(III) What Is the Fundamental Physical Nature of the BP Current Which Flows in Dermal Connective Tissue?

Upon application of an external voltage between two points on the skin, is the propagation velocity of the BP current simply attributable to the drift velocity of the various ionic species (Na^+, K^+, Cl^- etc.) in the ground substance?

As mentioned in Chapter I, the maximum velocity of ionic movement in the interstitial fluid can be seen to be about 20kHz in frequency terms. That is, due to velocity limitations, the ions are unable to respond rapidly enough to higher frequencies of the alternating field. However, from the skin current-response curve it is readily apparent that the BP current can pass the 20 ~ 30cm distance between fingertips and wrist (150 ~ 180cm between toes and wrist) in less than 0.1 ~ 1μsec. So in frequency terms the BP current can be considered as an extremely rapid phenomenon occurring at frequencies greater than 1 ~ 10MHz. Therefore the propagation velocity of the BP current in response to an externally applied field cannot be explained in terms of ionic movement. To clarify this point further we will now consider the ionic movement in more detail.

Table I gives the mobilities of various ions in aqueous solution at 25°C extrapolated to infinite dilution.

Table II shows the corresponding maximum drift velocities (v) calculated for each ion assuming the finger-wrist distance is 20cm and the toe-wrist distance is 150cm.

An implicit assumption used in these calculations is that the mobilities of

Table I: Mobilities of Various Ions in Aqueous Solution at 25°C Extrapolated to Infinite Dilution (Adapted from Benedek, G.B., et al.[6])

	H^+	Na^+	K^+	Ca^{2+}	Mg^{2+}
Mobility ($10^5\ \mu^{\infty}/cm^2 \cdot V^{-1} \cdot s^{-1}$)	363	52.0	76.2	61.6	55.0
	Cl^-	OH^-	NO_3^-	SO_4^{-2}	Br^-
Mobility ($10^5\ \mu^{\infty}/cm^2 \cdot V^{-1} \cdot s^{-1}$)	79.0	205	81.3	82.7	81.2

$v = \mu^{\infty} E$
- v = drift velocity
- μ^{∞} = ion mobility in aqueous solution at 25°C extrapolated to infinite dilution
- E = electric field strength
- V = Voltage

In AMI measurements,
E = 3.0 Volt / 20cm = 0.15 Volt·cm^{-1} (in hands)
E = 3.0 Volt / 150cm = 0.02 Volt·cm^{-1} (in feet)

Using the above E values, the ion mobility at the Sei point measurements in hands and feet are in Table II.

Table II

① Drift velocities calculated for various cations in the hand assuming a finger–wrist distance of 20cm

Drift Velocity	H^+	K^+	Na^+	Ca^{2+}	Hg^{2+}
$cm \cdot s^{-1}$	0.000544	0.0001140	0.0000780	0.0000924	0.0000825

② Drift velocities calculated for various anions in the hand assuming a finger–wrist distance of 20cm

Drift Velocity	Cl^-	OH	NO_3^-	SO_4^{2-}	Br^-
$cm \cdot s^{-1}$	0.0000825	0.0003080	0.0001220	0.0001240	0.0001220

③ Drift velocities calculated for various cations in the feet assuming a toe–wrist distance of 150cm

Drift Velocity	H^+	K^+	Na^+	Ca^{2+}	Mg^{2+}
$cm \cdot s^{-1}$	0.0000725	0.0000151	0.0000103	0.0000123	0.0000109

④ Drift velocities calculated for various anions in the feet assuming a toe–wrist distance of 150cm

Drift Velocity	Cl^-	OH^-	NO_3^-	SO_4^{2-}	Br^-
$cm \cdot s^{-1}$	0.0000109	0.0000410	0.0000162	0.0000165	0.0000162

ions in the dermal connective tissue is of the same order of magnitude as those quoted in Table I. This assumption seems reasonable in view of the known dilute salt concentrations present in the interstitial fluids and moreover is supported by the work of Joseph et al.[7]

As shown in Table II, the maximum drift velocity of a sodium ion (Na^+) in the hand is 7.8×10^{-5} cm/sec and in the foot 1.03×10^{-5} cm/sec; much too slow to account for the propagation velocity of the BP current which is greater than $20\times10^{6-7}$ ~ $150\times10^{6-7}$ cm/sec.

In order to resolve this apparent dilemma we shall use, as an analogy, the movement of a "conduction" electron in a conductor such as copper. For example, the drift velocity of an electron in a uniform copper wire with current density 480Amp/cm^2 is only 1cm/28 sec. In contrast, however, the speed at which changes in the electric field configuration travel along the wire is known to approach that of light. A similar analogy can be made to the speed at which pressure transmission travels along a tube: When pressure is applied to one end of a long water-filled tube, the pressure is rapidly transmitted through the water to the other end even though the speed at which the water moves through the tube is much slower.[(8)]

In the light of these analogies we can understand more clearly the nature of the velocity of the BP current. Thus, even though the drift velocity of each ion in the ground substance is very slow (eg. $Na^+ = 7.8\times10^{-5}$ ~ 1.03×10^{-5} cm/sec), the BP current can pass through a distance of 20 ~ 150cm in less than 0.1 ~ 1μsec. because the velocity of the BP current does not depend on ionic movement in the ground substance but propagates rapidly through the ground substance in the form of a rapid electric field change. What is the mechanism of such a rapid change in the electric field?

To answer this question it seems useful to view the situation in terms of energy transmission. When energy is applied to an electric field in the form of an external potential, atoms or molecules in the electric field transmit the given energy very rapidly to one another by making successive energy transmitting movements without any actual movement taking place – just like waves in the sea.

Using this concept, when we apply 3 volts between two electrodes attached to different points on the skin, this applied electrical energy causes energy transmission in every atom and molecule in the ground substance as an electric field. Thus the applied energy is transmitted successively from one electrode to another at a very rapid speed.

In the next section, on the basis of a series of experiments, we shall consider the physical nature of Ki energy including its speed, direction and carrier medium.