Quantitative analysis of Electrical Skin Conductance in diagnosis: Historical and current views of Bioelectric Medicine

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ABSTRACT

The history and scientific basis for using electrical skin conductance measurements for diagnostic purposes are presented through new and updated analyses of past and current scientific data. Skin conductance is a measure of acupuncture points by two to six fields adjacent to skin points. Data presented here indicate that early stages of cancer, chronic viral infection (Epstein Barr virus, human immunodeficiency virus), and chronic inflammatory diseases are characterized by hyper-conductance at skin points associated with lymphocytes, joints, and connective tissue compared to the same points in controls. In contrast, terminal stages of cancer and AIDS are characterized by lower-than-normal electrical conductance, especially at the spleen point. Given reliable electrodermal screening instruments, early diagnosis of significant disease states via measurable changes in electrical conductance may be possible, making it possible to provide early and more effective auricular treatment.

INTRODUCTION

Bioelectromagnetic medicine (BEM) is an emerging science which studies the interactions between electromagnetic fields and the electrical properties of biological tissues and cells (1,2,3,4). Electromagnetic fields induce selective electrical changes in the micro-environment around and within cells (5). Numerous observations ranging from the cellular-molecular to the organ-system levels explain how electromagnetic fields interact with living systems. At the cellular level, a direct relationship exists between the electrical potential of the cell membrane and signal transduction with consequential gene expression (1,6,7,8). In vitro have demonstrated quantitatively that electromagnetic devices have therapeutic effects on immune and nervous system cells, including lymphocytes, natural killer cells, leukocytes, and neurons (2,9,10,11,12,13). For example, magnetic-field exposure to thymocytes enhanced signal transduction processes via calcium second messengers (14,15). Minute exposure of direct current to cultured neuronal cells evoked nearly equivalent protein synthesis as did nerve growth factor resulting in neuronal cell regeneration (16). New biomedical technology devices are needed for bioseizing of human physiology and multi-organ screening if instruments are reliable.

BEM instruments measure electrical properties of organs and tissues through related skin points on the body. These points are frequently acupuncture points, thus these instruments are generically called: Electromyopuncture according to Voll (SLA-V), electrodermal screening (EDS), or galvanic skin resistance analysis (GSR). Half a century ago, Rosenthal demonstrated that application of negative D.C. voltage and steady current to the skin caused the skin resistance to fall (17,18,19). Now, modern devices measure electrical resistance by providing a specific electrical stimulus to skin points using computer-controlled skin meters. Product names and stimuli provided by these devices are LISTEN (5.0 volts), compton (1.3 volts), veg (1.5 volts), demerton (1.6 volts), inter (3.0 volts), biores (0.6 volts), maso (1.3 volts), chas (1.2 volts), and photonic (5.0 volts). A standard amount of voltage is applied through a hand-held bar to the body, then passing direct current to skin points and consequentially moving ions in specific directions. Electrical current is measurable at specific skin points and is characterized by the following: 1) pH; 2) ion movement; 3) the number of ion channels in the cell membrane; 4) the permeability of the cell membrane; and 5) opening and closing of ion channels. Electrical resistance can be calculated from the measured current using Ohm's Law, V = IR (voltage = current x resistance, where resistance = inverse of conductance). Given a specified value for each parameter, a charge accumulates in the skin thus elevating increased permeability in cells of the epidermis and dermis (20, 21, 22). In simpler words, increased permeability results in an increased conductivity for the sites applied voltage.

The reason for hesitation on the part of scientists and clinicians to accept EDS bioelectromedical instruments as useful tools for diagnosis even though these techniques have been available for decades. This hesitation, in part, arises from lack of clarity between different electrodermal screening devices, their calibration and what they reliably measure (23). There are at least four variables that are significant:

- Standard voltage used: the instruments available vary in voltage applied, some use 1.2 - 2.0 volts while others apply 5.0 volts. Due to the fact that the average surface electrical potential of a grounded human is approximately 3.0 volts; signal-to-noise ratios significantly differ in various instruments (4).
- Standard timing for measurements: electrical conductance is dynamic, fluctuating over time. Measuring times for different instruments vary from a constant 1 second to random lengths of time. Therefore, characterization of conductance depends upon standard duration of timing.
- Conductive skin-point location: reliability of measurements depend upon correct point location and consistent pressure on skin points.
- Operator reliability: operator skill and reliability are important if the instruments are to be used for diagnostic purposes.

This manuscript presents scientific support to answer the following question: Do electrodermal screening devices provide accurate diagnostic information to clinicians about their patients? In order to answer this question, new analysis of previously published laboratory data are presented in graphic form. Additionally, new data collected from current clinical studies are presented.

TREYORY, RELIABILITY AND SCIENTIFIC BACKGROUND OF ELECTRODERMAL SCREENING

The theory of EDS is based on findings that skin conductance at specific points of approximately 1 cm2, differs from the conductance h

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may explain why EDS has potentially useful diagnostically. The cell membrane is electrically asymmetrically created by an unequal distribution of net cations on each side of the cell membrane. This characteristic creates direct current electrical potential that is maintained at different potential conditions (41). Abnormal cells on the microscopic level, such as the cells of the Koch’s postulates, show a reduction in the rate of ion transport across it and the subsequent change in electrical potential (42, 43). Vail infection and bacterial infection is also less as shown, after the presence of the cell membrane. The electron microscope is used to visualise the changes in the cell in the metastatic milieu. Vail’s experiment on the surface of the cell membrane with the use of electron microscopy in the late 1940’s and his reports that results were also confirmed in the late 1940’s and its reported that results were confirmed in the late 1940’s and its proposed that the physical changes in the cell were highly reflected by those electrical cells while the contamination and those changes were not reflected by other cells on the cell membrane. The scientific research of Yell’s publication in English was that the cell was being reflected by diagnostic analysis of patients’ conditions. Schimmel, Vail’s collaborator, presented electronic tracings profile which demonstrated the amplitude of the contaminating and the fluctuations of the contaminated over time the previous diagnostic studies (23).

Many studies successfully interpreted electrical conductors at skin points associated with the large immune system and X-rays of living tissue. One of the first scientific experiments correlating biophysical principles to organs in the body via measurements of electrical conductance was presented by human subjects working in a=contextualisation condition (39). Previous studies had by the clinician’s use of biophysical measurements to contextualise acute responses 5% of patients with normal blood pressure are for the first time presented in graphic form (Figure 1). Eighteen patients with uniaxial aortic insufficiency or cardiac failure demonstrated a marked higher conductance. An X-ray portrait, the image of the patient, located on the forehead, then the subject’s skin points (16.1 ± 2.7 ± 10-5 μS/m) versus 5.6 ± 2.7 ± 10-5 μS/m). Larger differences were observed in the best presenting patients, LIVES, located on the inner, between the subcutaneous patient versus with our patient’s liver disease. These data which were obtained on the skin points associated in Figure 2 but not that patients with liver inflammation, ie. liver biopsies or aortic biopsies had high electrical conductance of 48.4 ± 8.1 ± 10-5 μS/m compared to patients with no liver disease who had higher conductance of 4.8 ± 0.5 ± 1.0 x 10-5 μS/m. These are significant differences in electrical conductance between patients with and without liver disease at LIVES. B

Bergmann and Woolley’s data indicated that electrical conductance at skin points associated with specific tissues and did discriminate between healthy and diseased tissues.吮

Similarly, Sullivan et al. (40) found that X-rays of normal patients vs. the point measurements most closely evaluated in four long-term patients and 25 healthy controls. LIVES measurements of electrical conductance in the group of long-term patients showed a difference between 100% below the optimal values of the healthy controls (Bergmann, unpublished).

The cellular facsimile is available to electrical conductance
dio frequencies of 106 to 108 Hz (65). Thus, the frequency range of the stimulus signal seems to affect the conductivity measured. Progressive stages of tumor development in mice produced quantitatively significant different conductivities. When tumors were directly measured, conductivities were 6.0-7.3 times higher than normal tissue (66). The high conductivity may reflect either the increased net water content or the reduced potassium content or the altered chemical shifts within the cell membrane (46). Early stages of cancer may produce high conductivities due to retention of sodium and water, while later stages of cancer produce lower than normal conductivities due to tissue necrosis. Cancer, like AIDS, results in a destruction of the body. This ectoionization causes histological changes which consequently produce lower than normal electrical conductance profiles. An example of this is the disrupted architecture of the lymph nodes with involved germinal centers during the late stages of AIDS (67). Lymph tissue cells that become necrotic during AIDS would be expected to conduct current to a lesser extent than healthy tissue cells due to their disrupted cell membranes (Figure 3-4).

CURRENT CLINICAL DATA USING LISTEN ELECTRODERMAL SCREENING DEVICE

Methods and Instruments:
Electrodermal conductance measurements on several groups of patients were analyzed by us to test the hypothesis that measurements on skin points can detect differences between controls and patients with either chronic inflammatory conditions, degenerative illness or asymptomatic human immunodeficiency virus (HIV) (Figures 3-4). The EEDS device named, Life Information System TEN (LISTEN) (Bioidenture, Inc, Oxon, UT) was selected because it is a modified computer-based ohm meter that can store the dynamics of electrical conductance data during the testing period and then graphically plot the output instantly. This instrument provides a standard 2.0 volts of direct current (D.C.) and standartizes measurements over a one second time period. The patient holds a ground electrode, brass bar, in the palm of the hand, while a test probe is used to touch specific skin conductance points. The body becomes a closed circuit, where a low-voltage electric current is output from the LISTEN through the probe, through the body, and back to the LISTEN through the ground electrodes. The LISTEN measures the amount of electrons that flowed while the circuit was closed. The LISTEN provides a significant electrical signal above the background voltage of the skin, magnification of measuring times, and quantitative output from which data collected between patients can be compared.

Points selected for analyses were five of Voll's conductance points related to the peripheral immune system plus four traditional Chinese acupuncture points related to the spleen. The peripheral immune system points (associated with lymphatics, joints, and connective tissues) are often involved with chronic inflammatory responses, and are not considered significant by the Chinese. The spleen is not considered essential by conventional medicine, and is considered "wet" to the virility of the person by the Chinese. Electrical conductance of the immune points were measured on each patient during their first visit to the University Health Clinic in Seattle, Washington. The mean values of five peripheral points and the mean values of four 'core' spleen points were calculated for each patient and then the mean values of each of the two categories for all patients in each group were determined. The two categories for each group were plotted (Figure 3).

Results:
Electrodermal conductance measurements on different patient groups were analyzed for differences in immune-related points between non-viral, non-cancer controls and patients with various chronic symptoms involving the immune system. Figure 3 demonstrates that control patients (n = 34) had conductances within the normal range (45-55 relative units) in both the peripheral immune and spleen areas. Patients with chronic inflammatory conditions (n = 22), such as psoriasis in situ, chronic and symptomatic Easiin B cell infection, rheumatoid arthritis, and leukemia had higher than normal electrical conductances in peripheral immune system points (P < .0001). The conductance of acupuncture point points related to the spleen remained within the normal range, however were statistically different from the controls (P < .02). Patients with degenerative diseases (n = 7), i.e. terminal stages of cancer or symptomatic AIDS, had electrical conductances at spleen points below the normal range (P < .0001). The conductances of peripheral immune points remained in the normal range however were statistically different than the controls (P < .002). HIV asymptomatic patients (n = 10), i.e. in earlier stages of the disease process had electrical conductances that were higher than normal in the peripheral immune areas (P < .005) and were normal in the spleen points.

The electrical conductances at each of the nine skin points tested in each patient population is shown in Figure 4. The conductances of all nine points for control patients fell within the normal range (Fig. 4a). The distribution around the normal range was small as indicated by the small standard error of the mean. In contrast, there was a distinct high-conductivity for patients with chronic inflammation (Figure 4b). Amalgam of the points (sevens out of nine, 78%) rose above the normal range, especially in those points labeled J0, L.Y, L'Y, L'Y, and Fl which Voll correlated to joints, lymphatics, lymph drainage in the throat, lymph glands in the lungs, and connective tissue, respectively (25). The points related to the spleen were closer to the normal range however with inflammatory conditions there was a striking difference between the "control" group and patients with degenerative illnesses such as psoriatic AIDS or cancer (Figure 4d). All of the electrical conductances of patients with degenerative illnesses were significantly lower than the patients with inflammatory problems. All of the points related to the SP (spleen) acupuncture meridian were lower than the normal range in the degenerative illnesses.

Table 1 provides a two-tail t-test statistical analysis of each of the data points. The data in Figures 3-4 demonstrates that the LISTEN device is capable of characterizing healthy and pathological conditions based on measures in electrical conductance. This new technique will provide a useful diagnostic tool for evaluating systems in the body that are difficult to measure by conventional means, such as the spleen, the lymphatics and the connective tissues. These biophysical data confirm the scientific research conclusions of Burr and the statements made by Voll that inflammation correlates to hyper-conductance and degenerative disease correlates with hypo-conductance.

TIME SERIES ANALYSIS OF ELECTRICAL POTENTIAL FROM PAST IN VIVO STUDY

The original study in 1940 of Harold S. Burr and associates conducted a time series experiment with normal mice of the genetic strain called CBA and the same strain of mice developing psoriasis tumors caused by bi-weekly application of a carcinogen, 9,10% solution of benzoxyrene in benzene (31). Their ex-
pericardial tumors to observe the electrical phenomena and physiological changes associated with pleura on the skin hematoxylene in benzene (treating) or with only benzene (control) compared to normal mice. The three different indications they observed were: 1) an inflammato-
y reaction; 2) the formation of albumin; and 3) the development of the cornified. Burt's data were not published previously, as they publish
d in a table format. Now, for the first time, Figure 3 graphically
d the electrical potential of the minimal mice versus the mice
cated with benzene in benzene. The group of mice receiving the benzene only are not shown. The measured electrical potential at skin across the same area at the same time of day every two weeks (51). Electrical potential differs even electrical conduction in that the former measures potential energy whereas the latter meas-
ure is a stimulus current. These data of electrical potential,
painted from his raw data illustrates changes in the same group of animals over time. Both the benzene group showed and benzene
and (Fig. 3a) suggests an inflammatory response for each to
mice. After this period the electrical potentials returned to nor-
mal in the benzene group, while the benzene group returned to normal for only two mice more after which a wave of hypo-electr-
city occurred. The amplitude of the oscillations in the nor-
mal mice (Fig. 5a) differed significantly from mice developing
spongiosis tumors (Fig. 3a). Burt observed that repeated exposure to
cornified caused systemic metabolic changes in the animals, which
are expressed in inflammatory (hyper-conductivity) and later in cancer (hyper-conductivity) (51).

New analysis of Burt's experiment:
Quantitative image analysis of Burt's data presented in Figure 5 was necessary to gain clearer insight into the oscillatory significance of electrical potential in healthy mice versus mice developing
galactomycosis. This analysis had not been performed before, thus was a new quantitative method to confirm or challenge Burt's conclusions that electrical conduction measurements significantly distinguish between health and disease states. This analysis provides a quantitative approach for discerning and evaluating oscillatory growth. Fourier analysis is a method that discovers hidden oscillations in oscilla-
tions of a given frequency to appear in the data. This shows the amplitude in Fourier transformation, the greater the confidence that a significant oscillation is represented. Fourier transformation re-
solves time-dependent data into regular periodic components. Four-
tier transforms of the data in Figure 5 identified specific oscillatory periods for the healthy mice compared to the flavomycosis-laden mice (Figure 5). Both groups of mice contained as oscillatory period in common as approximately seven weeks. This common period shows the reproducibility of the measurements since the mice are from the same genetic strain and therefore contain cellular similarities. The Fourier analysis also identified two statistically different oscillatory frequen-
cies that are characteristic of a healthy state and one characteristic of an abnormal state. Fourier transforms identified a high-frequency oscilla-
tory period every 7 weeks for the healthy CBA mice. The latter forming mice lost this normal high frequency oscillation. Instead, the abnormal mice developed a long-term oscillatory period of 32 weeks, i.e., the entire length of the study. No such oscillatory period was present in the healthy mice.
CONCLUSION

Historically and currently, EDS instruments characterize differences between inflammatory and degenerative conditions. Electrical conduction data reviewed here correspond with histological reports. Chronic inflammation, benign tumors, and early stages of cancer create pressure on connective tissue cells (68) which result in measurable cellular charge density increases. The data presented in Figures 3 and 4 demonstrate that electrical conductance is related to skin points associated with connective tissue as well as other, but not all skin points during states of chronic inflammation, chronic Epstein Barr viral infection, benign tumors, and early cancer. Chronic viral infection is considered a chronic inflammatory state because it is histologically associated with the presence of lymphocytes and macrophages plus the proliferation of blood vessels and connective tissue (68). Early stages of HIV infection are histologically characterized by follicular hyperplasia in the lymph nodes (67). Figure 4d demonstrates hyperconductance in patients with asymptomatic HIV infection as would be predicted from states of hyperplasia. Excessive cell proliferation, as seen during development, has previously been correlated with increased electric potential (59). Long term pressure on connective tissue eventually leads to atrophy of parenchymal cells and expansion with tissue with consequent loss of charge density and lower electrical conductance. Late stages of cancer are characterized by progressive infiltration, invasion, and destruction of surrounding connective tissues (68). Late stages of AIDS are histologically characterized by determined germinal centers within lymph nodes (67). The data presented in Figures 3 and 4c demonstrate that electrical conductance of immune system points related to lymphatic and skin were lower than normal, coincident with histological findings of deteriorated cell membranes. In clinical practice, EDS instruments are useful as diagnostic supplements to blood tests, radiographic imaging, and case histories. The integration of reliable and valid bioelectronic medical instruments into the clinical setting augments the ability to rapidly evaluate tissues such as the spleen, lymph nodes, and connective tissue, which are difficult or impossible to assess by conventional test procedures. As the medical community has discovered with HIV, accurate evaluation of the lymph nodes and spleen are more effective than blood testing in understanding when the immune system will fail under the burden of HIV infection (67, 65). Given reliable noninvasive screen- ing instruments, early diagnosis of chronic viral infections might be possible via measurable changes in the electrical conductances of patients. This early and quantifiable diagnostic measurements could set the stage for early, hence more effective treatment. Bioelectronic medicine offers clinicians new quantitative methods for evaluating subtle electromagnetic changes in humans.

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Figure 1

Tuberculosis Patients (n = 18)

Figure 2

Figure 3

Figure 4

Steady state error boundaries shown.
Figure 6. All measurements were taken by H. Burt and associates in 1944 between 1:30-4:00 P.M. to prevent diurnal variations (2). Data presented here were extrapolated from their graphs. The dashed line indicates the range of the normal range (56) compared to the range developing a cancerous lesion (56). A significant decrease in electrical potential above the normal range is shown during the early inflammatory response to typhoid fever and below the normal range during experiments of papilloma formation.

Figure 7. Further analysis of Figure 6. The Fourier components are shown in the X-axis. The highest percentage of the Fourier component, the more representative that specific oscillatory frequency was the data point. The oscillatory periods in the data set shown on the X-axis. Normal mice have significant oscillations in electrical potential every two, four, six, and thirty-five weeks. Mice developing tumors have significant oscillations in electrical conductor only every eleven and thirty-one weeks.

Figure 8. All data from Healthy Spectrum shows Meas Two Years of Normal Mice. However, the normal mice showed a more oscillatory pattern. The Meas One Year normal mice were similar to Meas Two Years normal mice. Figure 7 shows similar results. The normal mice show a lower potential than the tumor developing mice.

Figure 7. Inflammatory conditions of patients from 1944. Mean values of the electrical conductance identified as peripheral points with standard deviation bars are shown. Patients arriving for measurement at the Clinic were measured at the skin points associated with the peripheral immune system every three to seven weeks, i.e., during the six to eight month period. The number of cancer and AIDS patients averaged over time at the Clinic decreased (visit 7 = 1 patient, visit 2 = 2 patient, visit 3 = 2 patient, visit 4 = 2 patient). Patients with cancer group (n = 42) maintained conductance within a range of 51.2 ± 53.2 units throughout the study period. Patients with inflammatory conditions (n = 17) remained higher than normal until the final visit with conductance ranging from 54.6 to 62.1 units and patients with degenerative (n = 17) remained lower than normal with values ranging from 43.1 to 44.3 units.
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