of which have previously been objectively demonstrated by the present author1,2,3, 5

**III) Experimental Equipment**

(1) Voltage Amplifier (developed by Motoyama & Kinoshita, Manufactured by Digitex LAB. CO., LTD)
A. Block Diagram

Basic Circuit Block (Fig. 2)

**Fig. 2: Basic Circuit Block**

![Basic Circuit Block Diagram]

B. Frequency, Voltage Range, Amplifier Gain and Noise Level

(1mV or less)

1. Functional Specification (Fig. 3)

**Fig. 3: Functional Specification**

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Channels</td>
<td>6</td>
</tr>
<tr>
<td>No. of Electrodes</td>
<td>12 electrodes &amp; 1 GND terminal</td>
</tr>
<tr>
<td>Input Impedance</td>
<td>1GΩ or greater</td>
</tr>
<tr>
<td>Frequency Range</td>
<td>DC ~5Hz</td>
</tr>
<tr>
<td>HFF (High Freq Cut Filter)</td>
<td>5Hz (18db/oct)</td>
</tr>
<tr>
<td>Sensitivity (internal setting)</td>
<td>250, 500, 2500mV/2.5V (for each channel)</td>
</tr>
<tr>
<td>Common Phase Signal Elimination</td>
<td>86dB or more</td>
</tr>
<tr>
<td>Output Range</td>
<td>±5V max</td>
</tr>
<tr>
<td>Safety Class</td>
<td>Protection against Electric Shock: Class I equipment</td>
</tr>
<tr>
<td></td>
<td>Protection Level: Type BF equipment</td>
</tr>
</tbody>
</table>
② Noise Level of the Amplifier (Fig. 4)

**Fig. 4: Noise Level of the Amplifier**

Memo: 1) + and − terminal of Ch 1 were grounded and measured 10 minute, 2) Amplifier gain = x 1, 3) Sampling interval=100ms

IV) Experimental Method

(1) Place of Measurement

- Inside the electrically shielded room (=Shield Room) a subject was asked to sit on a chair which was electrically floating from the earth (=GND).
- The amplifier and personal computer were set up outside the Shield Room.

(2) Amplifier Gain, Sampling Interval and Measuring Time

- Amplifier Gain = x 1
- Sampling Interval = 0.1sec = 100msec
Measuring Time = 600 sec

(3) Zero-point Adjustment

- Prior to performing measurements, + and – terminals of all channels were first grounded by connecting their cables to a grounded metal plate.
- Next, opened the offset screen (screen to fix the offset for zero adjustment) of the measuring software and, confirming that signals of all channels were at zero volts, completed the zero-adjustment process by pressing the offset button.

(4) About the Body-Earth

- Shield Room itself was grounded. An indifferent electrode (Model BR 100-K manufactured by MedicoTest KK) pasted on the subject’s left elbow was connected to the GND, which formed the body-earth. The subject was asked to place his/her feet on a piece of towel placed over a corrugated card board on the Shield Room floor.

(5) Measurement Points of Skin

- Acupuncture points on the left arm or the left leg, shown in Fig 5 below, were chosen for measurements and the electrical potential in the dermis (“dermal potential”) at these points were measured. For the dermal potential measurement a special insulated needle was prepared such that it is fully coated by insulating paint except the 0.3mm length at the tip, where metal of the
needle is exposed to allow electrical conduction. Measurement was performed by inserting this insulated needle to the depth of dermis. The (metal) handle of the needle was connected to the + (input) terminal of the amplifier by a cable with an alligator clip.

**Fig.5 : Name of the Meridians Being Measured the Electrical Potential in the Dermis**

<table>
<thead>
<tr>
<th></th>
<th>Yin Meridian</th>
<th>Yang Meridian</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ARM</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pericardium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jian shi</td>
<td>PC5</td>
<td>Wai quan</td>
</tr>
<tr>
<td>Neiguan</td>
<td>PC6</td>
<td>Zhi gou</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TH5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TH6</td>
</tr>
<tr>
<td><strong>Lung</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tai yuan</td>
<td>LU9</td>
<td></td>
</tr>
<tr>
<td>Kong Zui</td>
<td>LU6</td>
<td></td>
</tr>
<tr>
<td><strong>LEG</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liver</td>
<td></td>
<td>Gallbladder</td>
</tr>
<tr>
<td>Zhong Feng</td>
<td>LV4</td>
<td>Qiu xu</td>
</tr>
<tr>
<td>Qu quan</td>
<td>LV8</td>
<td>Yang ling quan</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GB34</td>
</tr>
<tr>
<td>Spleen</td>
<td></td>
<td>Stomach</td>
</tr>
<tr>
<td>Shang qiu</td>
<td>SP5</td>
<td>Jie xi</td>
</tr>
<tr>
<td>Yin ling quan</td>
<td>SP9</td>
<td>Zu san li</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ST36</td>
</tr>
</tbody>
</table>

Measured dermal potential was recorded for 10 minutes with each subject in relaxed state. Prior to dermal potential measurement AMI measurement was also performed for each subject. It was time-wise difficult to measure all the acupuncture points shown in Fig.5 with any one subject. Therefore, acupuncture points on either the left arm or on the left leg alone were measured for each individual subject.
(6) Acupuncture Meridians Measured and Sequence of Measurements

· For those subjects whose acupuncture points on the left arm were measured.

  ① Two points of Triple Heater meridian alone were measured (Fig. 6-1, 6-2)

  ② Two points of Heart Constrictor meridian alone were measured (Fig. 6-1, 6-2)

  ③ Five points of Heart Constrictor meridian and Lung meridian were measured (Fig. 6-1, 6-2)

· For those subjects whose acupuncture points on the left leg were measured.

  measurements were carried out in following sequence of ① ~ ②.

  ① Perform the dermal potential measurement at the four points of Liver and Gall Bladder meridian. (Fig. 7-1, 7-2)

  ② Perform dermal potential measurement at the four points of Spleen meridian and Stomach meridian. (Fig. 7-1, 7-2)

Fig. 6-1: Anterior and Posterior Aspect of Rt. Forearm

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**Fig. 6-2:** The number of subjects, initial and gender of the subjects on dermal potential measurement and AMI measurement on Triple Heater, Heart Constrictor and Lung Meridian

<table>
<thead>
<tr>
<th>No</th>
<th>Initial</th>
<th>Gender</th>
</tr>
</thead>
<tbody>
<tr>
<td>1*</td>
<td>It-Ka</td>
<td>Female</td>
</tr>
<tr>
<td>2</td>
<td>Tu-Em</td>
<td>Female</td>
</tr>
<tr>
<td>3</td>
<td>In-Hi</td>
<td>Female</td>
</tr>
<tr>
<td>4</td>
<td>Iw-Yu</td>
<td>Female</td>
</tr>
<tr>
<td>5</td>
<td>Tad-Hi</td>
<td>Male</td>
</tr>
<tr>
<td>6</td>
<td>Sa-Ke</td>
<td>Male</td>
</tr>
<tr>
<td>7</td>
<td>Tan-Hi</td>
<td>Male</td>
</tr>
<tr>
<td>8</td>
<td>Iw-Sh</td>
<td>Male</td>
</tr>
<tr>
<td>9</td>
<td>Ya-Na</td>
<td>Male</td>
</tr>
<tr>
<td>10</td>
<td>Ao-Ak</td>
<td>Male</td>
</tr>
<tr>
<td>11</td>
<td>In-Ti</td>
<td>Female</td>
</tr>
<tr>
<td>12</td>
<td>Tak-Ta</td>
<td>Female</td>
</tr>
<tr>
<td>13</td>
<td>Su-Su</td>
<td>Female</td>
</tr>
<tr>
<td>14</td>
<td>Wa-Ak</td>
<td>Male</td>
</tr>
</tbody>
</table>

* Dermal potential measurement for the Heart Constrictor of It-Ka was done on 3/24/2004.

**Fig. 7-1:** Lateral and Medial Aspect of Rt. Lower Leg

![Lateral and Medial Aspect of Rt. Lower Leg](image)
**Fig 7.2: Measurement Dates for dermal potential measurement and AMI measurement on Liver, Gallbladder, Spleen and Stomach Meridian**

<table>
<thead>
<tr>
<th>No</th>
<th>Initial</th>
<th>Gender</th>
<th>Measurement Date</th>
<th>AMI Measurement Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1#</td>
<td>It-Ka</td>
<td>Female</td>
<td>5/21/2005</td>
<td>5/21/2005</td>
</tr>
<tr>
<td>2</td>
<td>In-Ti</td>
<td>Female</td>
<td>5/25/2005</td>
<td>5/25/2005</td>
</tr>
<tr>
<td>3</td>
<td>Ch-Po</td>
<td>Male</td>
<td>5/26/2005</td>
<td>5/26/2005</td>
</tr>
<tr>
<td>4</td>
<td>Tad-Hi</td>
<td>Male</td>
<td>5/26/2005</td>
<td>5/26/2005</td>
</tr>
<tr>
<td>6</td>
<td>Oh-Ta</td>
<td>Male</td>
<td>5/31/2005</td>
<td>5/31/2005</td>
</tr>
<tr>
<td>7</td>
<td>Ta-Ta</td>
<td>Female</td>
<td>6/1/2005</td>
<td>6/1/2005</td>
</tr>
<tr>
<td>8</td>
<td>In-Hi</td>
<td>Female</td>
<td>6/2/2005</td>
<td>6/2/2005</td>
</tr>
<tr>
<td>11</td>
<td>Mi-Hi</td>
<td>Male</td>
<td>6/7/2005</td>
<td>6/7/2005</td>
</tr>
<tr>
<td>14</td>
<td>Iw-Yu</td>
<td>Female</td>
<td>6/10/2005</td>
<td>6/10/2005</td>
</tr>
</tbody>
</table>

* measurement for Liver and Gallbladder of subject It-Ka was done on 5/21/2005 and for Spleen and Stomach on 6/3/2005.

**V) Electrical Potential of Each Point**

(1) Heart Constrictor and Lung (Yin meridians) (Fig. 9) and Triple Heater (Yang meridian) (Fig. 8)

Measured for 600sec after insertion of the special insulated needle.
**Comments:**

- Measurement was performed by insertion of special insulated electrodes (with needle tip bared for electrical conduction) to the depth of dermis at these points: Ch1(+) = TH4, Ch2 (+)=TH5 and Ch3(+)=TH6.
- minus (-) terminals of each channel were grounded.
- Indifferent electrode was grounded.
- Shield room where measurement were taken place was grounded.
- Gain= x 1.
- Sampling Interval = 100ms.

(Note) Measured result of TH 4 (yang chi) was excluded because it did not fit the clinical experience that the Ki-energy flows from meridian points on the arm to those on the wrist. When the subject is in fatigued condition, it is often noticed that Triple heater meridian does not show the usual Yin-Yang relationship in terms of $\overline{BP}$, i.e., $\overline{BP}$ of Heart Constrictor(Yin meridian) > $\overline{BP}$ of Triple Heater Meridian. In such cases dermal potential measured at TH 4 (yang chi) tend to be lower than that at TH 5 (wai guan). (Ref. Hiroshi Motoyama “Meridians exit in the Dermis” (to be published in 2006))
**Fig. 9: Dermal potential: Heart Constrictor & Lung Meridians (Yin meridians)**

**Comments:**
- Measurement was performed by insertion of special insulated electrodes (with needle tip bared for electrical conduction) to the depth of dermis at these points: Ch1(+) = PC6, Ch2 (+)=PC5, Ch3(+)=PC4, Ch4(+)=LU9 and Ch5(+)=LU6
- minus (-) terminals of each channel were grounded
- Indifferent electrode was grounded
- Shield room where measurements were taken place was grounded.
- Gain= x 1
- Sampling Interval = 100ms

Note: Dermal potential measured at PC 4 (xi men) was also excluded for the same reason as that for Fig. 8.

(2) Voltage Generator in the Dermis

1. As evident in Fig. 8 and Fig. 9, the dermal potential lies in the range from $-300\text{mV}$ to $+1,025\text{mV}$. Dermal potential differences between the two points range from $135\text{mV}$ (for Heart Constrictor meridian), $250\text{mV}$ (for Lung meridian) and $1,200\text{mV}$ (for
Triple Heater meridian). The noise level of the differential amplifier employed was 1mVp-p or less, which ensures excellent signal-to-noise ratio for the above dermal potential measurements. This result shows the existence of an electrical voltage of about 135~1,200mV in the dermis at those meridian points. Within the electric field of such electrical potentials in the dermis, it is possible to hypothesize the existence of a system that propagates electrical energy and/or signals.

2) An experiment to study the propagation channel and speed of electrical energy within acupuncture meridians. A “BioAmp” (voltage amplifier) was used.

Fig. 10-1
(Ref. Hiroshi Motoyama “Measurements of Ki Energy, Diagnosis & Treatments” p74~75)
In the experiment of Fig. 10-1, a grounded indifferent electrode was pasted on the right wrist of the subject. A special insulated needle, which had 1mm exposure at its tip for electrical conduction, was inserted to about 0.5mm depth at well point of the Lung meridian (LU 11). The needle was then connected to the output terminal of a signal generator, which continuously sent sinusoidal stimulus of 50mVp-p and 10Hz frequency.

Fig. 10-1 shows that a negative potential response of 200 μV was first generated at well points of the Lung meridian. About 4.9 sec later a 220 μV negative potential was detected only at associate point of the Lung meridian (located 3~4 cm away on
either side of T3-T4 from the center line of the spinal column). No such response was detected at LU9 (tai-yuan), LU5 (chi ze) and LU1 (zhong fu), despite the fact that they lie along the meridian channel between the Lung well point and the Lung associate point. The distance from the Lung well point to the Lung associate point is about 80 cm. It took about 4.9 sec for the electrical signal (energy) to travel this distance. This is probably due to the flow of the Ki-energy, which has been talked about since ancient times. An electric current caused by motion of electrons, assuming speed of electrons to be 70% of the speed of light, would be 21 km/sec. Thus, it is evident that propagation of energy at much slower speed (80 cm/4.9 sec = 16.3 cm/sec) takes place along the Meridian channel. This propagation of energy gave rise to the reaction in the form of a negative electrical potential at the Lung associate point. A number of similar experiments had been performed and described in Chapter 2 of “Measurements of Ki Energy, Diagnosis & Treatments”.68

(3) Conclusion

① From the explanation given in ① of (2) above, it is evident that a mechanism exists within the dermis such that it generates electrical potential of 135 mV~1,200 mV and consequent electric field.

② From the description given in ② of (2) above, the propagation speed of the electrical energy within the meridian channel is estimated at 15 cm/sec. Furthermore, this is a “painless response”: namely, no sensation of pain is recognized by the subject.
It is thus an entirely different expression of response & speed in contrast to GSR, which is an autonomic nervous reaction detected at entire body surface after a latent period of 2~3 seconds from the moment of stimulation. It might as well be named “meridian response” therefore.9

Next, structure of electrical potential generation within the dermis and the equivalent circuit containing C(capacitance) and R(resistance) will be investigated by means of electrical studies in the epidermis and dermis.

VI) Equivalent Circuit of Epidermis and Dermis

(1) Equivalent Circuit Known to Date

At the moment when a square pulse of 3 VDC and 512usec duration is applied between the measurement point and the indifferent electrode, initial current having amplitude of 1,200-2,000 μA and frequency component of 3MHz flows in the dermis to charge up a capacitance($Z_c = \frac{1}{2\pi fC}$) at the basement membrane of epidermis. This transient current flows within the dermis before completion of the polarization at the basement membrane of the epidermis. It is defined as “BP” or “before polarization” current. Therefore, electrical resistance of the dermis is estimated to be about 2 kΩ. This dermal current decreases as the polarization proceeds until finally the current flows only through the epidermis at about 3 μA corresponding to the epidermal
resistance of $100 \text{ k } \Omega \sim 1 \text{ M } \Omega$. This current is defined as “AP” or “after polarization” current. This observation led to a simple equivalent circuit such as the following:

![Fig. 11](image)

Electrical Resistance of Epidermis

Electrical Resistance of Dermis

Capacitance at Basal Membrane

$6,000 \sim 10,000 \text{pF}$

However, the experiments for measuring the electrical potential gradient in dermis made it clear that a DC voltage generator exists in the dermis as demonstrated by the experiment (1) of V above. The voltage range found is $300 \text{mV} \sim 1,200 \text{mV}$.

(2) Time Dependent Variation of Dermal Potential and its FFT Analysis

![Fig. 12: Time Dependent Variation of Dermal Potential](image)
Comments:
- Measurement was performed by insertion of special insulated electrodes (with needle tip bared for electrical conduction) to the depth of dermis at these points: Ch1(+) = TH4, Ch2 (+)=TH5 and Ch3(+)=TH6.
- minus (-) terminals of each channel were grounded
- Indifferent electrode was grounded
- Shield room where measurement were taken place was grounded.
- Gain= x 1
- Sampling Interval = 100ms

Fig. 12 shows the DC voltage continuously recorded at left TH4 (yang chi), left TH5 (wai guan) and left TH6 (zhi gou) of Triple Heater Meridian over 0~600sec time span. The voltage amplitude is found to range from $-100\, \text{mV}$ to $+1380\, \text{mV}$. The voltages of the meridian points on the wrist side are larger than those of the points on the upper arm. This result is in agreement with the direction of the Ki-energy flow which has been talked about since ancient times.

*Fig. 13: Results of FFT Analysis – Amplitude vs Frequency*
Fig. 13 shows the relation between the voltage amplitude and the frequency as computed by FFT. At 0.08Hz the amplitudes are about 200 μV for all three points. As frequencies increase amplitudes decrease. At 5Hz the amplitude is quite small at 0.0003mV.

This experiment shows that electrically the dermis contains not only DC but also AC electromotive forces. The study concerning frequencies, which are the signal components within the meridians, is our next important research theme. Therefore, the instruments to be used, methods for experiments and analytic methods are being discussed.

(3) Dermis has Capacitance(C) as well

*Measurement of the capacitance within the dermis by a digital meter (Fig. 14)*

A digital meter (model M-3860M manufactured by METEX KK) was used to measure the capacitance(C) between the left TH5 (wai guan) and left TH9 (si du). Special insulated electrodes (with needle tip bared for electrical conduction) were inserted to the depth of dermis at these points. Measurement was performed by connecting the (+) cable of the digital meter to the left TH9 (si du) and the (-) cable to the left TH5 (wai guan).

*Fig. 14: Condenser capacity between Left TH5 (wai guan) and left TH9 (si du) (measured by Digitaltesta)*

<table>
<thead>
<tr>
<th>No</th>
<th>Subject's Initial</th>
<th>Condenser C[nF]</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Y.Y</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>K.M.</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>H.M.</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C in the air</td>
<td>0</td>
<td>C in the air</td>
</tr>
</tbody>
</table>

- Date of Measurement: July 13, 2005
- Place of Measurement: Shield Room 3rd floor, IRP
- Number of Subjects Tested: 3
- Digitaltesta (model M-3860M manufactured by METEX KK)
- 400μF max, minimum resolution = 1pF
As shown above (Fig. 14), it is evident that there is capacitance within the dermis. While further experiments using more accurate equipment are necessary, this experiment has revealed the fact that capacitance does exist in dermis.

(4) Equivalent Circuit Derived for Epidermis and Dermis (Fig. 15)

Experimental results obtained thus far as described above lead to the following equivalent circuit for the epidermis and dermis.

![Fig. 15](image)

A. Explanation of the Circuit

$R_2$ represents the large resistance which exist within the epidermis, the value of which is estimated to be $100 \, k\Omega \sim 1M\Omega$ from AP values obtained by AMI. $R_1$ represents the resistance of the dermis, which is estimated to be $1.5 \, k\Omega \sim 2k\Omega$ from the fact that BP values by AMI fall in $1,500 \sim 2,000 \mu A$ range. On the other hand, $R_3$, $R_4$, $R_5$, $R_6$ and $R_7$ are considered to be larger than $1M\Omega$. This is because the
electric current that flows through the collagen at the boundaries of individual layers within the dermis was unmeasurably small when 0.5V was applied.\textsuperscript{11}

$C_2$ and $C_3$ represent the capacitance of epidermis and are considered to be $6\text{nF}\sim15\text{nF}$. On the other hand, measured capacitance value of the dermis was $5\text{nF}$. However, other studies indicate that capacitance of the dermis should be greater than that of the epidermis. (ref VII) This discrepancy may be ascribed to the insufficient accuracy of the digital meter used.

The DC voltage is $300\text{mV}\sim1,200\text{mV}$. AC frequencies are $0.08\text{Hz}\sim5\text{Hz}$ and the AC voltages are $200\ \mu\text{V}\sim0.3\mu\text{V}$.

\textbf{Fig. 16: Equivalent Circuit 1}

Circuit parameters were determined, within the value range derived from the experiments described in preceding sections, to fit the BP, AP and IQ values of the AMI measurements when an external rectangular pulse of $3\text{VDC}$ and $512\ \mu\text{sec}$ duration is
applied. By this simulation it was possible to obtain BP, AP and IQ values and waveform that were nearly identical to those of actual measurements of a subject’s skin by AMI.

Since AMI when the subject K.M was measured could not save AMI wave form which contains current values of each measurement time, the value of the equivalent circuit was calculated by actual AMI parameters (BP, AP, IQ). Therefore, AMI wave form is displayed only in the form of the simulation wave form. (see Fig. 18).

Contrary, since AMI that was used to measure the rheumatoid patient could record the waveform and the current values of each measurement time, therefore simulation wave form (Fig. 21) is displayed together with actual waveform (Fig.19)

**B. AMI Waveform Simulation by Equivalent Circuit : S=K.M. (Fig. 17)**

AMI waveform was simulated by using the parameters R1, R2, C1, C2 and C3 of the Circuit Diagram 1 calculated from AMI data of the subject K.M.

*Fig. 17: Equivalent Circuit 2*
The AMI data of this subject as obtained by standard AMI measurement was as follows.

* TC (time constant of polarization) is not available in standard AMI measurement.

* Date of Measurement: 2005/6/30

* Average of Body Surface Points: BP=1,570, AP=14, IQ=1,265

From these AMI data values of R1, R2, C1, C2 and C3 of the equivalent circuit were calculated as follows.

(i) Determine R1 (dermal resistance) from the value of BP

BP is the current that flows at the initial moment when 3VDC is applied to the equivalent circuit. At this initial moment all capacitance components may be considered “short-circuited”. Then the effective load to the 3VDC is a series combination of R1 and R8 (=100Ω output impedance of the AMI equipment).

Therefore

\[ \text{BP} = \frac{3 \text{V}}{R1 + R8} \]

which leads to

\[ R1 = \frac{3 \text{V}}{\text{BP}} - R8 = \frac{3 \text{V}}{\text{BP}} - 100\Omega \]

Substituting the BP with subject K.M’s BP value, 1,570μA, R1 is obtained. .

\[ R1 = \frac{3 \text{V}}{1.570 \times 10^{-3} \text{A}} - 100\Omega = 1.911\Omega - 100\Omega = 1.811\Omega = 1.811\text{kΩ} \]

This result, i.e., R1 ≅ 1.8 kΩ, coincides well with the value obtained by AMI.
(ii) **Determine \( R_2 \) (epidermal resistance) from the value of \( AP \)**

After the lapse of about 50 \( \mu \) sec from the onset of the 3VDC across the equivalent circuit, capacitors \( C_1, C_2 \) and \( C_3 \) are fully charged allowing no further flow of electric current. Current then flows through the compound resistance of \( R_2, R_3, R_4, R_6 \) and \( R_7 \). This current is considered to correspond to \( AP \). Here we assume that \( R_3, R_4, R_6 \) and \( R_7 \) are all \( 1 \) M\( \Omega \).

\( R_6 \) and \( R_7 \), which represent resistance of the collagen, are electrically connected in parallel giving a compound resistance of \( 0.5 \) M\( \Omega \). \( R_3 \) and \( R_4 \) are connected in series to this resistance. Therefore, total effective resistance of \( R_3, R_4, R_6 \) and \( R_7 \) is \( 2.5 \) M\( \Omega \). \( R_2 \) is connected to this resistance in parallel. Thus \( AP \) is obtained by:

\[
AP = \left( \frac{1}{R_2} + \frac{1}{2.5 \text{ M}\Omega} \right) \times 3\text{ V}
\]

which leads to

\[
\frac{1}{R_2} = \frac{AP}{3\text{ V}} - \frac{1}{2.5 \text{ M}\Omega}
\]

Using measured \( AP \) value (14 \( \mu \) A) of the subject K.M. in this equation:

\[
\frac{1}{R_2} = \frac{14 \times 10^{-6} \text{ A}}{3\text{ V}} - \frac{1}{2.5 \times 10^6 \Omega} = 4.267 \times 10^{-6} \Omega^{-1}
\]

Hence,

\[
R_2 = 234.4 \text{ k}\Omega
\]

This value falls in the typical range \( (100\text{ k}\Omega \sim 1\text{ M}\Omega) \) of epidermal resistance as implied by many examples of \( AP \) values by AMI measurements. Thus above value of
R2 of the equivalent circuit is consistent with the compound resistance of actual human skin.

\( \text{(iii) Determine } C_1, C_2 \text{ and } C_3 \text{ from IQ value} \)

It is not possible to determine individual values of \( C_1, C_2 \) and \( C_3 \) from a single value of the IQ measurement. Therefore, first obtain a compound capacitance of the three capacitors and then distribute the value equally to all three capacitors. As \( C_1, C_2 \) and \( C_3 \) are capacitance of collagen fibers, it may be reasonable to assume they are of equal magnitude.

IQ is the total electric charge built up in the capacitor. Therefore, IQ is equal to the product of the Voltage(3V) and the compound capacitance(\( C \)). As IQ of AMI is 1/10\(^{th} \) of its actual value, actual value of the total electric charge is 10xIQ. Thus,

\[
10 \times \text{IQ} = 3V \times C
\]

which leads to

\[
C = \frac{10 \times \text{IQ}}{3V}
\]

Substituting IQ by measured IQ (=1,265) of the subject K.M., the compound capacitance (\( C \)) is obtained :

\[
C = \frac{10 \times 1,265 \text{ pC}}{3V} = 4,217 \text{ pF} = 4.217 \text{ nF}
\]

Next, as capacitors \( C_1, C_2 \) and \( C_3 \) are connected in series the compound capacitance (\( C \)) is related to \( C_1, C_2 \) and \( C_3 \) by

\[
\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}
\]
If $C_1$, and $C_2$ and $C_3$ are assumed to be equal

\[
\frac{1}{C} = \frac{3}{C_1} \quad (C_1=C_2=C_3)
\]

Therefore,

\[
C_1=C_2=C_3=3C=12.65 \text{ nF}
\]

This value falls within 6,000pF and 15,000pF, the range of C values as described in page 4 ~ 12 of “How to Measure and Diagnose the Functions of the Meridians and Their Corresponding Internal Organs” (1974) IRP Press\textsuperscript{12}.

Using the Equivalent Circuit 1 with physical parameters determined as above, i.e., $R_1=1.811k\Omega$, $R_2=234.4k\Omega$, $C_1=C_2=C_3=12.65\text{ nF}$, a simulation of AMI measurement was performed on the circuit yielding AMI waveform shown in Fig. 18 (Ref. Fig.17 Equivalent Circuit 2)

**Fig. 18:** Current pattern at resistor $R_8$ being 100$\Omega$

$V_2$ was set to 100$\mu$V $p-p$ and 0.1 Hz

<table>
<thead>
<tr>
<th>Xa</th>
<th>521.7u</th>
<th>Xb</th>
<th>10.00u</th>
<th>a-b: 511.7u freq: 1.954k</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yc</td>
<td>1.583m</td>
<td>Yd</td>
<td>14.50u</td>
<td>c-d: 1.569m</td>
</tr>
<tr>
<td>Units/Div</td>
<td>X: 100u</td>
<td>Y: 1.000m</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
AMI parameters obtained by above simulation were:

\[ \text{BP}(=Y_c) = 1,583 \mu\text{A}, \quad \text{AP}(=Y_d) = 14.5 \mu\text{A}, \quad \text{IQ} = 1,263 \text{pC}, \quad \text{TC} = 13.85 \mu\text{s} \]

AMI parameter values of the actual subject (average of all measuring points):

\[ \text{BP} = 1,570 \mu\text{A}, \quad \text{AP} = 14 \mu\text{A}, \quad \text{IQ} = 1,265 \text{pC} \]

(no TC available in standard measurement)

(5) Conclusion

As shown above, the fact that the AMI measurement simulation by using physical parameters of compound capacitance (C), compound resistance (R), DC potential, AC potential and frequency, gave waveform which largely matches that of actual AMI waveform of the subject implies that the Equivalent Circuit proposed above correctly represent the electrical equivalent circuit in human epidermis and dermis.

Lastly some considerations are presented below regarding structural factors of skin tissues that constitute generation of the DC potential, AC potential as well as capacitors at the basement membrane of epidermis and within the dermis.

VII) Histological Mechanism for the Generation of Dermal Potential and Capacitance of Epidermal Basement-Membrane and Dermis

(1) Hyaluronic Acid and Na⁺
Network of hyaluronic acid or acid mucopolysaccharides abundantly present in dermal connective tissues, contains carboxyl or sulfonic groups. It is therefore highly poly-anionic substance which reacts with various cations such as Na\(^+\), K\(^+\), Ca\(^{++}\) and Mg\(^{++}\), and extra-cellularly forms ionic bonding with NaCl, thereby closely interrelated to metabolism of electrolyte and water.\(^{13,14}\)

Excessive Na\(^+\) ions in connective tissues are sustained as counter-ions of the mucopolysaccharide’s negative ions. Liquid phase hyaluronic acid changes its physical characteristics depending on the concentration of Na\(^+\) ions in the base solution. It coagulates if salt concentration is low. As salt is added it gets dispersed. Therefore, the electrical potential of Na\(^+\) ions and hyaluronic acid is not fixed but changes. However, the presence of the hyaluronic acid plays a role in the mechanism to accumulate the Na\(^+\) ions within connective tissues.\(^{14,15}\)

From above consideration, it is possible to assume that a kind of battery is formed between the mucopolysaccharide’s negative ions, hyaluronic acid in particular, and the positive counter-ions (Na\(^+\)). It is such electrical potential which was measured in dermal connective tissues (i.e., in acupuncture meridian) as 135mV ~ 1,200mV by voltage amplifier.

As the balance between the two is not fixed but tend to fluctuate. This is the source of low frequency changes in dermal potential.
(2) Histological Mechanism for Dermal Capacitance (C)

That the epidermal basement membrane containing collagen has capacitance of $6,000 \, \text{pF} \sim 10,000 \, \text{pF}$ is evident from the experiment which proved that polarization takes place between the epidermis and dermis rather than between the epidermis and epidermis.\(^{16}\) (Ref. Page 19~21 “Measurements of Ki Energy, Diagnoses & Treatments”) Also, it is evident that polarization occurs within the dermal connective tissue.\(^{17}\) (Ref. page 61~63 of “Comparisons of Diagnostic Methods in Western and Eastern Medicine” 1999) This implies that collagen acts as a kind of dielectric substance and that the extracellular negative charge of hyaluronic acid and positive charges of $\text{Na}^+$, $\text{K}^+$, etc constitute the capacitor $C_1$. However, it is not an ideal capacitor but has small current leakage, which is represented by a high resistance ($1 \, \text{M} \Omega$) inserted in parallel with the capacitor $C_1$.

VIII) AMI Data of a Rheumatic Patient

(1) AMI Data of Rheumatic Patient (Fig. 19)
To simulate the AMI waveform of the rheumatic patient, R1, R2, C1, C2 and C3 were calculated using AMI data quoted in Page 63 “Measurements of Ki Energy, Diagnoses & Treatments”. At the time when this particular patient was measured about 20 years ago, measurement was done by an earlier model of the AMI which gave BP and AP values that were about 1/3 of those by latest model of AMI due to slower speed of the A/D conversion. Therefore, for this simulation, three times of the older BP and AP values were used. Likewise IQ was also re-calculated. Using these re-adapted AMI parameters, values of R1, R2, C1, C2 and C3 of the equivalent circuit were calculated.

- Values of BP, AP and IQ of the rheumatic patient re-adapted as described above are as follows.
  
  \[BP = 285.003 \mu A \quad AP = 133.926 \mu A \quad IQ = 1,030.787pC\]

- The AMI parameters obtained by equivalent circuit of the rheumatic patient are:

  \[BP(=Yc) = 290.0 \mu A \quad AP(=Yd) = 133.3 \mu A \quad IQ = 1,018pC\]

- V2 was set for 100 \(\mu V\) p-p and 0.1Hz.
The simulation of rheumatic patient (shown in Page 63 Figure 3 in “Measurements of Ki Energy, Diagnoses & Treatments,”) were estimated to be $R_1=19.35\,k\Omega$, $R_2=22.60\,k\Omega$, $C_1=C_2=C_3=10.31\,nF$\cite{19}, as parameters of the Equivalent Circuit 3 (Fig. 20).

AMI waveform simulated by these physical parameters is shown in Fig. 21.

In the case of rheumatic patient, cross-linking of hyaluronic acid in dermis is disrupted resulting in reduction of negative charges as well as $Na^+$ counter-ions. Under such conditions normal battery of $600mV\sim1,200mV$ cannot be constructed. Therefore, the potential decrease. The flow of body liquid within the dermis, i.e., the flow of positive and negative ions is stagnated causing dermal resistance to increase. Epidermal resistance decreases. The BP value of the rheumatic patient as measured by earlier model of AMI is about $100\,\mu A$ which corresponds to about $300\,\mu A$ if
measured by latest model of AMI. AP value is a little less than half of it. This means that dermal resistance increased and that epidermal resistance decreased. IQ value also decreased, which means that the capacitance (C) of epidermal basement membrane and collagen within dermis also decreased.

As shown above, when simulation is performed by determining R1, R2, C1, C2, C3 to fit the actual data of the rheumatic patient, a waveform, BP, AP, IQ and θ obtained were found to closely match those of the actual rheumatic patient. This provides further evidence that this equivalent circuit represents the actual electrical equivalent circuit existing in the epidermis and the dermis.
Acknowledgement:

As I stated in CIHS principles and missions, I have always been researching and seeking the truth lying within the sphere of body, mind and spirit in the hope of benefiting human beings for a better life. My quest to understand these mysteries has led me on a wondrous journey and many research articles. The article “Electrical Energy Generator in Dermal Connective Tissues and Equivalent Circuit of Epidermis and Dermis” in this first CIHS journal is one of the pinnacles of my research journey.

Along the way I have been helped by many gifted and generous people. For this particular article, I want to offer my heartfelt gratitude to two people. One is Dr. Toshiaki Harada, who translated this article from Japanese to English. His skills in both translation and understanding medicine and electrophysiology made this article precise and explorative. Another is Dr. Tsunetake Shoji, who is my research assistant. I am grateful for his contribution to research.

I am glad that I can publish this paper in this first issue of the CIHS journal and I hope this journal will contribute to the academic community.
References:


7 Kinoshita, H., Illustration of Acupoints, Ido no Nippon Sha, Kanagawa Japan, 9, 1970.


11 Motoyama, H., Comparisons of Diagnostic Methods in Western and Eastern Medicine, Human Science


