Laplace Plane Analysis of Transient Impedance Between Acupuncture Points Li-4 and Li-12

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***Abstract*—AC impedance between two acupuncture points (Li-4 and Li-12) and two pairs of anatomically similar points with the same separation was studied via Laplace plane analysis of the time domain current response to a predetermined voltage perturbation. The series resistance between the two acupuncture points was found to be significantly lower than between either pair of control points. The characteristic impedance of an equivalent transmission line was lower and the signal propagation velocity higher for the acupuncture point system as compared to both controls.**

INTRODUCTION

We have reported previously that many of the classical acupuncture points exhibit a significantly lower DC resistance than do otherwise similar control points [1]-[3]. Having thus confirmed a widely held assumption [4] and established that at least some acupuncture points have a real physical basis, we undertook a study of the acupuncture system as a whole, including meridian lines as well as points. In particular, we wished to examine the signal transmission properties of the meridian network.

Due to the limited information available from measurements of DC skin resistance alone, we decided to investigate the AC impedance of the system of points and meridians, from which its transmission characteristics could be derived.

Previous studies of skin impedance have generally involved direct measurement of impedance and phase angle as functions of the frequency of the applied voltage or current [5]-[7] or approximation methods [8]. Any such direct measurement of skin impedance over a wide range of frequencies tends to be cumbersome and time-consuming. Measurements made with an impedance bridge have, in addition, an inherent disadvantage in that some *a priori* assumption must be made about an equivalent circuit model for skin impedance [5]. We decided instead to study the impedance of a representative portion of the acupuncture system via its time domain current response $I(t)$ to a known external voltage perturbation $V(t)$. The corresponding frequency domain functions, including phase angle and real and complex components of impedance, were computed by means of a Laplace transformation. The time domain data could be obtained rapidly and subsequent analysis necessitated no prior assumptions about the form of the frequency domain functions.

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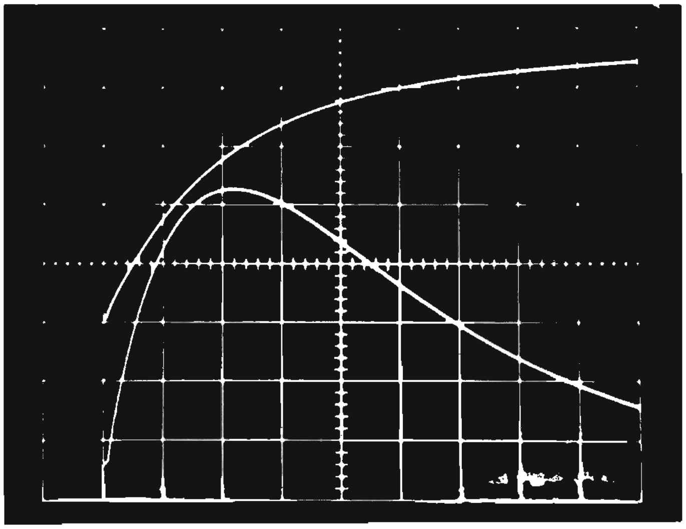

Fig. 1. Typical response curves at 2 μs/cm. The upper trace is $V(t)$ at 0.2 V/cm; the lower trace is $I(t)$ at 5 μamp/cm.

METHOD

The output of a Tacussel model GSTP-3 function generator was controlled by a model PRT-20-010-MOD potentiostat to produce an input voltage with a rise-time of 10 μs, a maximum amplitude of 1 V, and predetermined interval and duration. The voltage $V(t)$ was displayed on channel 1 of a Tektronix 564 oscilloscope with a 3A6 dual-trace input and 3B4 time base. The subject current response $I(t)$, directly proportional to the voltage across a small series resistor, was displayed on channel 2. We found that a pulse duration of 100 μs was sufficient to establish the DC current limit for all subjects. Preliminary studies indicated that an interval between successive pulses of less than 5 times the pulse duration often resulted in a current response different from that obtained with a single pulse; greater interval yielded a trace indistinguishable from a single pulse response. Therefore, the pulse interval was set at 1000 μs throughout the study. The resulting display was adequate for photography at sweeps slower than 0.2 μs/cm.

The two acupuncture points Li-4 and Li-12, found earlier to be valid points on most subjects [1], were located by means of standard charts and anatomical reference points (9). After the skin was cleaned with 90% ethanol followed by distilled water 1-cm diameter carbon-impregnated conducting-rubber electrodes were applied and connected to the voltage source. The resulting oscilloscope display of $V(t)$ and $I(t)$ was photographed for later analysis; a typical result is shown in Figure 1. Several exposures at sweep speeds ranging from 0.5 μs/cm to 10 μs/cm were necessary in order to obtain sufficient data to define the curves accurately for mathematical analysis. Two pairs of anatomically similar control points located in areas devoid of meridian lines or other acupuncture points were treated in identical fashion. Since the Li meridian is situated approximately on the accepted border between the dorsal and ventral surfaces of the forearm, one pair of control points was on the dorsal surface, the other on the ventral surface, so that any effect due to underlying differences in anatomical structure or skin texture would be clearly shown. The control points were located 1-½ cm away from the acupuncture points such that the distance between each pair of control points and between the acupuncture points was the same. All points were in areas devoid of cuts, abrasions, or pigmented moles, and there was no gross variation in skin texture. The subject was informed in general terms of the purpose of the study, but was ignorant of the nature of the various points. This procedure was repeated on a total of 10 subjects.

Points defining $V(t)$ and $I(t)$ were used as the input data for real and imaginary axis Laplace transformations performed on the time domain data for each individual test, using a FORTRAN program developed by Pilla [10]-[11]; The program output included data on skin impedance and phase angle as functions of frequency (DC to 1 MHz).

RESULTS

Bode analysis of the frequency domain data obtained from the imaginary axis Laplace transformation established that all of the experimental curves could be described by the complex impedance function

$$Z(\omega) = R_1 + 1/(1/R_2 + j\omega C),$$

which could be separated into its real and imaginary components

$$\mathrm{Re}\, Z(\omega) = R_1 + 1/(\omega^2 C^2 + 1/R_2^2) \text{ and}$$

$$\mathrm{Im}\, Z(\omega) = -\,\omega C/(\omega^2 C^2 + 1/R_2^2),$$

with a phase angle

$$\phi(\omega) = \tan^{-1}\,(\mathrm{Im}\, Z(\omega)/\mathrm{Re}\, Z(\omega)).$$

The real axis Laplace transform yielded the function

$$Z(\sigma) = R_1 + 1/(\sigma C + 1/R_2),$$

corresponding to a classic model for skin impedance [12]. The circuit elements R_1, R_2, and C could then be found by examination of the appropriate low and high frequency limits. For example, in the low frequency limit a graph of $|\mathrm{Im}\, Z(\omega)|$ versus ω yields a straight line through the origin with slope CR_2^2, while in the high frequency limit, $|\mathrm{Im}\, Z(\omega)|$ versus $1/\omega$ is a straight line with slope $1/C$. Two examples are shown in Figure 2. The normalized mean values for the circuit elements R_1, R_2, and C, together with the minimum phase angle $\phi_{\min}$ are listed in Table I.

The normalized series resistance R_1 was significantly lower between the two acupuncture points than between either pair of control points ($p < 0.05$, 2-tailed matched-pairs t-test). It should be noted that these controls were chosen so that any effect due to differences in anatomy or skin texture would be clearly shown (control line 1 was immediately dorsal to the experimental line while control 2 was just ventral to it). We did find that the capacitance of control 1 was significantly greater than that of control 2, even though the experimental capacitance was not significantly different from that of either control. Of the four parameters, the phase angle showed the least variation between individuals (see Table I).

It is useful to consider the acupuncture system as a network of transmission lines composed of elements defined by the acupuncture points. We can then assume that our two points define a single element with a series impedance R_1 and a shunt impedance $1/(1/R_2 + j\omega C)$. The characteristic impedance of an infinitely long transmission line composed of such elements is

$$Z_c(\omega) = (R_1/(1/R_2 + j\omega C))^{1/2}.$$

If the line is terminated by its characteristic impedance, its signal propagation velocity is [13]

$$v(\omega) = \omega/(R_1((1 + (R_2 \omega C)^2)^2 - 1)/2R_2)^{1/2}.$$

The resonant frequency of the line is given by

$$\omega_C = (4(R_2/R_1)^2((\pi/2)^2 + (R_1/R_2)^2/2)^2 - 1)^{1/2}/R_2 C.$$

Normalized mean values for these, together with ω_C, are listed in Table II.

The signal propagation velocity $v(\omega)$ and the resonant frequency ω_C were significantly greater between the two acu-

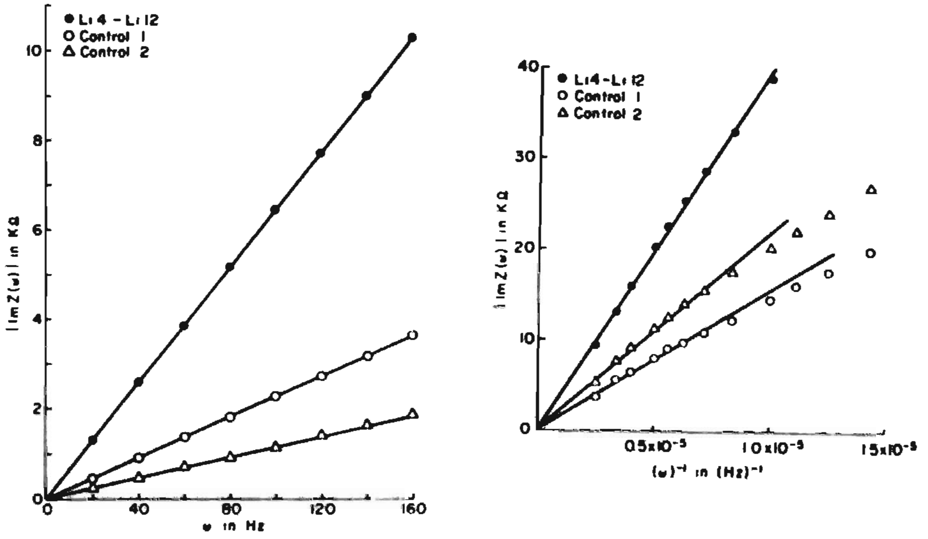

Figure 2. Typical results of an imaginary axis Laplace transformation. (a) $|\mathrm{Im}\, Z(\omega)|$ vs. ω at low frequency ($R_2 \omega C << 1$) has slope CR_2^2 and intercept 0. (b) $|\mathrm{Im}\, Z(\omega)|$ vs. $1/\omega$ at high frequencies ($R_2 \omega C >> 1$) has slope $1/C$.

TABLE I

Mean Normalized Values of R_1, R_2, C, and ϕ_{min} for the Group of 10 Subjects

	Range	Control 1 (dorsal)	Li-4 to Li-12	Control 2 (ventral)
R_1	2 - 200 KΩ	1.90 ± 0.98	1.0	1.77 ± 0.58
R_2	100 - 5000 KΩ	1.15 ± 0.45	1.0	1.45 ± 1.01
C	50 - 1500 pf	1.09 ± 0.22	1.0	0.86 ± 0.28
ϕ_{min}	$-(70^\circ - 80^\circ)$	0.93 ± 0.05	1.0	0.95 ± 0.08

Note: All quantities are normalized with respect to the experimental line (Li-4 to Li-12), with the range of values found for each parameter given at the left. The series resistance R_1 was significantly lower between the acupuncture points than between either pair of control points ($p < 0.05$, 2-tailed matched-pairs t-test), while there was no significant difference between the two controls. The capacitance C for control line 1 was significantly greater than for control line 2; the experimental capacitance did not differ significantly from that of either control. No observed differences in the other parameters were significant at the $p < 0.05$ level.

puncture points than between either pair of control points ($p < 0.05$, 2-tailed matched-pairs t-test). The characteristic impedance of the line was significantly lower for the acupuncture point system.

In addition, the propagation velocity at low frequencies and the characteristic impedance at high frequencies were significantly lower for control 1 than for control 2 ($p < 0.05$, 2-tailed matched-pairs t-test). This result justifies our use of two controls for the acupuncture point system. With only one control, any difference between the control and experimental systems could, with some justification, have been ascribed to possible minor differences in surface anatomy. This is demonstrated in the values for the capacitance (Table I), which clearly decreases from the dorsal to the ventral surface of the forearm. With two controls, one on either side of the meridian line, any such effect is immediately obvious and the results of that test can be discounted. Even though we did find that the two controls were different in some respects, in no case was there a statistically significant trend.

CONCLUSIONS

The acupuncture points Li-4 and Li-12 and the associated meridian have electrical characteristics distinct from those of the surrounding tissue. In particular, the equivalent series resistance between the acupuncture points is significantly lower than between either pair of control points. When these points are taken to define a single element of a transmission line, the signal velocity is higher and the characteristic impedance of the line is lower for the acupuncture points. This result may be significant in the context of Becker's model [14], in which the acupuncture system is viewed as an information transmission network. However, considerably more data will be required before any definitive conclusions can be made about the acupuncture system as a whole.

TABLE II

MEAN NORMALIZED VALUES OF THE SIGNAL PROPAGATION VELOCITY $v(\omega)$, CHARACTERISTIC IMPEDANCE $Z_C(\omega)$, AND RESONANT FREQUENCY ω_C

	Range	Control 1 (dorsal)	Li-4 to Li-12	Control 2 (ventral)
$v(\omega)^*$ $(R_2\omega C<<1)$	$(5 - 20) \times 10^4$/sec	0.66 ± 0.19	1.0	0.80 ± 0.17
$v(\omega)$ $(R_2\omega C>>1)$	$(500 - 1000)/(\omega)^{1/2}$-sec	0.73 ± 0.14	1.0	0.78 ± 0.14
$Z_C(\omega)$ $(R_2\omega C<<1)$	5 - 50 KΩ	1.55 ± 0.56	1.0	1.69 ± 0.96
$Z_C(\omega)$ $(R_2\omega C>>1)$	$(1 - 50) \times 10^6/(j\omega)^{1/2}$	1.30 ± 0.41	1.0	1.62 ± 0.82
ω_C	0.5 - 5 MHz	0.55 ± 0.21	1.0	0.68 ± 0.20

Note: All quantities are normalized with respect to the acupuncture point system, with the range shown at left. The characteristic impedance was significantly higher for the experimental line than for either control ($p < 0.05$, 2-tailed matched-pairs t-test). The low frequency velocity and the high frequency characteristic impedance were lower for control 1 than for control 2 ($p < 0.05$, 2-tailed matched-pairs t-test).

*$v(\omega)$ is given in units of d/s, where d is the distance between acupuncture points Li-4 and Li-12.

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[15] Informed consent was obtained from all of the volunteers included in this study after the nature of the procedure had been explained.