TANG HUMANITAS MEDICINE

Original Article

Factors influencing the bio-impedance data in tissue segments along the three arm meridians: a pilot study

Chi Eung Danforn Lim[1,*], Felix Wu Shun Wong[2], Warren Smith[3]

[1]*South Western Sydney Clinical School, Faculty of Medicine, University of New South Wales, Australia;* [2]*School of Women's and Children's Health, Faculty of Medicine, University of New South Wales Australia;* [3]*Chinese Medicine Clinical Research Centre, Liverpool Hospital, University of New South Wales Australia*

ABSTRACT

Bioelectric impedance measurements have been reported to show significant variation between individuals. Different physiological conditions like thickened skin, obesity, and fluid retention can affect the impedance measurement. Therefore, it is important to learn what other factors can affect the measurements of impedance even in healthy individuals. Such information is a prerequisite for understanding the changes in impedance associated with acupuncture treatment. This study investigated the bio-impedance properties of tissue segments in the arms of a number of healthy subjects, so as to define the factors that might influence the variation of the bio-impedance data in acupuncture meridians studies. 51 healthy subjects were recruited through Liverpool Hospital, Sydney. Demographic data was collected from each subject including the age, sex, BMI, and time since most recent meal. Electrodes were applied to the forearms of each test subject. Measurements were done by a purpose-built Bio-Impedance Research Device (BIRD-I) which allowed the determination of core resistance (Rc) and core reactance (Xc) of each of the three meridian tissue segments on the anterior surface of the forearm. No significant difference was found in the core resistance attributable to age group, gender, BMI or meal intake. However, a statistically significant trend in increasing resistance from the radial to ulnar aspect of the forearm ($p < 0.001$) was found. No significant difference was found in the core resistance of test tissue segments among the 51 healthy subjects measured in this study. However, the trend of increasing core resistance from the radial to ulnar aspects of the arm deserves further investigation.

Keywords bioimpedance, resistance, acupuncture meridians, traditional Chinese medicine, monitoring system

INTRODUCTION

Electrical bio-impedance is defined as the amount that an electrical current is impeded and is a measure of (1) the resistive qualities and (2) the reactance qualities of biological tissue (Ahn, 2007). The bioelectricity and impedance of the human body have been widely studied, with the development of systems for recording bioelectric signals from organs such as the heart (electrocardiograph, ECG) and brain (electroencephalograph, EEG) (Grimnes, 2000). As shown in Table 1, research over the past 30 years and more has suggested that there may be lines or zones of differential impedance in the body which may correspond to the meridians (channels) of Chinese acupuncture (Ahn et al., 2005; Ahn, 2007; Ahn et al., 2008; Cho, 1994; Colbert et al., 2008; Johng, 2002; Lee et al., 2005; Park, 2007; Pearson et al., 2007; Poon, 1979; Prokhorov et al., 2000; Prokhorov et al., 2005; Reichmanis, 1975)

The tissues of the extremities consist of a wide range of tissue types in terms of their electrical properties: muscle tissue can be considered as conductors having capacitive properties whilst tough, compact surfaces such as the stratum corneum have poor conduction properties (Prokhorov, 2005). Adipose tissue has a variable permittivity and conductivity where the variability to permittivity of the current flow has been attributed to the "*degree of perfusion with blood and other liquids.*" (Grimnes, 2000)

The features of tissue as both a capacitor and resistor are both relevant and important in the study of bioimpedance. Bioimpedance measurements are capable of providing information about the electrochemical processes in the tissue and can be used for characterizing the properties of tissue or for monitoring physiological changes (Zarowitz, 1989). Examining the current electrical theories which underpin the use of bioimpedance data may further guide research into acupuncture theory and the mechanism of action. It may also assist in developing techniques in acupuncture point location, treatment delivery and monitoring that renders the practice of acupuncture more evidence-based.

Acupuncture meridians are traditionally believed to constitute channels for *qi* flow connecting the surface of the body to internal organs (Kaptchuk, 2002). Acupuncture points are considered to represent needling sites where the flow of *qi* may be affected (Ahn et al., 2005). Studies that have attempted to define the effect of acupuncture based on anatomy and physiology have however only typically described subtle differences in the interstitial connective tissue architecture around acupuncture points compared to nearby non-acupuncture areas (Ahn et al., 2005). These studies have also

*Correspondence: Chi Eung Danforn Lim
E-mail: celim@unswalumni.com
Received April 22, 2011; **Accepted** November 22, 2011; **Published** November 30, 2011
doi: http://dx.doi.org/10.5677/tang.2011.0004

Table 1. Summary of key electrical bioimpedance studies in acupuncture

Reference	Design	Sample size	Site of testing corresponding to acupuncture points/meridians	Electrical current	Evidence
Reichmanis et al., 1977	Calculated resistance, capacitance between two acupoints on same meridian	10	Li4-Li12	DC, 1 V	+
Zhang et al., 2004	Measured impedance using four-electrode method	12	Pericardium meridian around PC3	AC, 5 kHz	+
Martinsen et al., 2001	Surveyed skin with a linear array of electrodes to find low resistance pathways	20	Volar aspect of arm	AC, 418 Hz	-, no significant association
Johng et al., 2002	Measured impedance across multiple frequencies using four-electrode method	30	Pericardium meridian around PC3	AC, 0.1-14 kHz	+
Anh et al., 2005	Measured impedance of meridian-associated connective tissue – four electrode method	23	Pericardium and spleen meridian	AC, 3.3 kHz	±, mixed result
Lee et al., 2005	Measured bi-directional resistance between two acupoints and between acupoint and non-acupoint	20	Li4-Li11	DC, 1.28 V	+

observed greater abundances of local neural and vascular connections. Some texts have also suggested that the effects of acupuncture needling may be mediated by neuropeptide modulation of neural networks (Chan, 1984; Moffet, 2006) and localised connective tissue responses (Ahn et al., 2005; Langevin, 2002). However, these results are unable to explain the spectrum of acupuncture's effects for wide-ranging disorders including fibromyalgia and nausea and vomiting (Kaptchuk, 2002). The veterinary effect of acupuncture also suggests that the mechanism of acupuncture is not merely placebo-related (Moffet, 2006).

Alternatively, theories regarding acupuncture meridians as "transmission lines" suggest that the meridians may represent networks of preferential electrical current flow (Yung, 2004). These lines may also represent how the local sensations of acupuncture needling may be propagated (Zhang, 1999).

MATERIALS AND METHODS

Randomisation and subject selection

In 2009-10, fifty one subjects were recruited at the Chinese Medicine Clinical Research Centre of Liverpool Hospital Sydney for the study and they were randomly selected according to absence or presence at allotted times during the testing period. All subjects were given a consent form explaining test procedures that was to be completed if they were willing to participate. Consent could be revoked at any time during the study. Subjects were identified only by their initials to ensure their confidentiality.

Experimental method

Fig. 1. Electrode specifications

- Ag/AgCl electrode
- Skin-friendly gel
- 19mm x 16mm dimensions
- 269 mm^2 area, skin contact area reduced to 44 mm^2 in this experiment by use of insulated adhesive washers. experiment to ≈80mm^2 area

This study was a double-blinded cross-sectional study. Each subject completed a pre-assessment survey of parameters including age, gender, height, weight, BMI and time since most recent meal. For each subject, the test region on the arm were first cleaned with a sterilising wipe and allowed to dry. The same qualified acupuncturist marked test points on the subject's right forearm and upperarm with a water-based felt pen. The proportional acupuncture measuring system was used to define electrode sites. Each electrode was attached by a cable to the multiplexer unit of the impedance test system, the so called Bio-Impedance Research Device (BIRD). Details of the electrical methods are described in the section "Physical and Electrical Analysis" below. Subjects were seated throughout the testing period with the arm under test resting on a volar surface facing upwards and slightly flexed throughout the period of testing. Chair height, room ambience and room temperature were kept constant thoughout the testing. Subjects were asked to remain seated and still during the testing which on average lasted about 10 minutes per test. The same pre-programmed sequence of impedance measurements of electrode combinations was performed on all subjects. The sequence included a repetition of each electrode combination. Data derived from the repeat impedance were presented as an average.

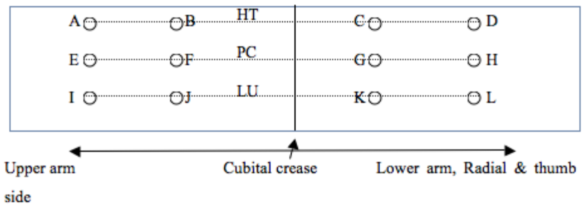


Fig. 2. Schema of electrode placement corresponding to acupuncture meridians.

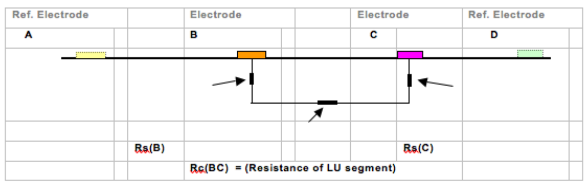


Fig. 3. Demonstration of surface (local) and core resistance.

Table 2. Summary of participant characteristics according to gender

Gender		Age group	Tally	Average age	Average BMI	Meal	Height	Weight
Male	20 subjects	20-29	10	36.8	24.51	13 had	173.45cm	79.35kg
		30-39	2		25.85	meal, 7		
		40-49	1		27.60	did not		
		50-59	6		28.67	have		
		60-69	1		25.8	meal		
Average				36.8	26.11	65%	173.45cm	79.35kg
Female	31 subjects	20-29	13	35.6	22.35	23 had	164.32cm	68.52kg
		30-39	7		24.21	meal, 8		
		40-49	4		28.45	did not		
		50-59	5		29.76	have		
		60-69	2		30.7	meal		
Average				35.55	25.29	74%	164.32cm	68.52kg
Total	51 subjects		51			51		
Overall averages				36	25.61	71%	167.9cm	72.76kg

Physical and electrical analysis

The BIRD system was developed particularly for this study to allow automated measurement of resistance and capacitance across a defined tissue segment. The BIRD was preset to operate at three different test frequencies (10 kHz, 20 kHz and 50 kHz), with data output in a format suitable for processing on a Microsoft Excel spreadsheet. The system was connected to the mains through a medical isolation transformer to ensure safety at all times of operation. The gel electrodes were pediatric cardiology sensor electrodes and were modified using adhesive washers to each have an area of 44 mm^2. The original electrode is shown in the Fig. 1.

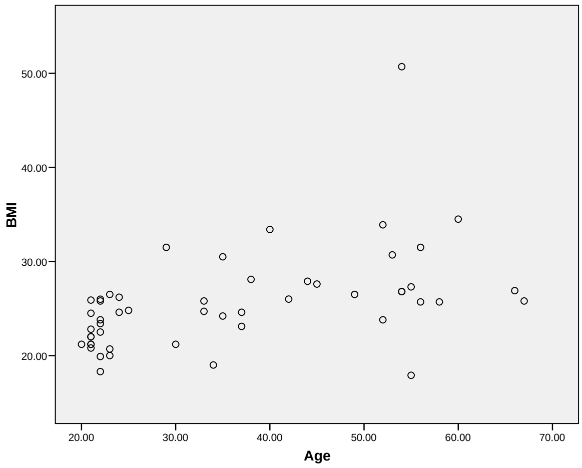


Fig. 4. Correlation of BMI and age in the study population.

The electrodes were placed on "tissue segments" along the length of the arm which corresponded to the regions of hypothesised "qi" flow in Traditional Chinese Medicine (TCM) theory. LU (Lung), PC (Pericardium), and HT (Heart) represent meridian channels and organ associations from TCM that are dissimilar to the concepts of organ physiology in Western Medicine.

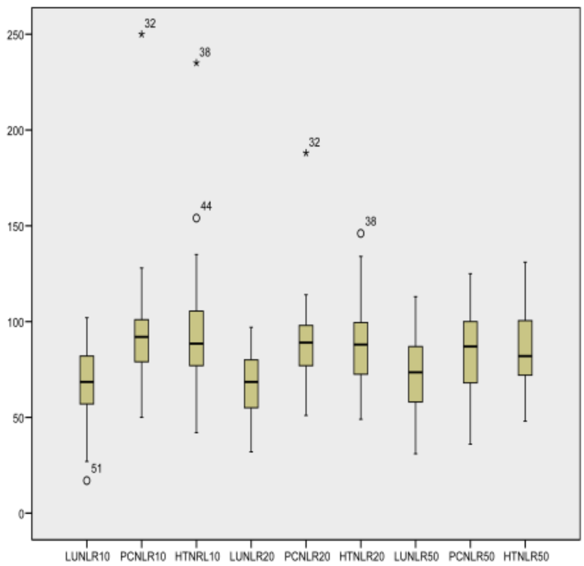


Fig. 5. Box-plot of core resistance (Ohms).

A four-electrode technique adapted from a technique first published by Horton & van Ravenswaay (1935) was used in the

Table 3. Mean core resistances

	Frequency (kHz)	Subject total	Mean resistance (Ohms)	Standard error mean
Lung		50[a]	67.72 ± 18.22 (1S.D.)	2.58
Pericardium	10	49[a]	92.71 ± 27.66 (1S.D.)	3.95
Heart		48[a]	93.17 ± 29.49 (1S.D.)	4.26
Lung		50[a]	67.98 ± 15.66 (1S.D.)	2.21
Pericardium	20	49[a]	87.63 ± 20.93 (1S.D.)	2.99
Heart		48[a]	87.31 ± 20.13 (1S.D.)	2.91
Lung		50[a]	72.82 ± 18.35 (1S.D.)	2.59
Pericardium	50	49[a]	84.39 ± 20.12 (1S.D.)	2.87
Heart		48[a]	84.27 ± 21.18 (1S.D.)	3.06

[a] Data not included because of reading irregularities e.g. negative resistance values possibly due to loss of contact with skin surface.

electrical analysis. This technique, re-introduced here, is a method almost totally superceded by the standard “4-electrode method” (Grimnes, 2000). Technological improvements in the automation of crude, repetitive measurements have made the old Horton & van Ravenswaay (1935) technique, however, more technologically viable and efficient.

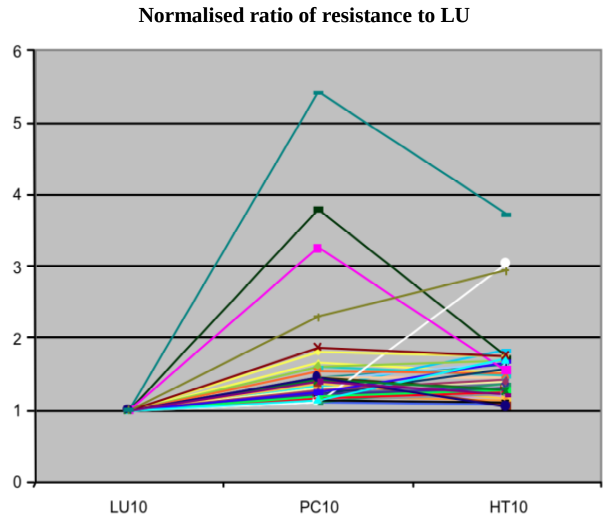
Advantages of this technique include the ability to resolve the internal core resistance of the tissue segment using measurements of the surface and local resistance of the same tissue segment (Fig. 3). This allows for the use of basic electrical principles in the calculations of impedance, resistance and capacitance and in so doing, allows improved electrical definition of the system under measurement. Further considerations relating to the advantages and limitations of the technique can be found in our other published paper (Wong, 2010). In this study only the resistive component of the impedance, in particular, core resistance (Rc) will be considered. With the upper and lower arm divided into segments, Fig. 2 illustrates the placement of test electrodes on the upper and lower arm, corresponding from the radial to ulnar aspects of the arm: the lung, pericardium and heart meridians.

Table 4a. Ranks according to Wilcoxon signed ranks test

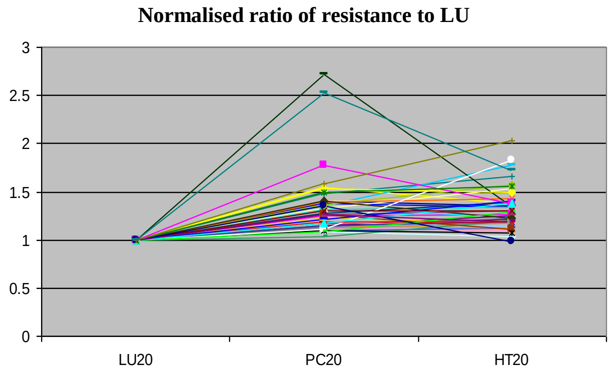
		N	Mean Rank	Sum of Ranks
PCNLR10 - LUNLR10	Negative Ranks	0(a)	.00	.00
	Positive Ranks	48(b)	24.50	1176.00
	Ties	0(c)		
	Total	48		
HTNRL10 - LUNLR10	Negative Ranks	1(d)	32.00	32.00
	Positive Ranks	46(e)	23.83	1096.00
	Ties	0(f)		
	Total	47		
HTNRL10 - PCNLR10	Negative Ranks	24(g)	20.67	496.00
	Positive Ranks	21(h)	25.67	539.00
	Ties	1(i)		
	Total	46		
PCNLR20 - LUNLR20	Negative Ranks	0(j)	.00	.00
	Positive Ranks	48(k)	24.50	1176.00
	Ties	0(l)		
	Total	48		
HTNLR20 - LUNLR20	Negative Ranks	2(m)	10.25	20.50
	Positive Ranks	45(n)	24.61	1107.50
	Ties	0(o)		
	Total	47		
HTNLR20 - PCNLR20	Negative Ranks	20(p)	22.00	440.00
	Positive Ranks	24(q)	22.92	550.00
	Ties	2(r)		
	Total	46		
PCNLR50 - LUNLR50	Negative Ranks	5(s)	18.30	91.50
	Positive Ranks	41(t)	24.13	989.50
	Ties	2(u)		
	Total	48		
HTNLR50 - LUNLR50	Negative Ranks	7(v)	18.71	131.00
	Positive Ranks	39(w)	24.36	950.00
	Ties	1(x)		
	Total	47		
HTNLR50 - PCNLR50	Negative Ranks	21(y)	21.93	460.50
	Positive Ranks	21(z)	21.07	442.50
	Ties	4(aa)		
	Total	46		

a PCNLR10 < LUNLR10
b PCNLR10 > LUNLR10
c PCNLR10 = LUNLR10
d HTNRL10 < LUNLR10
e HTNRL10 > LUNLR10
f HTNRL10 = LUNLR10
g HTNRL10 < PCLR10
h HTNRL10 > PCLR10
i HTNRL10 = PCLR10
j PCNLR20 < LUNLR20
k PCNLR20 > LUNLR20
l PCNLR20 = LUNLR20
m HTNLR20 < LUNLR20
n HTNLR20 > LUNLR20
o HTNLR20 = LUNLR20
p HTNLR20 < PCNLR20
q HTNLR20 > PCNLR20
r HTNLR20 = PCNLR20
s PCNLR50 < LUNLR50
t PCNLR50 > LUNLR50
u PCNLR50 = LUNLR50
v HTNLR50 < LUNLR50
w HTNLR50 > LUNLR50
x HTNLR50 = LUNLR50
y HTNLR50 < PCNLR50
z HTNLR50 > PCNLR50
aa HTNLR50 = PCNLR50

a



b



c

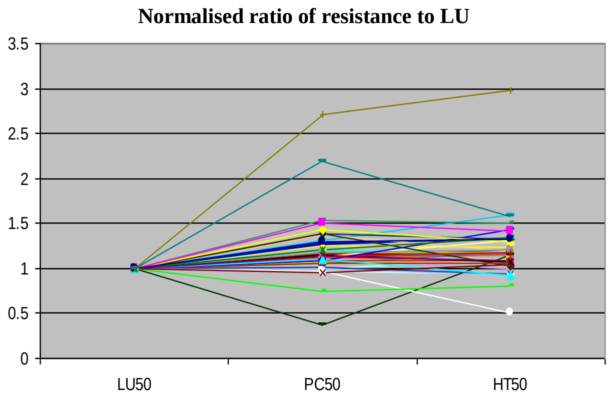


Fig. 6. (a) Normalised ratio to resistance to LU comparisons at 10 kHz; (b) comparisons at 20 kHz; (c) comparisons at 50 kHz.

Table 4b. Test statistics(c) for the Wilcoxon signed ranks rest

	PC10 - LU10	HT10 - LU10	HT10 - PC10	PC20 - LU20	HT20 - LU20	HT20 - PC20	PC50 - LU50	HT50 - LU50	HT50 - PC50
Z	-6.033(a)	-5.631(a)	-.243(a)	-6.034(a)	-5.754(a)	-.643(a)	-4.908(a)	-4.476(a)	-.113(b)
Asymp. Sig. (2-tailed)	.000	.000	.808	.000	.000	.520	.000	.000	.910

a Based on negative ranks.
b Based on positive ranks.
c Wilcoxon Signed Ranks Test

The following algebraic formulae were used to calculate core resistance of the three tissue segments against reference electrodes (A &D, E &H, I&L, respectively):

- Rc(BC) = [R(AC) + R(BD) – R(AB) – R(CD)] / 2
- Rc(FG) = [R(EG) + R(FH) – R(EF) – R(GH)] / 2
- Rc(JK) = [R(IK) + R(JL) – R(IJ) – R(KL)] / 2

Statistical analysis

Statistical analysis was performed using SPSS ver 15.0. The Student's T Tests, Pearson and Spearman's correlation coefficients and Wilcoxon signed rank tests were used to analyse the data.

RESULTS

Study participants

The study population consisted of 20 healthy males and 31 healthy females. They were mostly aged between 20 and 30 years of age, and this range comprising 45.1% (n = 23) of the total. The mean age of participants was 36 ± 14.86 (1 S.D.) years. The average BMI for the subjects was 25.6 ± 5.3 (1 S.D) Thirty six subjects (71%) had had a meal on the day of testing while 15 had not. In general, females in the younger age groups (20-39) had lower average BMI 23.0 ± 2.5 (1 S.D.) compared to males 24.7 ± 3.7 (1 S.D.); this relationship reversed after age

Table 5. Pearson correlation tests for resistance, age, and BMI

		Age	BMI	LU10	LU20	LU50	PC10	PC20	PC50	HT10	HT20
BMI	Pearson Correlation	.479(**)									
	Sig. (2-tailed)	.000									
	N	51									
LU10	Pearson Correlation	-.408(**)	-.480(**)								
	Sig. (2-tailed)	.003	.000								
	N	50	50								
LU20	Pearson Correlation	-.349(*)	-.399(**)	.919(**)							
	Sig. (2-tailed)	.013	.004	.000							
	N	50	50	50							
LU50	Pearson Correlation	-.308(*)	-.337(*)	.785(**)	.905(**)						
	Sig. (2-tailed)	.030	.017	.000	.000						
	N	50	50	50	50						
PC10	Pearson Correlation	-.267	-.318(*)	.345(*)	.413(**)	.499(**)					
	Sig. (2-tailed)	.064	.026	.016	.004	.000					
	N	49	49	48	48	48					
PC20	Pearson Correlation	-.287(*)	-.363(*)	.475(**)	.594(**)	.651(**)	.957(**)				
	Sig. (2-tailed)	.045	.010	.001	.000	.000	.000				
	N	49	49	48	48	48	49				
PC50	Pearson Correlation	-.153	-.236	.577(**)	.753(**)	.589(**)	.129	.365(**)			
	Sig. (2-tailed)	.294	.103	.000	.000	.000	.377	.010			
	N	49	49	48	48	48	49	49			
HT10	Pearson Correlation	-.201	-.154	.475(**)	.561(**)	.571(**)	.305(*)	.430(**)	.484(**)		
	Sig. (2-tailed)	.171	.297	.001	.000	.000	.039	.003	.001		
	N	48	48	47	47	47	46	46	46		
HT20	Pearson Correlation	-.260	-.263	.581(**)	.725(**)	.711(**)	.383(**)	.555(**)	.730(**)	.903(**)	
	Sig. (2-tailed)	.074	.071	.000	.000	.000	.009	.000	.000	.000	
	N	48	48	47	47	47	46	46	46	48	
HT50	Pearson Correlation	-.294(*)	-.366(*)	.505(**)	.673(**)	.599(**)	.540(**)	.664(**)	.707(**)	.367(*)	.668(**)
	Sig. (2-tailed)	.042	.011	.000	.000	.000	.000	.000	.000	.010	.000
	N	48	48	47	47	47	46	46	46	48	48

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).
Significant correlation results have been shaded

Table 6. Summary of determined arm core resistances

Frequency (kHz)		Resistance
10	LU	67.72 ± 18.22 (1S.D.)
	PC	92.71 ± 27.66 (1S.D.)
	HT	93.17 ± 29.49 (1S.D.)
20	LU	67.98 ± 15.66 (1S.D.)
	PC	87.63 ± 20.93 (1S.D.)
	HT	87.31 ± 20.13 (1S.D.)
50	LU	72.82 ± 18.35 (1S.D.)
	PC	84.39 ± 20.12 (1S.D.)
	HT	84.27 ± 21.18 (1S.D.)

40 (29.4 ± 8.3) (1 S.D.) in females and (27.4 ± 3.7) (1 S.D.) in males.

Average core resistance

Core resistance was calculated using the Horton & van Ravenswaay (1935) technique. The results are shown in Table 3. A small amount of data noted as being nonsensical negative resistance data was not included in the calculations. Such data has been attributed to either instrumental noise or loss of contact between the electrode and skin. As can be seen, the average core resistance showed a consistent increasing trend from the LU tissue segment to other segments for all three frequencies.

Fig. 5 shows the same data in the form of a box plot, with means core resistances at each defined frequency and tissue location. It is clearly evident that the values for the LU tissue segments at each frequency are significantly lower ($p < 0.001$) than the corresponding measurements on adjacent tissue segments.

The correlation between adjacent tissue segments was also examined using the Wilcoxon Signed Ranks Non-Parametric Test (Tables 4a and b). This test shows that the core resistance of the LU tissue segments is in every case below that of the PC and HT tissues.

On the other hand, comparisons between the HT and PC, the medial and radial aspects of the ventral forearm, found that they were not significantly associated. The reduction in resistance to the radial aspect of the arm represented a consistent trend across all frequency ranges.

Normalised ratios to LU tissue segment

Normalising values to the LU tissue segment, it is evident that there is less variance occurring at higher frequencies (Fig. 6a-c).

Correlation with BMI, age, gender, and meal intake

Generally, in comparison with age or BMI, there appears to be no correlation in the values of the core resistance obtained at 10, 20, and 50 kHz, as represented for one frequency (50 kHz) in Fig. 7. Comparatively, there was a greater association between tissue segment resistance at different frequencies and different tissue segments at the same frequency. The PC and HT

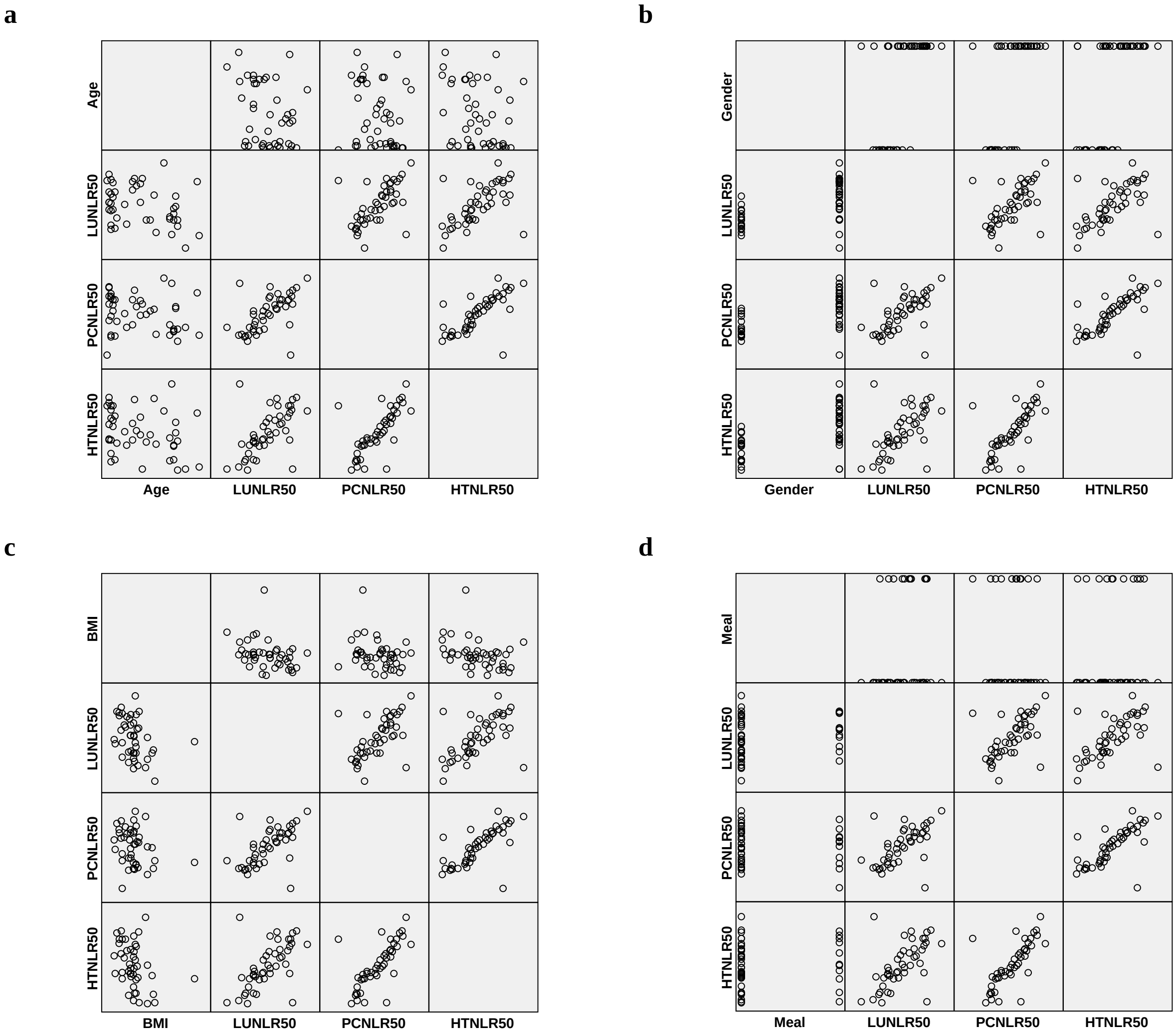


Fig. 7. Correlation with (a) age, (b) gender, (c) BMI and (d) meal intake.

meridians were more closely correlated compared to measurements for the LU meridian. There appeared to be no correlation between gender and meal intake and measured resistances (Table 5).

DISCUSSION

Investigation of tissue core resistance of the volar surface arm meridian segments has shown that there is an observable electrical conductance pattern in healthy tissue and that this may represent a fundamental property of tissues. This trend appears to remain the same between subjects and to be independent of other factors such as age, gender, and BMI. Accordingly, it may be possible to generate from this data a standard range of values for healthy subjects as shown in Table 6.

(i) Major findings:

a) The determination of core resistance in healthy subjects may be inherently predictable

First, these results suggest that there is a patterned response to an applied external current in the cases of healthy individuals. This includes the trend of a low to high resistance from the radial to ulnar side on the ventral surface of the arm. The trend may reflect the presence of underlying bony structures that impose greater impedance to current flow at the ulnar sites. Predictably, healthy individuals would be expected to share similar variations in tissue impedance and any disturbance to this pattern may represent a source of underlying tissue change.

b) The relative similarity of resistance data between patients suggests that it may be possible to characterise healthy tissue according to fundamental principles of electrical conductance

Secondly, analysis of intersubject data underlines the concept that it may be possible to make fundamental generalisations about the characteristics of the healthy human body in terms of bioimpedance. As shown in Table 6, a standard range of values could be developed that represent healthy, functioning tissue. The standard deviations in this data fall within the normal range and suggest that these readings for resistance can be generalised. Furthermore, variations of core resistance in adjacent sites along the arm could suggest the presence of universal variations in tissue flow and impedance, correlating anatomically to underlying structures or possibly, the presence of lines or bands of preferential electrical current flow.

c) Correlations between other parameters such as comparison according to age, gender, BMI or last meal intake

There was no significant data to suggest that variables such as age, gender, BMI or last meal intake affected the measurement of resistance data. As trends in resistance represent a uniform property of tissue, the lack of significant difference due to intrinsic values such as age and gender could suggest that this data could be attributable to tissue properties alone. A lack of correlation between BMI and core resistance suggests that no apparent relationship exists between BMI and the distribution of fat/muscle affecting core resistance in the arm.

d) Frequency

The frequency of the applied waveform is known to have important implications for the behaviour of the current. For example, at higher frequencies in general, resistance tends to less affected by the presence of membraneous structures. Interestingly, however (Table 6) it can be seen that for the LU meridian segment, a weak opposite trend was observed. The reason for this is unknown.

(ii) Assessment of study protocol

The strengths of this project include its reference to previously published work that a sample size of approximately 50 patients would provide sufficient significance to the study. This is in comparison to studies which involved groups of much smaller size as noted in Table 1.

Weaknesses of this study design include the non-representative nature of the study population and the lack of a formalised measuring system for determining the positioning of the electrodes. Sources of error have included loss of contact between the electrode and skin surface and changes in fluid volume because of the duration of each subject’s assessment. These errors may be minimised by fixing electrodes onto the skin with tape and ensuring subjects rested for 30 minutes before each test

Overall, this research may be furthered by elucidating with greater certainty the optimal equipment, methodology, and process of randomised subject selection. First, the choice of equipment must carefully consider the parameters of electrical stability, accuracy in overcoming the resistance of the stratum corneum, and patient safety during use. The current choice of electrode, while used physiologically in cardiology, may be too large for defining the width of the tissue segments that ideally should be measured. The system is also in development and further refinements towards making the system more compact will assist in its mobility and applicability in current research. An advantage of the current set-up is its ability to give automated measurements of many electrode combinations. In the future, developments are expected to enable dual measurement using both the present system and also the standard four-electrode bio-impedance measurement method.

The methodology may be improved by using a referential system such as describing the location of electrode placement relative to body surface markings. While this was similar to the proportional method of measurement, greater repeatability of data may be obtained by creating a system of point location. The utility and placement of the reference electrodes as well as the optimal frequency for the experiment should also be explored further. Ideally, the reference electrodes should be located far enough away from the test electrodes to not affect core resistance determination. The optimal choice of frequency will depend on measurement reproducibility and sensitivity of the equipment to detect small differences in core resistance against large measured total resistances. Use of frequencies higher than used in this study may be worth examining.

The randomisation process could also be improved, and may include a more case-controlled selection of patients from a nominal database. Responder bias may also be eliminated in this case by setting targets for each study group and recruiting subjects based on a quota for each age group.

(iii) Future applications

The development of bioelectric and bioimpedance datasets will enable further study into the physiological components of human tissue. Studies in the past have compared the electrical characteristics of acupuncture points to non-acupuncture points (Ahn et al., 2005; Ahn et al., 2008; Colbert et al, 2008; Kaptchuk, 2002; Lee et al., 2005; Pearson et al., 2007; Prokhorov et al., 2005). These experiments have provided mixed results regarding the presence of areas of preferential electrical energy conduction. However, there has been considerable discussion as to the optimal methodology (Ahn, 2007; Ahn et al., 2008), particularly in light of developments in modern technology. Whether it is possible to conclude if acupuncture as well as points represent preferred pathways for the conduction of electrical energy conduction has not been addressed in this study. Here it is worth mentioning that other studies have suggested that it is the insertion of acupuncture needles which elicits a temporal drop in tissue bioimpedance (Reichmanis, 1975; Vickland et al., 2008). Overall, modern technology has allowed for improvements to be made in the repeatability and sensitivity of tissue bioimpedance measurement. With further improvements to the methodology, it may be possible to develop a system of detection and assessment for sites believed to be active in acupuncture treatment but which currently have no physiological correlate in Western medicine.

These measurements and the potential use of an active, continuous monitoring system based on changes in bioimpedance, phase angle, and resistance may also provide clues as to the prognosis of conditions such as lymphoedema. Much like an ECG-monitor, bioimpedance, and phase angle have clinical applications in the detection of tissue pathology (Baumgartner, 1988; Gupta et al., 2004; Gupta et al., 2004; Gupta et al., 2008; Ott et al., 1995). The significance of these results is that a system of monitoring that is cost-effective, non-invasive, and simple to perform allows clinicians to make earlier, more informed decisions regarding the patient's progress (Adami, 1993).

Tissue bio-impedance measurements have the potential to be utilised in clinical applications including determining tissue health and assessing progress in treatment response. Its uses also extend to exploring the physiological properties of tissue and in collaborating the theories of acupuncture "meridians" as lines or bands of reduced electrical impedance. This study has suggested that tissue impedance in healthy people can be inherently predictable in terms of its trends and its range of values. Given these results are reproducible from person to person, it seems prudent to explore the potential of developing a standard series of topographical measurements mapping the body according to the features of impedance and resistance.

The experimental method should be refined to account for the observed differences in frequency and to validate the type and placement of the reference electrode used. In addition, it is considered that further attention to optimal skin preparation, electrode placement and randomisation of subject selection will improve subsequent study designs. The incorporation of more test sites, including sites adjacent to tissue areas tested in the present study, will improve significance of studies such as that reported here.

ACKNOWLEDGEMENTS

We would like to thank our research students of the team – Miss Yvonne Yii and Miss Veronica Wong for their help in this project to make it possible.

CONFLICT OF INTEREST

The authors do not have any conflict of interest in the present study.

REFERENCES

Adami GF, Marinari G, Gandolfo P, Cocchi F, Friedman D, Scopinaro N. The use of bioelectrical impedance analysis for monitoring body composition changes during nutritional support. Surg Today. 1993;23:867-870.

Ahn AC, Wu J, Badger GJ, Hammerschlag R, Langevin HM. Electrical impedance along conective tissue planes associated with acupuncture meridians. BMC Complement Altern Med. 2005;5:10.

Ahn, AC, Colbert AP. Anderson BJ. Martinsen OG. Hammerschlag R. Cina S. Wayne. PM, Langevin HM. Electrical Properties of Acupuncture Points and Meridians: A Systematic Review. Bioelectromagnetics. 2008;29:245-256.

Ahn AC, Martinsen OG. Electrical Characterisation of Acupuncture Points: Technical Issues and Challenges. J Altern Complement Med. 2007;13:817-824.

Baumgartner RN, Chumlea WC, Roche AF. Bioelectric impedance phase angle and body composition. Am J Clin Nutr. 1988;48:16-23.

Chan SHH. What is being stimulated in acupuncture: evaluation of the existence of a specific substrate. Neurosci Biobehav Rev. 1984;8:25-33.

Cho SH, Chun SI. The basal electrical skin resistance of acupuncture points in normal subjects. Yonsei Med J. 1994;35:464-474.

Colbert AP, Yun J, Larsen A, Edinger T, Gregory WL, Thong T. Skin impedance measurements for acupuncture research: development of a continuous recording system. Evid Based Complement Alternat Med. 2008;5:443-450.

Grimnes S, Martinsen OG. Bioimpedance & Bioelectricity Basics, 1st ed. (Waltham, USA: Academic Press), 2000.

Gupta D, Lammersfeld CA, Bashi PG, King J, Dahlk SL, Grutsch JF, Lis CG. Bioelectrical impedance phase angle as a prognostic indicator in breast cancer. BMC Cancer. 2008;8:249.

Gupta D, Lis CG, Dahlk SL, Vashi PG, Grutsch JF, Lammersfeld CA. Bioelectrical impedance phase angle as a prognostic indicator in advanced pancreatic cancer. Br J Nutr. 2004;92:957-962.

Gupta D, Lammersfeld CA, Burrows JL, Dahlk SL, Vashi PG, Grutsch JF, Hoffman S, Lis CG. Bioelectrical impedance phase angle in clinical practice: implications for prognosis in advanced colorectal cancer. Am J Clin Nutr. 2004;80:1634-1638.

Horton JW, VanRavenswaay AC. Electrical impedance of the human body. J Franklin Inst. 1935;220:557-572.

Johng HM, Cho JH, Shin HS, Soh KS, Koo TH, Choi SY, Koo HS, Park MS. Frequency dependence of impedances at the acupuncture point Quze (PC3). IEEE Eng Med Biol Mag. 2002;21:33-36.

Kaptchuk TJ. Acupuncture: Theory, Efficacy, and Practice. Ann Intern Med. 2002;136:374-383.

Langevin HM, Yandow JA. Relationship of Acupuncture Points and Meridians to Connective Tissue Planes. Anat Rec. 2002;269:257-265.

Lee MS, Jeong SY, Lee YH, Jeong DM, Do YG, Ko SB. Differences in Electrical Conduction Properties Between

Meridians and Non-meridians. Am J Chin Med. 2005;33:723-728.

Moffet HH. How might acupuncture work? A systematic review of physiologic rationales from clinical trials. BMC Complement Altern Med. 2006;6:25.

Ott M, Fischer H, Polat H. Bioelectrical impedance analysis as a predictor of survival in patients with human immunodeficiency virus infection. J Acquir Immune Defic Syndr Hum Retrovirol. 1995;9:20-25.

Park HD, Song MH, Myoung HS, Lee KJ. A New Acupuncture Point Detection Using the Impedance Measurement System based on ANF and Phase-Space-Method. Conf Proc IEEE Eng Med Biol Soc. 2007;2007:2572-2574.

Pearson S, Colbert AG, McNames J, Baumgartner M, Hammerschiag R. Electrical Skin Impedance at Acupuncture Points. J Altern Complement Med. 2007;13:409-418.

Poon C. Comments on "Laplace Plane Analysis of Transient Impedance Between Acupuncture Points Li-4 and Li-12". IEEE Trans Biomed Eng. 1979;26:181-182.

Prokhorov EF, Prokhorova TE, González-Hernández J, Kovalenko YA, Llamas F, Moctezuma S, Romero H. In vivo DC and AC measurements at acupuncture points in health and unhealthy people. Complement Ther Med. 2006;14:31-38.

Prokhorov EF, González-Hernández J, Vorobiev YV, Morales-Sánchez E, Prokhorova TE, Zaldivar Lelo de Larrea G. In vivo electrical charactersitics of human skin, including at biologically active points. Med Biol Eng Comput. 2000;38:507-511.

Reichmanis M, Marino AA, Becker RO. Electrical Correlates of Acupuncture Points. IEEE Trans Biomed Eng. 1975;22:533-535.

Vickland V, Rogers C, Craig AR, Tran YH. Electrodermal activity as a possible physiological marker for acupuncture. Complement Ther Clin Pract. 2008;14:83-89.

Wong WSF, Lim CED, Smith W. A new bioimpedance research device (BIRD) for measuring the electrical impedance of acupuncture meridians. J Altern Complement Med. 2010;16:257-264.

Yung KT. A birdcage model for the Chinese Meridian System: part I. A channel as a transmission line. Am J Chin Med. 2004;32:815-828.

Zarowitz BJ, Pilla AM. Bioelectrical impedance in clinical practice. DICP. 1989;23:548-555.

Zhang W, Xu R, Zhu Z. The influence of acupuncture on the impedance measured by four electrodes on meridians. Acupunct Electrother Res. 1999;24:181-188.