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Research Articles

Characterisation of human skin conductance at acupuncture points

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Abstract. Some physicians use the electrical conductance of the skin, particularly at the acupuncture points, for diagnostic purposes. This paper deals with the quantification of the skin conductance at some acupuncture points under well defined conditions using the electrode materials gold, graphite, silver and brass. The observed current response appeared to be best described by two exponentials.
Key words. Acupuncture points; skin conductance.

The electrical conductance of skin at acupuncture points is normally higher than that of the skin in general[1–3]. While most acupuncture points coincide well with high conductance points, only some of the high conductance points coincide with the acupuncture points described in traditional Chinese medicine. The acupuncture points are anatomically and topographically defined surface points, often located in palpable indentations of the underlying bones, and are considered as passages of the so-called life energy 'qi'. The close coincidence of these points with high conductance points led to the suggestion that the higher conductance is characteristic of the acupuncture points and electrical methods are consequently used for a precise locating of these points. Although different commercially available electronic devices for measuring electrical properties at acupuncture points are used for diagnostic purposes, the basis of the measuring technique and the reproducibility of results are scantily described[3–5].

The state of the art. Most commercially available instruments are direct current devices which measure the current intensity in a series circuit (fig. 1) containing a voltage source (U_0, usually a few volts) and two resistors. One of these is the resistance between the electrode-acupuncture point and a cylindrical contact electrode kept firmly in the other hand; the other, of a fixed value R_0, is usually chosen to represent the mean value of many measurements of acupuncture points in healthy persons. The value of R_0 (50 kΩ up to 1 MΩ) depends on conditions: electrode material, contact surface, contact pressure, dampness. Such an instrument gives the following readings:

Circuit condition	Instrument reading	Current intensity	Voltage between the 2 electrodes
open	0	0	U_0
$R_{acup.} = R_0$	50%	$1/2\ U_0/R_0$	$1/2\ U_0$
shorted	100% f.sc.	U_0/R_0	0

The instrument is therefore a kind of conductance-measuring device with a nonlinear scale.

When measuring acupuncture points, the practitioner generally observes two quantities: a) the maximum reading immediately after contacting the point; and b) the rate of current decrease.

The aim of the present paper was a mathematical description of the behaviour of skin high conductance points corresponding to the acupuncture points following dc-voltage steps under well-defined measuring conditions and using different electrode materials.

Methods

Our measuring procedure was guided by clinical practice used for diagnostic and therapeutic purposes. The preparation of the skin for all measurements involved hand washing, with soap containing some percent of glycerine, followed by normal drying for three minutes.

Measured acupuncture points. The three acupuncture points at the radial corners of the thumb (LU 11), index LI 1) and middle finger (HC 9) of one hand were measured. An electrode with a diameter of 2 mm was used for contacting the acupuncture points and a reference electrode of the same material was firmly held in the other hand.

Point-searching procedure. The exact locations of the high conductance points were determined by measuring

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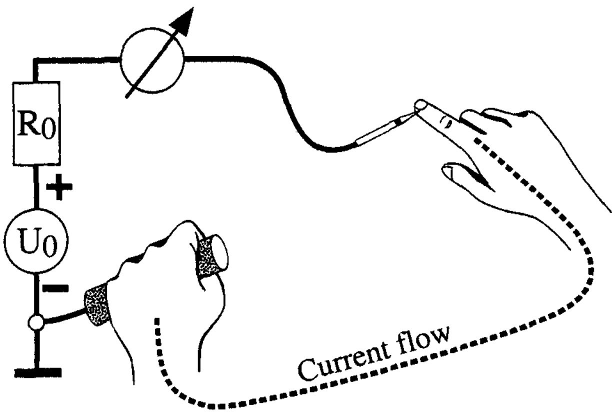

Figure 1. Typical circuit of commercially available direct current instruments. U_0 is normally in the range of 1 to several volts, positive at the point electrode. R_0, depending on the mentioned conditions between 50 kΩ and 1 MΩ.

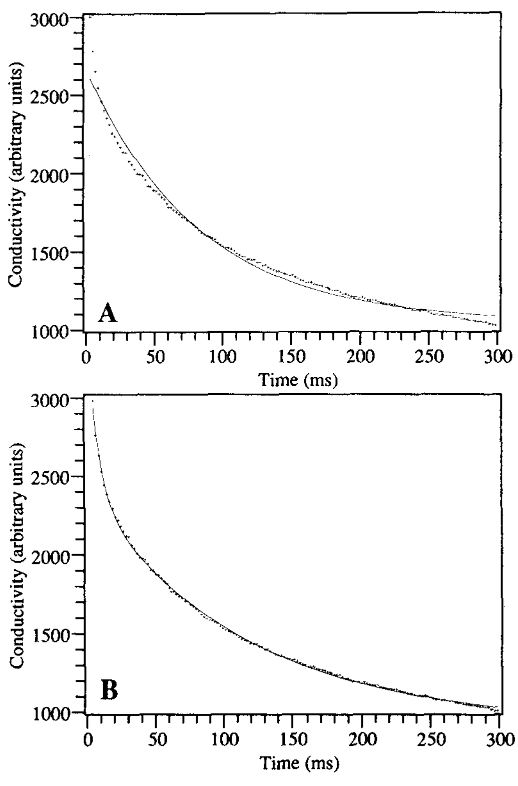

Figure 2. Representative current recording after a positive voltage step applied with a gold point electrode at the radial corner of the left thumb nail (LU 11). The dotted line is the response at the acupuncture point and the solid line is an optimized fit by (A) one and (B) two exponentials.

the skin conductance with alternating, rectangular voltage of 0.4 V and 10 Hz. The resulting current intensity was expressed acoustically through the frequency level. The electrode was applied to the point of highest frequency, corresponding to the respective acupuncture point, in a sidewards and downwards movement. The

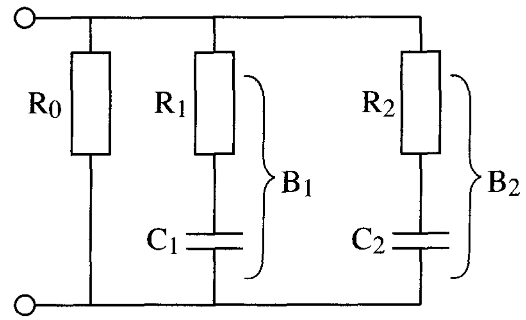

Figure 3. Electrical network that shows the same characteristic as human skin following a voltage step during 300 ms.

used point electrode guaranteed a well-defined pressure when applied perpendicularly to the contact surface. But when using our sidewards/downwards searching procedure, the pressure was somewhat higher. This method however enabled us to find the spot of the highest conductance and to position it correctly in its natural location. In addition, the results were practically independent of the degree of skin humidity, whereas perpendicular application of the electrode revealed a strong dependence on the skin humidity. Our method gave reproducible results within a few minutes.

Measurement. The measuring with direct voltage was immediately started by a foot switch after detection of the highest conductance point. Constant voltage steps of 0.4, 0.8, and 1.2 V, respectively, were applied to the skin for 2 s. The current intensity was recorded at intervals of 1 ms. As the rise time of the isolation amplifier was approximately 1.5 ms, the data recording started only at 3 ms. Both voltage application and data recording were accomplished using a PC. Four different electrode materials (gold, graphite, silver and brass) were used. In each case the hand-held reference electrode was of the same material as the point electrode.

Data processing. The data were transferred to a database and processed by the statistical analysis system SAS.

Mathematical procedure. The observed current responses appeared to be exponential, and they were therefore fitted by non-linear least squares procedures (SAS PROC NLIN, using Marquart's method) to either one or two exponentials:

(1) $\text{conductance} = C + A \exp(-Bt)$

(2) $\text{conductance} = C + A_1 \exp(-B_1 t) + A_2 \exp(-B_2 t)$

Analysis of the data suggested that a single exponential was unsatisfactory, but two described the observed relaxation quite well (fig. 2). Therefore all our measurements yielded five parameters, viz. the 'background' C, the two 'inverse relaxation time constants' B_1 and B_2, and the corresponding amplitudes A_1 and A_2.

Table 1. Effect of four different electrode materials on skin conductance.

Standard Material	U_0 (V)	A_1 (S)	A_2 (μS)	B_1 (s^{-1})	B_2 (s^{-1})	C (μS)	($A_1 + A_2$)	N
Gold	0.4	9.2 ± 6.6	6.6 ± 4.7	123 ± 40	10 ± 3	4.2 ± 3.1	4.8 ± 3.6	9
	0.8	6.8 ± 5.1	4.9 ± 2.9	117 ± 23	11 ± 3	2.8 ± 1.9	4.7 ± 1.8	9
	1.2	6.5 ± 4.5	4.7 ± 3.2	110 ± 31	11 ± 1	4.1 ± 2.8	3.2 ± 1.5	9
Graphite	0.4	4.5 ± 4.0	2.9 ± 2.7	127 ± 19	11 ± 1	1.6 ± 1.4	4.9 ± 1.8	9
	0.8	3.4 ± 2.9	2.3 ± 2.3	129 ± 25	11 ± 2	1.6 ± 1.3	3.6 ± 1.2	9
	1.2	4.3 ± 3.3	2.9 ± 2.5	139 ± 22	11 ± 1	2.6 ± 2.2	3.0 ± 0.7	9
Silver	0.4	2.9 ± 1.3	3.0 ± 2.1	97 ± 27	7 ± 2	8.8 ± 3.0	0.7 ± 0.3	7
	0.8	3.3 ± 3.0	4.7 ± 4.4	109 ± 26	6 ± 2	10.0 ± 8.9	1.0 ± 0.7	7
	1.2	2.5 ± 1.9	4.2 ± 3.5	91 ± 45	6 ± 2	9.7 ± 8.6	0.9 ± 0.5	8
Brass	0.4	3.0 ± 2.2	2.4 ± 1.4	144 ± 35	6 ± 2	15.6 ± 10.4	0.4 ± 0.2	7
	0.8	3.3 ± 3.3	2.9 ± 2.0	115 ± 62	6 ± 3	15.1 ± 15.8	0.7 ± 0.4	5
	1.2	1.0 ± 0.6	1.8 ± 1.0	102 ± 36	5 ± 2	9.0 ± 7.0	0.4 ± 0.4	5

Results are mean ± SD

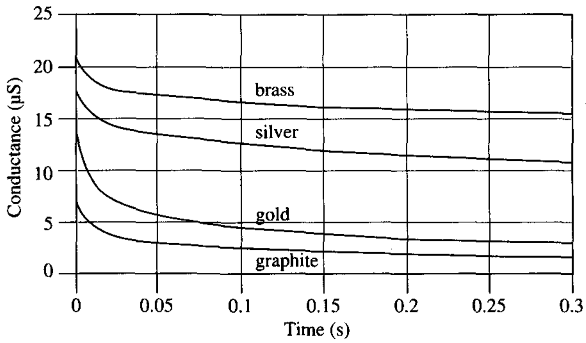

Figure 4. Skin conductance for different electrode materials. Data taken from table 1, 0.8 V.

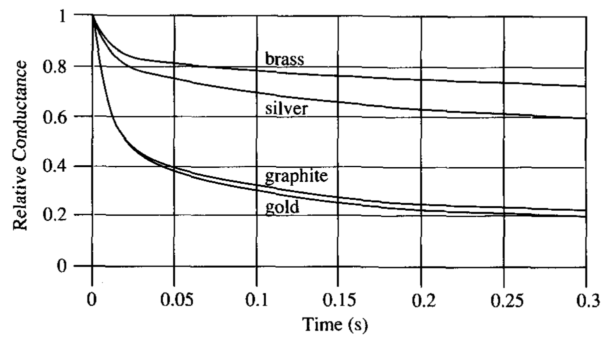

Figure 5. Skin conductance for different electrode materials relative to ($A_1 + A_2 + C$). Data taken from table 1, 0.8 V.

This model suggests an electrical equivalent circuit as is shown in figure 3. Thus, the resistors, R_1 and R_2, and the capacitors, C_1 and C_2, describe the time dependence of the skin conductance. The five experimentally observable parameters are related to the electrical components by: $A_n = 1/R_n$, $B_n = 1/R_nC_n$, $C = 1/R_0$ ($n = 1, 2$).

Data were taken for a given experimental condition (electrode materials, voltage applied) from 9 healthy probands. Only occasionally, particularly with silver and brass electrodes, could the current trace not be fitted to the model.

Our measuring circuit consisted of a voltage source U_0, the internal resistance of which was very small compared to the resistance value R of the acupuncture point. As the contact resistance of the hand held reference electrode is equally small, it is not taken into account. As the voltage across the skin point is constant, the current value represents the conductance $I/U_0 = 1/R$ of the point.

Results

Table 1 represents the five parameters resulting from our measurements. It is seen that the conductance values are independent of the applied voltage within the rather large variations.

Figure 4 is a graphical illustration of the behaviour of the conductance for 0.3 s after applying positive voltage steps of 0.8 V. Two groups of curves can be distinguished, one for gold and graphite, the chemically inert electrodes, and another for silver and brass, the chemically active electrodes. If one plots the conductance values relative to the value for $t = 0$, which means relative to ($A_1 + A_2 + C$), the difference between inert and active electrodes emerges more clearly (fig. 5).

As there is no dependence of the conductance on the applied voltages, the mean values over the three voltages can be taken (table 2). This table shows clearly that the parameters A_1, A_2 and B_1 are nearly independent of the electrode material, whereas the parameter C, which represents the final direct current conductance, and parameter B_2, the relative long-term slowing down speed, are strongly affected.

Discussion

The significantly higher values of the C-parameters of the chemically active electrodes are likely due to a leaching of metal ions. This can be deduced by observ-

Table 2. Main difference between the four electrode materials.

Electrode material	A_1	A_2	B_1	B_2	C	$(A_1 + A_2)/C$
Gold	7.5 ± 3.1	5.4 ± 2.1	117 ± 19	11 ± 1.5	3.7 ± 2.6	4.2 ± 1.4
Graphite	4.1 ± 2.0	3.0 ± 1.4	132 ± 13	11 ± 1.4	2.1 ± 1.7	3.8 ± 0.8
Silver	3.3 ± 1.3	4.0 ± 2.0	99 ± 20	6 ± 1.2	9.2 ± 7.4	1.1 ± 0.3
Brass	2.4 ± 1.4	2.4 ± 0.9	120 ± 27	6 ± 1.4	13.2 ± 11.6	0.5 ± 0.2

The values of 0.4, 0.8 and 1.2 V of each electrode material (table 1) were averaged. Results are mean ± SD.

ing the current responses either to positive or negative voltages, especially if the skin is in its naturally dry state. If the contact to the skin is enhanced by wetting the contact zone, the difference diminishes greatly within the observed period of 0.3 s. The difference in positive and negative conductance also vanishes for alternating current except for the first half wave, when starting with negative polarity. Thus, the nearly exclusive use of positive polarity combined with chemically active electrodes (like silver and brass) helps commercial equipment overcome the resistance of the epidermis. The decrease of the conductance with chemically inert electrodes is merely due to a diminution of the concentration of naturally present ions in the epidermal area facing the electrode. The speed of the relative conductance decreases, B_2, is twice that of active electrodes.

Practitioners normally observe the direct current conductance taken at about 0.3 s after contacting the acupuncture point, as well as the following decrease of this quantity. They claim that deviations of these quantities from representative mean values are indications for an insufficient regulation quality of the system belonging to the measured point. In German the conductance decrease is called 'Zeigerabfall'. Our parameters C and B_2 represent these two quantities, which, as shown above, strongly depend on the electrode material and vary substantially from proband to proband (standard deviation of the parameters quoted).

Our systematically repeated measurements on the finger nail points of highest local conductance permitted the observation of individual patterns of the probands. The rigorously applied measuring procedure gave a reasonably good reproducibility within time periods of about 20 min. But the values changed considerably in the course of a day in a rather complex manner depending on factors like changes in physical and emotional conditions, making it difficult to get scientifically acceptable results. Further investigations on this subject are ongoing. To diagnose under the usually less rigorous conditions in medical practice seems to us a difficult task in which the physician's intuition is predominant.

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