

Electrical Characterization of Acupuncture Points: Technical Issues and Challenges

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ABSTRACT

Acupuncture points are frequently described as having distinct electrical properties. These properties include increased conductance, reduced impedance and resistance, increased capacitance, and elevated electrical potential compared to adjacent nonacupuncture points. Commercial electrodiagnostic devices have used this assertion as a means to localize and analyze acupuncture points for diagnostic purposes. Yet, the electrical characterization of acupuncture points is associated with important technical issues that are often overlooked. Electrode polarizability, stratum corneum impedance, presence of sweat glands, choice of contact medium, electrode geometry, and other factors contribute to the final electrodermal reading and may cause doubts about the validity of available electrodiagnostic devices. The goal of this review is to help researchers and clinicians understand these factors affecting electrodermal readings, to make apparent the difficulties and challenges confronting electrodermal readings, and to increase understanding about how these possible associations can be interpreted and understood from the perspective of biology.

INTRODUCTION

The use of electrical devices to detect and monitor acupuncture points has a long and “checkered” history. The first claims for the electrical detection of acupuncture points date to the 1950s, when Reinhard Voll (Germany) in 1953,^{1,2} Yoshio Nakatani (Japan) in 1956,³ and J.E.H. Niboyet (France) in 1957,⁴ each independently concluded that skin points with unique electrical characteristics were identifiable and resembled traditional acupuncture points. Since then, a number of studies have elaborated the electrical properties attached to these “bioactive” points, which are frequently equated with acupuncture points. These properties include increased conductance,^{5–7} reduced impedance and resistance, increased capacitance,^{8–11} and elevated electrical potential^{7,12–14} compared to nonacupuncture points.

While these claims form the basis for the widespread use of acupuncture-point-locating devices in the acupuncture

community, the authenticity and reproducibility of these studies are being debated and viewed with considerable skepticism in the conventional biomedical community.¹⁵ While the lack of support may partly originate from inherent biases against anything denoting “energies,” the most significant barrier is the innumerable confounders and difficulties associated with obtaining electrical readings from the skin. The lack of a physiologic explanation for this electrical distinction at acupoints adds another dimension to the skepticism.

The goal of this review is to help researchers and clinicians understand factors affecting electrodermal readings (see Table 1), to make apparent the difficulties and challenges involved with electrodermal readings, and to help understand how these possible associations can be interpreted and understood from the perspective of biology. This paper for clinicians and researchers and provides a descriptive overview of the technical issues regarding electrodermal readings without delving into detailed mathematics.

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TABLE 1. SUMMARY OF RELEVANT FACTORS AFFECTING ELECTRODERMAL MEASUREMENTS

<i>Relevant factors</i>	<i>Electrical effects</i>	<i>Important clinical characteristics</i>	<i>Recommended conditions</i>
Stratum corneum	Acts as the greatest contributor to resistance to electrical currents	Skin integrity Skin hydration Stratum corneum thickness	Maintain consistent, uniform conditions across testing (i.e., avoid cuts or skin lesions).
Sweat ducts	Serve as a shunt for ionic currents	Sweat gland density	Evaluate areas with lower sweat gland density, if possible.
Electrode polarization	Acts as an unwanted capacitor at the electrode-skin interface	Electrode material Electrode size Contact medium Current amplitude and frequency	Use higher electrical frequencies, nonpolarizable electrodes, larger electrodes. Alternatively, use the four-electrode method.
Electrode material	Affects electrode polarizability	Type of electrical measurement	For electrical impedance, use non-polarizable electrodes (Ag/AgCl electrode). For electrical potential, use identical materials for all electrodes, active and reference.
Contact medium	Affects electrode polarizability and skin electrical resistance (via skin hydration)	Dry versus hydrogel versus wet mediums Contact area with skin	For dry electrodes, maintain constant pressure and use higher current frequencies. For wet electrodes, maintain constant contact medium-to-skin area.
Electrode geometry	Determines current path	Electrode size and shape	Recognize that current density is greatest at smaller electrodes and greater electrode surface convexity
Electrode arrangement	Determines current depth	Distance between electrodes	Decrease the distance between electrodes to study more superficial skin layers. Increase the distance to study deeper layers.

BASIC ELECTRICAL PRINCIPLES

Various electrical measures, such as electrical resistance, impedance, and potential, have been used to detect and monitor acupuncture points. To appreciate how these measures differ, fundamental electrical concepts must be understood. Most electrodermal devices deliver an electrical stimulus to the skin. The amount of stimulus can be quantified by either a voltage or current amplitude. Voltage is the difference of electrical potential between two points measured in Volts (SI units) and the current is the flow of electric charge through a given cross-section at a given time measured in amperes (SI units). In either case, a continuous direct input can be used (DC) or an alternating input can be used (AC). The DC output maintains a constant flow of current or voltage in one direction, whereas the AC output deliver currents or volts that alternate in direction (e.g., clockwise and counterclockwise in a representative rectangular circuit). The alternating currents can be square, sinusoidal, or pulselike in form.

Popular acupuncture diagnostic machines frequently use a DC stimulus in the range of 1–12 V (listed in Table 2). These values are distinct from the levels used for therapeutic electroacupuncture where much higher levels of electrical input are routinely administered (~ several mA at 2 or 100 Hz versus 200 μ A for the Ryodorakyu Instrument, the most intense electrodiagnostic device¹⁶).

During a current stimulus, electrical impedance is frequently calculated. Impedance quantifies how much the cur-

rent is impeded and is a comprehensive expression of all forms of opposition to charge flow—both resistance and reactance. In biologic tissue, two major responses are possible when an electrical field is introduced: (1) charged particles are *mobilized* in response to the field or (2) stationary particles become *polarized*. Consequently, electrical impedance entails two components, resistance (encountered by mobile elements) and reactance (for the stationary element). Reactance, in turn, is composed of inductance and capacitance. The resistance often implies the friction encountered by moving ions such as sodium and chloride. Reactance often implies polarization of stationary molecules, such as membranes and proteins, within an electrical field similar to a dielectric material embedded between capacitor plates. Inductance appears not to play a significant role in biologic systems.

The relative contributions of resistance and capacitance toward the total impedance are frequency-dependent. In an ideal resistor, the resistance directly follows Ohm's law and the current traveling through a resistor is directly proportional to the voltage across the resistor, regardless of frequency.

$$|I| = \frac{|V|}{R}$$

In a capacitor, the current–voltage relationship depends not only on the capacitance of the capacitor, but also on the voltage frequency. The amount of current traveling through a capacitor is smaller at lower frequencies and greater at higher frequencies.

TABLE 2. COMMERCIAL ELECTRODIAGNOSTIC DEVICES

<i>Device</i>	<i>Electrical output</i>	<i>Active electrode</i>	<i>Test site</i>	<i>Reference electrode</i>	<i>Measurement</i>
Apparatus for Meridian Identification (AMI-Motoyama Institute of Life Physics, Tokyo, Japan) ^{b,c}	3 V DC square wave for 256 μ s	7 7 mm silver plate with conducting gel	<i>Ting</i> points ^a	30 mm diameter EKG electrode on ipsilateral wrist	“Before polarization” current registered 1–2 μ s after electrical stimuli—believed to correlate most with acupuncture processes
Dermatron (Pitterling Electronic, Munich, Germany) (Voll) ²⁷	<2 V DC	3 mm diameter brass	EAV points throughout the body	30 mm diameter hand-held cylindrical brass electrode	Resistance and “Indicator drop” (ID)—the drop in current amplitude \sim 10–30 secs after stimuli—believed to correlate with associated organ function
Neurometer (Ryodoraku Research Institute, Ltd., Tokyo, Japan) (Nakatani) ^d	12 or 21 V DC	Cup containing saline and moist wool	24 Points on wrist and feet	Hand held “metal cylinder”	“Conductance”
Prognos ^e (MedPrevent, Walderschorf, Germany)	1.1 μ A DC for \sim 223 ms	4.57 mm diameter, flexible spring-loaded probe tip	<i>Ting</i> points ^a	6 \times 3.5 cm velcro strap to volar surface of forearm	Resistance

^aDistal acupuncture points frequently located on the proximal corners of the fingernails. Motoyama H. *Measurements of Ki Energy: Diagnosis & Treatments*. Tokyo: Human Science Press, 1997.

Note: Superscript numbers represent references in the text.

^bBorg H. Alternative method of gifted identification using the AMI: An apparatus for measuring internal meridians and their corresponding organs. *J Altern Complement Med* 2003;9:861–867.

^cVoll R. Twenty years of electroacupuncture diagnosis in Germany: A progress report. *Am J Acupunct* 1975;3:7–17.

^dSchmidt J, Sparenberg C, Fraunhofer S, Zirngibl H. Sympathetic nervous system activity during laparoscopic and needlescopic cholecystectomy. *SugrEndosc* 2002;16:476–480.

^eColbert AP, Hammerschlag R, Aickin M, McNames J. Reliability of the Prognos electrodermal device for measurements of electrical skin resistance at acupuncture points. *J Altern Complement Med* 2004;10:610–616.

$|I| = |V|\omega C$ [under steady-state conditions
with a sinusoidal-voltage input]

Therefore, at lower frequencies (low ω) capacitors tend to contribute greatly to the total impedance and to play a relatively minor role at higher frequencies. In biologic tissues, the polarization of molecules in response to a low-frequency electrical stimulus can play a prominent role in the total impedance and should be combined with resistance to derive the overall impedance when lower frequencies are used. With a DC current, however, the biologic molecules become polarized over time and currents no longer traverse through them. The resistance to moving ions becomes the main contributor to the total impedance, and for that reason “resistance” is the term frequently used to represent the impedance encountered in a DC system.

The inverse of impedance is admittance. The converse of resistance is conductance, and that of reactance is the susceptance. These latter variables may be better suited to characterize biologic response to electrical stimuli, depending on the conceptual circuit chosen to represent the biologic sample. Other terms and concepts lie beyond the scope of this dis-

cussion and include such concepts as permittivity, dielectrics, displacement currents, and transmittance, to name a few.

The electrical potential of a particular point holds no meaning without a reference. The potential is a relative quantity that quantifies how much energy capacity something possesses as compared to another thing. Once a reference point is established, an electrical potential is defined as the work required to move a unit charge from the point of reference to its present location. The total amount of work is proportional to the charge of the ion.

BIOIMPEDANCE AND BIOELECTRICITY

The study of electrical effects in biologic systems can be categorized into two fields: bioimpedance and bioelectricity.¹⁷ Bioimpedance is a measure obtained when an external electric source is applied to a biologic organism. Impedance and admittance are examples of such measurements and they assess *exogenic* current. Bioelectricity is a broader concept and includes measures of electrical currents associated with life processes. Electrical potential is a typical mea-

sure used to study bioelectricity due to the minimal amounts of current required to obtain a measurement. It measures *endogenous* currents.

Several properties of biologic systems make them notably different in their behavior compared to electrical circuits:

1. *Ionic currents*—In biologic tissue, the charge carriers are mainly ions, whereas, in electrical circuits, the carriers are electrons. This becomes a significant factor at the electrode–tissue interface where the electron-to-ion charge transition occurs.
2. *Complexity*—Biologic tissues are extremely complex with heterogeneous materials at multiple spatial scales. This leads to interfacial effects, shunt paths, and frequency-dependent effects that cannot be readily modeled by a lumped circuit abstraction such as a capacitor or a resistor.
3. *Nonlinearity*—Many parameters do not maintain their values at varying intensities. Electrical resistance, for instance, can change with current amplitude, frequency, and direction. For current frequencies above 1 MHz, for instance, ionic flow greatly diminishes as it becomes too slow to adjust to the rapid change in current direction.
4. *Open system*—Living biologic organisms are open systems and cannot easily be isolated as is possible with electronic circuits. Emotion, perspiration, movement, and respiration are examples where external influences can dramatically affect the reliability of electrodermal measurements.

SKIN

Skin is divided into three major layers: the epidermis; the dermis; and the hypodermis (also known as subcutaneous tissue).¹⁸ The epidermis is the most superficial layer and is divided further into five layers (from most superficial to deepest) as follows: the *stratum corneum* composed of largely dead keratinized tissue; the *stratum lucidum* found only in thick epidermis (e.g., palm, sole); the *stratum granulosum* where keratinization is initiated; the *stratum spinosum/malpighii* composed of spiny, prickly cells that interlock to structurally support the skin; and the *stratum basale/germinativum* composed of continuously dividing cells to generate a steady supply of keratinocytes to the epidermis.

The dermis is frequently considered to be divided into two layers. The *papillary* layer is largely loose connective tissue and contains Meissner's corpuscles, sensory touch receptors, and capillaries to nourish the epidermis. The *reticular* layer is made of dense irregular connective tissue and contains Pacinian corpuscles, sensory receptors for deep pressure, sweat glands, lymph vessels, smooth muscles, and hair follicles. The deepest skin layer, the hypodermis, is made of loose connective tissue where adipose, large blood vessels, and nerve bundles exist.

Electrically, the most superficial epidermal layer, the stratum corneum, offers the greatest resistance to electrical currents. The dry keratinized tissue presents a barrier to the flow

of most charge carriers. At frequencies less than 10 kHz, skin impedance is largely determined by the stratum corneum. At 10 kHz, it represents 50% of the measured impedance¹⁹ and at 100 kHz only 10% of this impedance.²⁰ These values are derived from the use of large macroelectrodes, and, for smaller electrodes, the impedances from the stratum corneum are even higher. Because the stratum corneum plays such an important role, factors that affect this skin layer's properties can dramatically alter the electrical measures. Skin hydration influenced by humidity or the use of a wet contact electrolyte, for instance, can significantly lower the overall impedance. With low sweat activity and a dry environment, the skin admittance can be less than 1 $\mu\text{S}/\text{cm}^2$ at 1 Hz. With saturation by water or an electrolyte, this admittance can increase to greater than 100 $\mu\text{S}/\text{cm}^2$.¹⁷ Breakdown of the stratum corneum by either trauma or rigorous rubbing can also reduce the impedance. In some cases, the electrical currents from electrodermal devices themselves can burn the epidermal layer and contribute to a sudden, inexplicable drop in impedance levels.²¹ This tends to occur in devices that introduce large current or voltage amplitudes.

The most important, yet probably most understated, factor in electrodermal testing is the sweat duct. Sweat ducts can act as an electrical short circuit where charge carriers can bypass the stratum corneum altogether. Most ionic flow traverses the sweat duct,²² and the lower resistance and impedance found at the palms, soles, and face are easily explained by the high densities of sweat ducts found in these areas. Sweat ducts may also be a possible explanation for the reported lower impedances found at acupuncture points.

The susceptibility of electrodermal measures to factors associated with skin clarifies why rigorous attention should be paid to the testing conditions of the skin. The investigator should pay particular attention to skin hydration, stratum corneum thickness, skin structural integrity, and sweat-gland density.

ELECTRODE–TISSUE INTERFACE

In ideal situations, the measure of electrical potential or electrical impedance should be a manifestation of the biologic tissue itself. Unfortunately, the electrode–tissue interface is part of the equation and can play a nonnegligible role in the final measurement, particularly in current-delivering systems. The moment an electrode is submerged in water or biologic tissue, a charge distribution develops at the liquid/tissue aspect of the interface. Ions are either attracted or repelled by the electrode surface charge. This electrostatic effect is greatest nearest the electrode surface and diminishes with distance as diffusion of ions play a more prominent role.

The net effect is an electrical potential difference across the interface frequently referred as a half-cell potential. This half-cell potential applies to a single electrode and arises from two main factors: metal ionization and electron-to-ion charge transfer. The effect of metal ionization on half-cell

potential depends largely on the *type of metal* electrode used for experimentation. This potential can be estimated with the *metal/ion equilibrium potentials* provided in tables found in standard chemistry textbooks. Metal ionization leads to a negative potential on the electrode as positive metal ions enter the solution. Conversely, precipitation of a metal ion onto the electrode leads to a positive potential on the electrode.

The effect of electron-ion charge transfer on half-cell potential depends on the *chemical reaction* occurring at the electrode surface. It can be estimated with the *equilibrium electrode potentials for redox reactions* also provided in standard textbooks. These equilibrium potentials are frequently categorized into reduction and oxidation reactions. Reduction reaction occurs at the cathode where charge from an electron is transferred from the electrode to a molecule within the solution/tissue. Oxidation reaction occurs at the anode where ions or neutral molecules within the solution/tissue lose an electron to the electrode. These redox potentials reflect the energy required to transfer charge from electrons in the electrode to ions or neutral molecules in solution. In cases of high redox potential, charges do not readily transfer across the interface and electrons can accumulate (at the cathode) or become depleted (at the anode). This process generates strong polarization at the electrode surface until sufficient energy is introduced to overcome the charge transfer barrier and permit electrons to be transferred to the tissue and, conversely, from tissue to electrode.

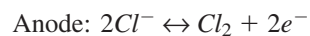
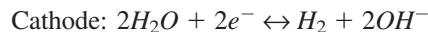
In electrodermal devices, this polarization can interfere with impedance measures and behave like an unwanted capacitor added to the system. Because charge accumulates greatest at lower frequencies, DC circuits are particularly susceptible to this confounding effect. What makes this confounder so unsettling is its highly variable nature, and investigators cannot simply predict and subtract the confounder's influence from the obtained impedance measure.

Polarization at electrode surfaces becomes less important at higher frequencies since the polarization at the electrode cannot be generated quickly enough in the short cycle and currents can be transmitted by means other than ion conduction (i.e., displacement current). Larger electrodes are also less susceptible to polarization effects because electrode polarization is inversely related to the surface area of the electrode. As discussed below, electrode material can also influence the level of polarizability.

ELECTRODE MATERIAL

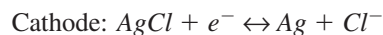
The electrode material is an important determinant in the polarizability of an electrode. This stems from the electrode's role in the transfer of charge from the electrode to the biologic tissue (and vice versa). The electrode can play either a passive or active role. In inert electrodes such as platinum, stainless steel, or titanium, the electrode primarily serves as a conduit for electron flow and does not directly participate in the redox reaction at the electrode sur-

face. For instance, two platinum electrodes immersed in saline solution would yield the following reactions at the cathode and anode respectively:



Since the total redox potential is ~ 2.0 V, no redox reactions occur at the electrode surface, no transmission of ions occur across the solution, and no current is actually registered through the circuit until this external voltage threshold is reached. These inert electrodes are considered "polarizable."

For a less inert electrode such as silver-silver chloride (Ag/AgCl) electrodes, the material within the electrode actively participates in the reactions for the transfer of charge from electrode to biologic tissue (and vice versa). For example, two Ag/AgCl electrodes immersed in saline would produce these following reactions at the cathode and anode respectively:



In this instance, even a small voltage would generate an electrode reaction and a current will be registered coursing through the circuit. This property confers a level of immunity to the Ag/AgCl electrode from local polarizing effects and, for this reason, the Ag/AgCl electrode is considered "nonpolarizable" and the best electrode for biology and medicine for DC-carrying applications. The biocompatibility of silver, however, is not entirely clear.

Under DC-potential settings where strict-zero current conditions are established, the platinum electrode functions well, as no current is being introduced to produce electrode polarization. Platinum may, in fact, be the preferred electrode for electrical potential measures because of its high level of biocompatibility. For obtaining electrical potential in tissue, one must also be careful to account for the combination of electrodes used for experimentation. Two different electrode materials can generate an electrical potential difference as high as a few hundred millivolts originating from differences in metal-ion equilibrium potentials.¹⁷ In this case, one may mistakenly interpret the measurement as an intrinsic characteristic of biologic tissue. Two identical Ag/AgCl electrodes, however, often generate less than 1 mV in DC potential differences.⁷ Identical electrodes with minimal metal/metal ion potentials are the preferred arrangements for DC-potential readings.

CONTACT MEDIUM

A number of choices are available for a contact medium placed between electrode and skin. These choices include dry contact (no intervening medium), wet electrolyte (including paste, creams, and liquids), hydrogels (solid gels

with natural or synthetic hydrocolloids), and insulating materials. Hydrogels are the most common type of contact medium found in medical applications and can be found in most electrocardiograph and electroencephalograph electrodes. The appropriate selection of contact media for electrodermal devices depends on the experimental conditions. Even now, despite the extensive studies performed in the various types of electrodes, no single medium is perfect for all experimental conditions and researchers still debate the merits of each medium type.²³ Nevertheless, several important factors should be considered in assessing the appropriateness of a medium. They include contact area between electrode and medium and between medium and tissue, polarization of the electrode–medium interface, and the moisturizing effects of the medium on the skin.¹⁷

Because the amount of current passing from electrode to tissue is dependent on the cross-sectional area of passage, the contact area should be maintained as constant as possible. For dry electrodes, the irregularity of the skin surface and the associated variable contact area make this requirement difficult to achieve especially in the presence of physical movement. In addition, pressure can increase the effective contact area and thereby reduce the electrical impedance readings. This may explain why applying greater pressure leads certain acupuncture-point locator devices to mistakenly identify non-specific areas as acupuncture points. Wet electrodes are also prone to contact-area variability when a lateral spread of electrolyte over the skin occurs. Generally, hydrogels are spared from this confounding effect due to their ability to maintain constant contact area with both electrodes and skin.

Contact mediums should minimize the polarization effects seen at the electrode surfaces. This can be achieved through the appropriate selection of electrode and contact medium combinations. Silver/silver chloride electrodes and chloride-containing wet electrolytic solution, for instance, form a good pair for minimizing electrode polarization effects. Wet electrolytes have the advantage of providing the adequate ionic and molecular movement needed for the acceptance and donation of charges from the electrode surface. For dry and insulating electrodes, however, freely mobile ions and molecules do not occupy the space between the electrode and the skin, and ionic currents do not readily occur. Strong polarization effects develop at the surface. For this reason, dry and insulating electrodes are not ideal for low-frequency currents compared to wet mediums (although some studies may dispute this²³). At higher frequency stimuli, currents traverse through a different mechanism known as a displacement current, and it may confer dry or insulating electrodes with added advantages over wet electrodes.

The contact medium may also directly influence the skin impedance itself. By moistening the stratum corneum, wet electrolytes and hydrogels (albeit slower) significantly diminish the primary resistive force and can lead to greatly decreased impedance or resistance. The electrolyte may also fill sweat ducts and further diminish the impedance by creating a shunt for ionic currents to flow. Dry metal electrodes may

also, with time, contribute to sweat and humidification of the stratum corneum. These effects are tolerable as long as the investigator wishes to bypass the stratum corneum as a means to evaluate possible deeper point/meridian processes.

ELECTRODE GEOMETRY

Because electrical currents in biologic tissues are not uniformly distributed, a variable that accounts for the current's magnitude and direction at a segmental tissue volume is preferred. This variable is called the current density. It importantly conceptualizes biologic tissue as an object composed of finite parts, each contributing to its portion of the total impedance. Volumes with highest current density contribute greatest to the overall resistance and impedance of the tissue. Since the highest current density occurs near the electrode, much of the resistance and impedance parameters are determined by the area closest to the electrode.¹⁷ This area is frequently referred as the constriction zone. In the case of skin electrodes, changes in the local skin resistivity can greatly influence the overall tissue impedance value, whereas changes in tissue conductivity at deeper layers may not dramatically alter the total impedance due to the lower current densities traversing there.

This fact can be used to gain an advantage as well. By making one electrode much smaller than the other, one can increase the current density around the smaller electrode and thus cause the local resistivity around the smaller electrode to play a greater role in the impedance readings. The volume under the smaller “active” electrode becomes the focus of study while the area under the larger “indifferent” electrode plays a more passive role. Such an arrangement is called a *monopolar setup*. *Dipolar* current injecting systems, on the other hand, use two identical electrodes each contributing equally to the output readings.

For disc electrodes, the greatest current density is around the electrode periphery. Consequently, investigators should be cautious in using larger electrodes over purported acupuncture points considering that much of the current can bypass the area of interest. For needle electrodes, the highest current density is located at the tip. Most of the current is injected through the shaft, but the current density at the tip is determined by the length/radius ratio and can be twenty times as high as that of the shaft (for a 0.5-mm needle inserted 10 mm deep).¹⁷

ELECTRODE ARRANGEMENTS

The arrangement of electrodes dictates, to some extent, what volume of tissue is being evaluated in electrodermal studies. In dipolar electrodes, the closer the electrodes are placed together, the more likely superficial layers, such as the epidermis, are being measured. As the distance between

dipolar electrodes are increased, the current traverses through deeper layers and the measuring depth increases. Nevertheless, the epidermis immediately under the electrode maintains an important contribution to the overall impedance since the current density is still greatest near the electrode. Measuring depth is an important consideration for those who feel that acupuncture points and meridians are manifestations arising exclusively from the skin or, conversely, from deeper tissue.

The importance of electrode arrangement may be more critical for DC potential applications. As mentioned previously, DC potential values have little meaning without a reference and thus a reference electrode is needed. Due to the common use of differential amplifiers in DC-potential devices, a third ground electrode is also required. These devices output the differences in voltage between the active electrode (located at an acupuncture point) and a reference electrode (located at an adjacent nonacupuncture control) while using the ground electrode to determine the relative potential values for the two. Placing the active and reference electrode too close to each other can lead to failure in distinguishing the activities of the acupuncture point. Placing the two electrodes too far from each other can contribute to unwanted noise originating from the intervening spaces. Power-line noise and movement are examples of such noise. The ground electrode should also be placed on a relatively inactive area for it, too, can contribute to undesired noise.

METHODS TO OVERCOME ELECTRODE POLARIZATION

As mentioned previously, polarization at the electrode surface is a major confounder for electrodermal measures. One can *minimize* polarization by using nonpolarizable electrodes (such as Ag/AgCl electrode), larger-sized electrodes, or high electrical frequencies. Other methods can *compensate* for the polarization effect. For instance, the electrode polarization impedance can be measured separately and subsequently subtracted from the impedance obtained in tissue. Alternatively, the distance between electrodes can be varied along a linear trajectory. One can measure the impedance between two electrodes at a given distance, move one of the electrodes further away, and then obtain another impedance measure. The difference in impedances would be attributed to the segment not initially measured by the first.

A more widely accepted technique used to overcome electrode polarization is the four-electrode method. In this technique, four electrodes are placed linearly on or in tissue. The outer two-electrodes introduce a current while the inner-two electrodes measure the voltage. Impedance is calculated by dividing the voltage (between the inner two electrodes) by the current (delivered at the outer two electrodes). Because the inner two electrodes do not carry current, the polarization experienced at the outer electrodes is not encountered and the

measured voltage is interpreted as an accurate representation of the tissue impedance between the two inner electrodes. Although, the four-electrode method is considered, at present, the "gold standard" for measuring bioimpedance, it is not without its faults.²⁴ For instance, greater impedance in the tissue between the inner lead electrodes and the outer current-delivering electrodes can contribute to diminished registered voltages at the inner electrodes and to the wrongful interpretation of decreased impedances at the tissue of interest.²⁴

DEVICE HARDWARE

The level of complexity and diversity in electrodermal devices is too great to permit a discussion about device hardware concise enough for this review. Regardless of the sophistication of the device, however, the critical factor in evaluating the device is its reliability and validity. Does it accurately and repeatedly deliver the stated amount of electrical current or voltage? Does it administer precise frequencies? Does it account for 50/60 Hz power lines or other sources of noise? Are the measures valid? A key component to these questions is the rigorous testing of devices against standardized and calibrated measures. Ideally, testing should occur in the research site to account for any unexpected noise originating from the research environment. DC potential devices, in particular, are prone to noise stemming from power lines, voltage differentials between patient and device, among other factors due to the absence of an external current that can essentially override these effects.

ASSESSMENT OF POPULAR ELECTRODERMAL DEVICES

The four major devices listed in Table 2 are DC-resistance devices using a monopolar arrangement. The probes placed over an acupuncture point act as an active electrode and the resistance is largely determined by the skin underlying the probe. Deeper tissue layers also contribute to the overall resistance since the distance between the reference and active electrode is large enough to permit greater measuring depths. However, it is unlikely that this contribution would differ significantly between an acupuncture point and a nonacupuncture point a few mm away.

Due to the electrode materials, the DC current delivery, and the small electrode size, all these devices are prone to electrode polarizing effects. The Apparatus for Meridian Identification (AMI-Motoyama, Institute of Life Physics, Tokyo, Japan) may be immune from this effect by relying on the instantaneous "before polarizing" current but would have to assume an electrical conduction through tissue to completely neglect the necessary potential drop across the electrode arising from the transfer of charge from electrons to ions. The Dermatron's (Pitterling Electronic, Munich, Germany) emphasis

on the indicator drop may also nullify the concern for the electrode polarizing effects since the change in resistance over 10–20 seconds are likely to stem from polarization of biologic macromolecules within living tissue and not the electrode.

Variable contact area, pressure, skin hydration, and, most importantly, the presence of sweat ducts can all confound these devices to one degree or another. The reliability and validity of the machinery cannot be determined from the information provided by the literature. As a whole, these devices are imperfect from a technical standpoint and require major modifications to overcome the aforementioned confounding effects.

CONCLUSIONS

The extent to which acupuncture points are truly associated with unique electrical measurements remains a contested issue and should be systematically reviewed. The numerous complicating factors involved in the electrodermal readings present a daunting challenge for anyone intent on studying the electrical characteristics ascribed to the acupuncture point and meridian. From a technical standpoint, the present commercial electrodiagnostic devices mentioned in this review are inadequate, and different methods are likely needed to appropriately pursue this line of research.

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