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# DEVELOPMENT AND EVALUATION OF A NOVEL FOUR-ELECTRODE DEVICE SYSTEM FOR MONITORING SKIN IMPEDANCE

**Rezaei Shima[1,2] ; Zhu Jiang[1] ; She Yan Fen[3]; Afzal-Aghayi Monnavar[4] and Khorsand Ali[1,2]***

[1]The School of Acupuncture and Moxibustion, Beijing University of Chinese Medicine, Beijing, China.
[2]Nuclear Medicine Research Center, Mashhad University of Medical Sciences, Mashhad, Iran.
[3]The School of Traditional Chinese Medicine, Hebei Medical University, Shijiazhuang, China.
[4]Mashhad University of Medical Sciences, Mashhad, Iran.
***E.mail:** khorsanda1@mums.ac.ir

## Abstract

Qi, meridians, and acupoints are important issues in Chinese medicine. One of the theories claims that acupuncture points and meridians have unique electrical properties. The associations between acupuncture points or meridians and special electrical properties are still under debate. In the current study, we introduced and explained a device for this kind of research and evaluated the reliability of this device as well as effects of pressure, cleaning the skin by alcohol and exfoliation on electrical skin measurements. Fifteen subjects (10 female, 5 male) were recruited to participate in the study. An impedance meter based on the four-electrode technique was designed and fabricated specifically for this study. The effects of pressure, cleaning of the skin by alcohol, and exfoliation on electrical skin impedance were evaluated separately. The device repeatability was also evaluated 30 times in a 30 minutes period. Scale weight up to 200 grams, cleaning the skin with alcohol, and exfoliation didn't affect the performance of this device. The device performance didn’t change significantly during the 30 minutes measurement either. The new system we evaluated can be a reliable tool for researches on electrical skin impedance in acupuncture, as its performance is fairly stable even in the presence of various confounding factors such as various pressures on the probe, cleaning the skin with alcohol and exfoliation.

**Key words:** Acupuncture, Meridian, Acupoints, Electrical skin impedance, Chinese medicine.

## Background

Qi, meridians and acupoints are important issues in Chinese medicine. Until now many scientists proposed several theories to explain what meridians are. One of these theories claims that acupuncture points and meridians have unique electrical properties, for example it is claimed that electrical skin impedance of these points are lower than the surrounding areas(Ahn et al., 2008). The use of electrical devices to detect and monitor acupuncture points has a long history. The first claim for the electrical detection of acupuncture points can be dated back to the 1950s. Some workers (Nakatani, 1956; Niboyet, 1958; Voll, 1975), independently reported that skin acupoints had unique electrical characteristics. Since then, several studies have evaluated the electrical properties of acupoints. Some researches reported that skin impedance in these points are different from the adjacent areas (Ahn et al., 2005; Hu et al., 1992; Hyvarinen et al., 1977; Johng et al., 2002; Reichmanis et al., 1977), while others didn’t accept this claim (Kramer et al., 2009; Martinsen et al., 2001; Pearson et al., 2007). A review article by Ahn et al. in 2008 evaluated 18 studies concerning the electrical resistant and acupoints: nine studies evaluated Electrical skin properties at acupoint, and nine studies evaluated meridians. Five out of 9 point studies showed positive association between acupuncture points and lower electrical resistance and impedance, while 7 out of 9 meridian studies showed positive association between acupuncture meridians and lower electrical impedance (Ahn et al., 2008).

The most important problem in many researches was the control of confounding factors which influence electrical skin impedance results. Some factors are environmental, some are physiological and others are related to device such as electrode application pressure, skin moisture, electrode contact and abrasion of the stratum corneum. Because of these problems, scientists couldn’t conduct precise research and the associations between acupuncture points or meridians and special electrical properties are still under debate.

Many scientists tried to develop new devices to increase the reliability of electrical skin impedance results measurements. For example Kramer et al. used a devise consisted of a field of 64 electrodes on a flexible plastic foil surface of 6 × 6 cm. The probes were placed and fixed with a standard blood pressure cuff. In this way they tried to omit the pressure and time duration interference during electrical skin impedance measurements (Kramer et al., 2009). Martinsen et al. used an electrode vehicle with an array of 16 resilient steel electrodes. When the two vehicle rollers were in contact with the skin, the electrodes were applied with a pressure of about $15g/mm^2$. The electrodes were periodically scanned through a multiplexer during movement of the vehicle (Martinsen et al., 2001).

In the current study, we introduced and explained a device system for this kind of research which could resolve many of the limitations listed above. The system is based on the four-electrode technique and was designed and fabricated specifically for

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this study by Yang Weisheng and colleagues in the School of Physics, Beijing University, China. We evaluated the reliability of this device system as well as effects of pressure, cleaning the skin with alcohol and exfoliation on electrical skin impedance measurement.

## Materials and Methods

### Participants

Participants were students of Beijing University of Chinese Medicine. They were healthy individuals, aged between 18 to 32 years (25 ± 7 year;10 female, 5 male). There was no scar on their skin and none of the females were pregnant. The Subjects gave verbal and written informed consent before participation. The testing was performed in the Research Center at acupuncture department of Beijing University of Chinese Medicine from May to Jun 2010 between 9 am and 12 am. The study was approved by The Medical Ethics Committee of Beijing University of Chinese Medicine.

### Acupuncture points

Ximen (PC4), Kongzui (LU6), Shousanli (LI10) were selected for this research. These acupoints have been chosen because of the appropriate location on the skin which made them ideal for installing the probes. These points were marked on the skin with nontoxic, washable ink by an expert acupuncturist.

### Statistical analysis

Statistical analyses were performed by SPSS 11.5 software. All p-values were two-tailed, and the cut off of significance was set at 0.05. We used repeated measures ANOVA for evaluating the difference between electrical skin impedance. Levene's test was used to evaluate the repeatability of the device.

### Instruments

An impedance meter based on the four-electrode technique was designed specifically for this study. The Model of device was LRM30-R. The Impedance meter outputs a regulated AC 5 kHz sinusoidal current of variable amplitude (30μA) between two outer electrodes and the current used was alternating (AC) as opposed to direct current to avoid saturating of the electrode surfaces as a result of mobile ion build up (electrolysis) (Yang Weisheng, 1978; Zhang et al., 1999). The calibration process was performed automatically each time the device was being turned on as shown in Figure 1. For more details please refer to another study on this device (Yang Weisheng, 1978). As schematically shown in Figure 2, the specific arrangement of the skin electrodes makes it measure only the impedance of the small subcutaneous region lying just below the current electrode PI. The electrode type was Ag/AgCl. This property is a result of the densely populated current lines along with equipotent lines in that region, which in turn is a result of the special PV-PI-PVR-PIR electrode sequence in the method. Specifically, in the present study the diameter D of the three electrodes PV, PI, and PVR were all 5 mm, while PIR was much larger and put outside PVR but far from it, and the PV-PI and PI-PVR distances L1 and L2 were 8 and 12 mm, respectively. The system used in the present study was also modified and computerized in such a way that it consisted of 12 four-electrode probes with a common PIR electrode shared by the 12, and that the user was allowed to program these probes to do automatic measurements for a maximum of 600 rounds, or to do manual measurement if necessary. In a round, each probe takes only 3 seconds to collect the data and thus the shortest span of a round is only 1 minute although can be set to much longer. The schematic diagram of the system is given in Figure1. A digital screen on the device displays the measured impedance values in ohms (Ω). The data were imported to a laptop computer via a serial cable. The device was connected to a PC (Dell Inspiron mini10 laptop, Dell Inc., Windows XP Operating System) through a serial port; then automatically entered into Microsoft Excel for analysis (Figures 1- 3).

### Procedure

Subjects were advised to rest for 15 minutes before measurements. We asked them to shave the location if necessary on the evening before experiment. Participants were asked to lie down quietly 10 minutes before and while the measurements were being performed. The points for each study were marked on the skin with nontoxic, washable ink by an expert acupuncturist. The probe tips were cleansed with ethyl alcohol at the beginning of each session. Probes were installed on the skin with an adhesive tape without pressure exertion. For each part study, different points were chosen. In the repeatability part, probes were installed on one side of the body (left side). For the remainder of the study, we installed the probes on both sides (left side as study points and right side as control points). For all measurements, the reference lead was pasted on the left leg. All environmental disturbances such as room temperature, relative air humidity, body temperature, skin moisture, electromagnetic devices, and noise were controlled. Temperature was set at 22-24$^{o}$ C and humidity at 30-40%. Each point had an identification number. The computer screen was positioned out of the line of sight of the researcher who did the procedure. Data were directly recorded in the computer. The operator who recorded and saved the data could not manipulate the results. The study was performed in four phases to evaluate the reliability of this device system, effects of pressure, cleaning the skin with alcohol and exfoliation on electrical skin

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impedance measurement.

**Study repeatability of device for 30 minutes**

Two acupoints were chosen for this part. One was Shousanli (LI10) and the other was Ximen (PC4). Two probes were installed on these points. Electrical impedances were measured 30 times in a 30-minute period. As it has been explained in device information, when we installed the probe on the location, there would be no need to remove and install them again for the next measurement and device measured electrical impedance each minute automatically for 30 minutes.

**The effect of pressure**

In this part of study, Ximen (PC4) was used as the study points. We chose this point because of the appropriate location for fixing the probe and put the weight on (one probe on the left side as the study probe and another one on the right side of the body as control probe). Three different scales (50 grams=63mmhg, 100 grams=126mmhg, 200 grams=252 mmhg) were used. We used scale weight because it is more accurate than blood pressure cuff and other methods. We chose these three scales because pressure equal to 50 grams is a pressure which can easily occur when we use the probes and pressure more than 200gm cannot be tolerated by the subjects. With different scales (50 grams, 100 grams, and 200 grams) electrical skin impedance was measured during 15 minutes. Each 15 minutes-measurement was divided to three periods. In the first period, electrical impedance was measured for 5 minutes without pressure. In the second 5 minutes, a scale weight was put on the probe and for the third 5 minutes the scale was removed. When the probes were installed on the location, there was no need to remove and re-install them during these 15 minutes and we just put and removed the scales at appropriate times. The control probe was operating without pressure at the same time on the right hand.

**Effect of cleaning the location by alcohol**

Kongzui (LU6) was used as the study point in this phase. First, probes were installed on the skin as it was explained above and electrical skin impedance was measured for 10 minutes, then the probe was uninstalled from the location and the subjects were asked to rest for 1 hour in order to minimize the effect of electrolyte on the skin. Then acupoints were cleaned with alcohol (75%) and electrical impedances were measured again for another 10 minutes with the same method and the data of two parts were compared,

**Effect of Exfoliation of the skin**

Shousanli (LI10) was used as the study point. First, electrical impedances were measured for 10 minutes, then the probe was uninstalled from the location and the subjects were asked to rest for 1 hour. We used adhesive tapes for exfoliation. We did exfoliation 15 times on the chosen location. Then Electrical impedances were measured again for another 10 minutes.

## Results

**Repeatability**

As shown in Figure 4, there is no significant change of electrical impedance during the time of measurement and mean of coefficient of variation of the device in Ximen (PC4) was 0.015±0.007 and in Shousanli (LI10) was 0.014±0.010. Leven's test of equality of variances was not statistically significant in either point.

**Pressure**

Tables 1 and 2 show P values, means and standard deviations for test and control groups for different pressures on Ximen (PC4).There was no statistical difference between electrical skin impedance of different weight scales and control group.

**Alcohol**

There was no significant difference between pre and post alcohol application on the skin measurements (P-value=0.937). Figure 5 shows electrical skin impedance results of Kongzui (LU6) before and after cleaning with alcohol.

**Exfoliation**

There was no statistically significant difference between pre- and post-exfoliation measurements (P-value=0.9). Figure 6 shows electrical skin impedance results of Shousanli (LI10) before and after exfoliation.

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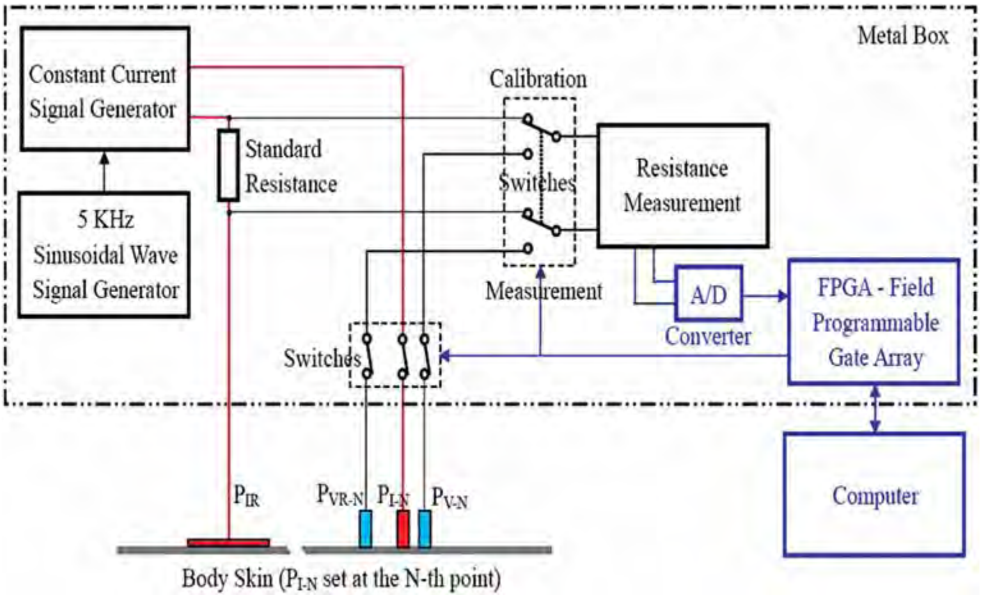


**Figure 1:** Schematic diagram of the system

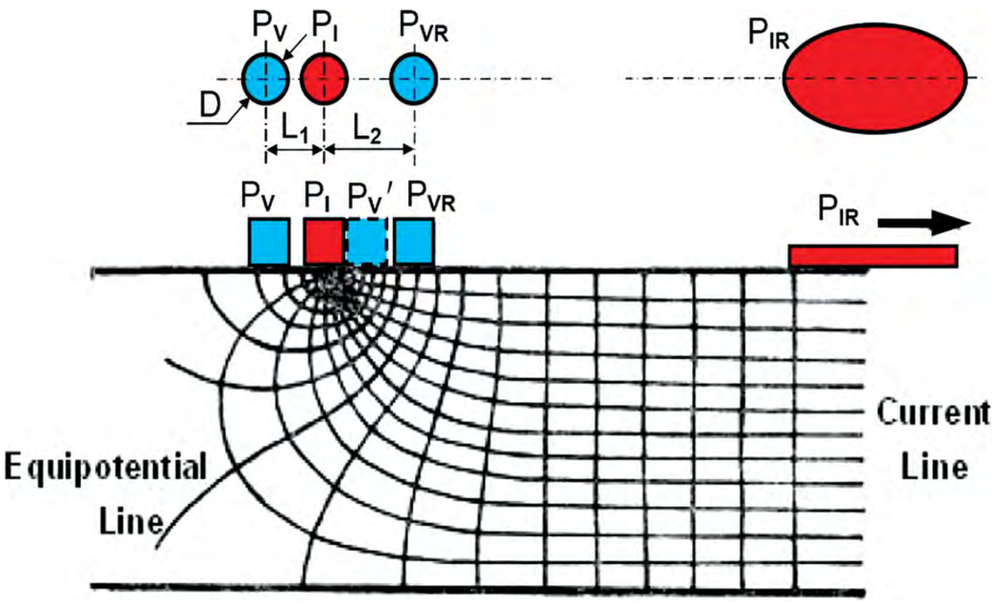


**Figure 2:** specific arrangement of electrodes to measure impedance of the small subcutaneous region

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**Figure 3:** Device and computer

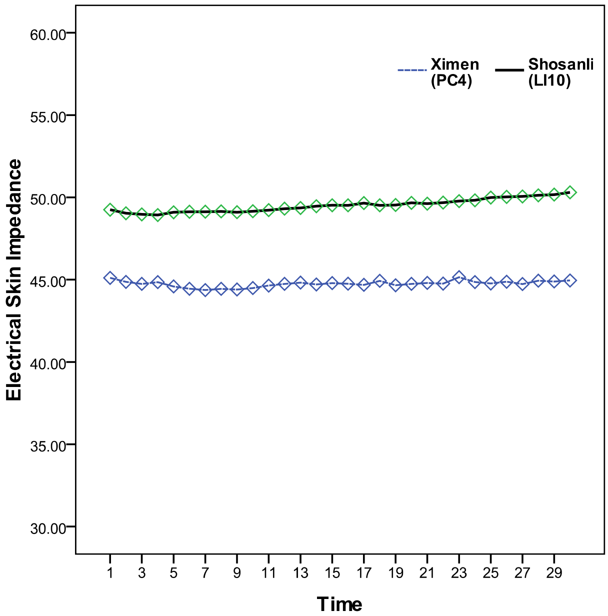


**Figure 4:** Repeatability of device during a 30 minute period

## Discussion

Both the two and four-electrode methods have been used for the measurement of skin electrical impedance. Ahn et al. (Ahn et al., 2005) and Yang et al (Yang Weisheng, 1978; Zhang et al., 1999) used four-electrode method; while in many

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**Table 1:** pressure evaluation of the **test probe** on the left Ximen (PC4) with different scale weights

| Scale | Group | Mean±SD | P .value |
|---|---|---|---|
| 50 gr | Test | 44.76±0.82 | 0.428 |
| 100gr | Test | 45.82±1.20 | 0.180 |
| 200gr | Test | 50.22±2.44 | 0.307 |

**Table 2:** pressure evaluation of **control probe** on the right Ximen (PC4) without pressure

| Scale | Group | Mean±SD | P .value |
|---|---|---|---|
| 50gr | Control | 45.67±1.28 | 0.832 |
| 100gr | Control | 44.62±0.25 | 0.144 |
| 200gr | Xontrol | 47.29±0.65 | 0.780 |

Researches, two-electrode devices have been used (Kramer et al., 2009; Matsumoto et al., 1973). Many studies tried to find the relation between electrical skin impedance results and acupoints and meridians while others tried to find a relation between electrical skin impedance results of special acupoints and diseases (Matsumoto and Hayes, 1973; Oleson et al., 1980; Yuangen et al., 2001). For this purpose, it is very important to use accurate and more reliable devices and some scientists such as Colbert et al tried to do so (Colbert et al., 2004). Many confounding factors affect the electrical impedance. One of the most important confounding factors is pressure. As Ahn et al mentioned: “Pressure can increase the effective contact area and thereby reduce the electrical skin impedance readings. This may explain why applying greater pressure leads certain acupuncture-point locator devices to mistakenly identify nonspecific areas as acupuncture points”(Ahn et al., 2007). Hu et al also agree with this notion (Hu, 1990). Some groups tried to control the effect of pressure on the electrode by applying same pressure on each electrode during measurements. For example Kramer et al used a blood pressure cuff to control and put the pressure on all probes (Kramer et al., 2009; Kramer et al., 2008). In our study, pressure didn’t have any statistically significant effect on the measurements which is a major advantage of the device used in our research.

The most superficial epidermal layer, the stratum corneum, highly contributes to the impedance to electrical currents (Ahn and Martinsen, 2007), and factors affecting this layer can alter the electrical measures. Tatsuma Yamamoto and Yoshitake Yamarnoto in 1976 studied the effect of different part of skin on electrical skin impedance results. They investigated stratum corneum using adhesive tape to remove this layer and showed that the epidermal stratum corneum was a very important element for the skin impedance as a high-electric impedance layer. They also reported a rapid impedance decrease during continuous stripping after about 15 times of stripping. In our study, no statistically significant change in the readings after exfoliation was noted which shows that this confounding factor doesn’t affect the device. In some studies alcohol was used to clean the surface of the skin (Colbert et al., 2004; Yamamoto et al., 1976) and it could affect the electrical impedance measurements because of different methods of cleaning. We evaluated the effect of this cleaning on electrical skin impedance and no change was noted in our study again.

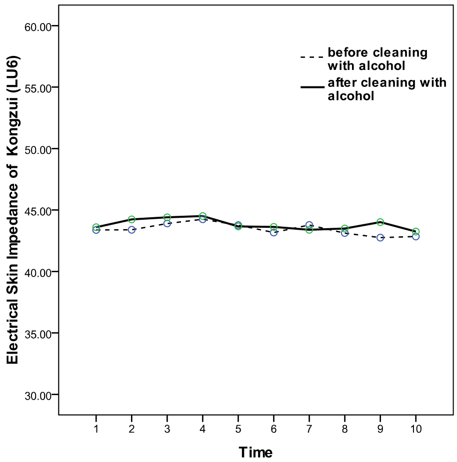


**Figure 5:** Electrical skin impedance of Kongzui (LU6) before and after cleaning by alcohol

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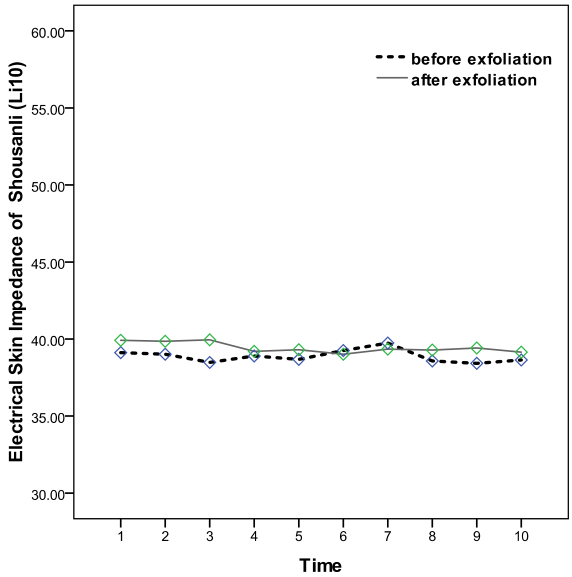


**Figure 6:** Electrical skin impedance of Shousanli (LI10) before and after exfoliation

Another problem in some researches is the need to measure electrical skin impedance of one point for several times and usually the probes are removed and re-installed for this purpose. We showed that using our device for 30 minutes, electrical skin impedance measurement was possible without any significant variation in readings and no need for removing the probes. Considering the sizes and the distances between the electrodes used in our study, the place which was measured was a small area approximately 1-2mm under the surface of the skin (Yang Weisheng, 1978). This can be the reason that confounding factors which are related to the surface of the skin such as exfoliation and cleaning with alcohol could not affect this device.

**Conclusion**

Our new device has some properties which can make it a good choice for future researches. It connects to computer and records electrical skin impedance of each probe automatically. This device has 12 probes and is able to connect to 12 different locations at the same time. It can also be used for a prolong period in recording electrical skin impedance. Pressure up to 200 grams, cleaning the skin with alcohol, and exfoliation did not affect the performance of this device.

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