

Comparison of representative skin pretreatment methods for body surface biopotential measurement

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Abstract

Various skin pretreatments for body surface biopotential measurement need a quantitative comparison. In this paper, 6 representative skin pretreatments, namely: no pretreatment, cleaning skin with alcohol, spreading saline on skin, rubbing skin with sandpaper, cleaning skin with alcohol and spreading saline, rubbing skin with sandpaper and spreading saline, are selected to be investigated. Two methods are particularly designed to test and compare the 6 pretreatments. Method one relies on comparing their skin-electrode impedances. The lower skin-electrode impedance means better electrical contact between skin and electrode. Practically, the measured skin-electrode impedance always includes internal human body impedance and skin-electrode contact impedance; when subject's physical state and detecting points remain almost constant, it can indicate the relative value of skin-electrode contact impedance. In method two, two electrodes are placed close enough to each other on the skin under the premise of no contact, and the voltage value between the two electrodes, which is exactly the interference and noise signal caused by the skin-electrode contact impedance, is directly measured with NI PCI4461. Amplitudes of the measured voltages are also used to evaluate different skin pretreatment methods. Through performing experiments on ten subjects in these two methods and evaluating the results of these two methods, obvious differences in effect between 6 different skin pretreatments have been shown, and their performance ranking has been given.

Introduction

Body surface biopotential measurements, such as ECG, EEG, EMG, etc., are becoming more and more widely used in our lives. Actually, there are a variety of seen skin pretreatments for measurements. From hospital we learn that, as for measuring ECG, some people directly place electrodes on bodies without doing any skin treatments for convenience; some people, with a bit more particular cares, clean the skin of the measuring position with 75% alcohol before arranging electrodes; there are also some more careful testers, who always abrade the skin with fine sandpaper or abrasion paste to remove the stratum cornea and then place electrodes. The representative skin pretreatment methods used in the actual clinical measurements and experimental researches are shown in Table 1.

Are various skin surface pretreatments really necessary to biopotential measurements, and what are the differences in effect between these skin treatment methods? These questions need the answers from experimental test and quantitative comparison. YH Chen invented a kind of polymer-based dry electrodes for high user comfort and tested its use, finding that skin pretreatment with abrasive rubbing and gel swabbing can reduce the impedance obviously [1]. To find out if ECG electrodes with appropriate skin pretreatments can substitute for EEG electrodes, Literature [2,3] tested the impedances under two different skin pretreatments: (1) alcohol skin cleaning, (2) alcohol skin cleaning and abrasive rubbing. The result is that the latter pretreatment

is better, with which ECG electrodes can be used for EEG measurement. However, to our best knowledge, profound comprehensive test and comparison of representative skin pretreatments have never been done yet.

This paper designed two methods to test and compare the 6 representative skin pretreatment methods quantificationally. The second part of this article introduces the first method, measuring human body output impedances [4-9] under 6 pretreatments and indirectly illustrating their magnitudes of contact impedances between skin and electrode. Section 3 describes another method, placing two electrodes on the skin ensuring one close enough to the other under the premise of no contact, and directly measuring their voltage value by a biopotential acquisition system to evaluate the different skin pretreatment methods. Section 4 is the conclusion.

Method one

Principle

Different skin pretreatment results in different skin-electrode impedance or different electrical contact between skin and electrode. The lower skin-electrode impedance, the better quality of the detected bio-electricity signal [2]. Theoretically, we can test and compare the 6 skin pretreatments by comparing their skin-electrode impedances. The problem is that it is difficult to test skin-electrode impedance directly.

However, as we know, the recorded human body impedance always includes two parts, internal human body impedance and skin-electrode

Table 1. Representative skin pre-treatment methods

(1)	No pretreatment
(2)	Cleaning skin with alcohol
(3)	Spreading saline on skin
(4)	Rubbing skin with sandpaper
(5)	Cleaning skin with alcohol and spreading saline
(6)	Rubbing skin with sandpaper and spreading saline

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impedance [10-15]. Since the internal human body impedance is changeless under certain condition, the distinctions of measured human body impedances must demonstrate the distinctions of skin-electrode impedances for different skin pretreatments.

For a biopotential acquisition system, the internal human body impedance and skin-electrode impedance might as well be collectively referred to as human body output impedance (HBOI). HBOI changes with the frequency of excitation signal. Considering that the energy of most physiological signals is centralized in low frequency band, this study mainly explores HBOIs in frequency range of 0.1 Hz-1000 Hz.

Experiment

No matter what HBOI to be measured is inductive or capacitive, we regard it as a black box temporarily, marked as $R+jX$, shown as Figure 1. In Figure 1, the human body, a resistance R_0 with the standard value of 10 k Ω , and the excitation signal v_s complete a series circuit. Compared to the excitation signal, our body's internal biopotential is so weak that it is ignored. Polarization voltage, which is near direct, is also left out of account because what we measured here is AC HBOI.

The HBOI measuring system is composed of a multifunction DAQ device 6289 [16] produced by National Instruments and a personal computer. The DAQ device 6289 which acts as excitation source and data acquisition module simultaneously, communicates with the PC machine via a dedicated USB cable. Equipped with the LabVIEW program on PC, the analog output Ao0 of 6289 provides a sinusoidal voltage excitation v_s with the amplitude of 1V (secure enough to human body), while, from analog input port Ai0 and Ai1, it is performed the synchronous acquisition of voltage excitation v_s and resistance voltage v_R with the same sampling rate of 10kHz. It is easy for us to accurately calculate and record the amplitude, frequency and phase information of the two sine signals from Ai0 (v_s) and Ai1 (v_R). The PC machine also can automatically change the frequency of excitation signal v_s .

Suppose that with an excitation sine wave of frequency f Hz, the amplitudes and phases of the measured voltage signal v_R and v_s are $A_s, \varphi_s, A_R, \varphi_R$. This means that we will have the resistance voltage $v_R = A_R * e^{j(2\pi f + \varphi_R)}$ for the excitation signal $v_s = A_s * e^{j(2\pi f + \varphi_s)}$. According to the principle of voltage divider, we also have equation (1). Furthermore, the calculation formula of HBOI is finally obtained, shown as (2):

$$\frac{v_s}{(R + jX) + R_0} = \frac{v_R}{R_0} \quad (1)$$

$$R + jX = \left(\frac{v_s}{v_R} - 1 \right) * R_0 = \left(\frac{A_s * e^{j(\varphi_s - \varphi_R)}}{A_R} - 1 \right) * R_0 = \left(\frac{A_s * e^{j\varphi_s}}{A_R} - 1 \right) * R_0 \quad (2)$$

In equation (2), φ is the phase difference between excitation signal v_s and resistance voltage v_R , i.e., $\varphi = \varphi_s - \varphi_R$.

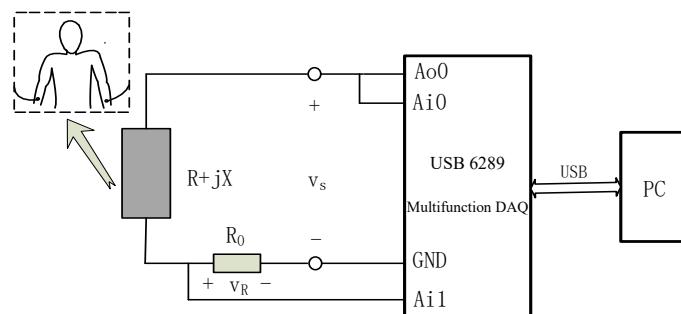


Figure 1. Schematic of human body output impedance measuring

In order to investigate the effects of different kinds of skin surface pretreatment methods on HBOI, hundreds of experiments were carried out on 10 healthy adults. We used three types of emblematic electrodes [17]: Nihon Kohden's standard limb clamp-electrode (with the model number of SF450), silicone ball-electrode (pz26) and MEDITRACE adhesive electrode (200) produced by American Kendall. Six skin surface pretreatments mentioned above were adopted on each kind of electrodes [18] conditions of experiments were made up with these three kinds of electrodes and six skin pretreatments. The forearms of test subjects were selected due to operating convenience.

The experimental procedure using clamp-electrode, for example, can be described as: (1) Seat the test subject by the experimental desk with her/his inner forearm upward on the desktop and then connect the circuit according to Figure 1; (2) Clamp one electrode holder on each arm, keeping its metal side close to the skin surface, then start the LabVIEW software and record and calculate the information of voltage v_s and v_R repeat 10 times for each frequency; (3) At the same position of step 2, wipe the skin with alcohol-soaked swab for a clean thumb-sized area, then place the clamp-electrode there in the same way after alcohol is evaporated and then record 10 sets of data for each frequency; (4) Spread normal saline on skin surface of a new test site near the position in step 3, then place the clamp-electrode and record 10 sets of data; (5) Gently rub skin with water-soaked 5000 sandpaper at a new location in a small area, then place the clamp-electrode and record 10 sets of data; (6) Spread normal saline at the position of step 3, then place the clamp-electrode and record 10 sets of data; (7) Spread normal saline at the position of step 5, then place the clamp-electrode and record 10 sets of data.

In order to avoid cross interaction, the electrodes used in the experiments of alcohol should not be used in the experiments of saline any more during the course of the experiment and vice versa; Rubbing with alcohol or sandpaper can remove cuticle to different levels, so we should better not perform these two experiments at one point on the premise that conditions of different skin surface in small scale are comparable so that it does not affect the results of experiment.

Results

As mentioned above, for each subject's each experiment condition we recorded 10 sets of data, and for each set of data, HBOI at every frequency point was figured out according to equation 2 with the solved amplitude and phase of the corresponding v_s and v_R . Then, we performed statistical analysis to all obtained HBOI values-calculating the average and range of the 10 sets of impedances under each experiment condition. One subject's average and range change curves of measured HBOIs for different pretreatments with clamp-electrode are plotted in Figure 2. In order to illustrate all subjects' differences of HBOIs between six skin pretreatment methods, we calculated the average value of HBOI amplitudes of 0.1 Hz-1000 Hz in each pretreatment condition, shown as Table 2. For the sake of contrastive analysis, line charts of data in Table 2 were also drawn in Figure 3.

By comparing the HBOI values and charts under 6 pretreatment methods in Table 2 and Figure 3, we can find that any pretreatments can reduce the output impedance to certain extent; the two pretreatments smearing saline after cleaning with alcohol and smearing saline after gently rubbing with sandpaper can reduce impedance amplitudes most of all. For instance, the average HBOI amplitudes after 6 pretreatment methods using clamp-electrode for subject I are accordingly 573 k Ω , 275 k Ω , 187 k Ω , 109 k Ω , 41 k Ω , 26 k Ω , and the largest reduction of average value is 573 k Ω -26 k Ω =547 k Ω .

Table 2. Average HBOI Amplitudes $R + jX$ (Ω)

Skin Pre-treatment		Subject Number									
		I	II	III	IV	V	VI	VII	VIII	IX	X
Clamp-electrode	(1)	573k	339k	335k	569k	267k	358k	736k	429k	439k	384k
	(2)	275k	318k	219k	240k	118k	260k	485k	273k	293k	219k
	(3)	187k	281k	107k	173k	77k	133k	406k	176k	227k	153k
	(4)	109k	97k	85k	77k	59k	109k	188k	130k	125k	66k
	(5)	41k	73k	27k	48k	56k	31k	183k	108k	76k	19k
	(6)	26k	18k	17k	22k	22k	6k	67k	47k	63k	14k
Ball-electrode	(1)	2274k	451k	531k	1223k	628k	721k	1899k	736k	1335k	342k
	(2)	783k	315k	448k	470k	484k	386k	551k	585k	937k	185k
	(3)	513k	118k	223k	420k	269k	319k	492k	419k	556k	158k
	(4)	434k	108k	206k	360k	238k	217k	353k	232k	252k	125k
	(5)	160k	41k	148k	125k	121k	188k	203k	215k	128k	65k
	(6)	33k	28k	44k	50k	100k	36k	152k	159k	52k	37k
Adhesive electrode	(1)	797k	924k	710k	543k	609k	758k	721k	840k	702k	380k
	(2)	561k	650k	493k	508k	405k	714k	648k	546k	408k	263k
	(3)	347k	502k	155k	327k	183k	192k	281k	280k	359k	151k
	(4)	105k	148k	98k	198k	133k	167k	278k	175k	217k	73k
	(5)	103k	79k	37k	90k	112k	55k	151k	146k	196k	47k
	(6)	78k	33k	20k	34k	58k	15k	126k	110k	134k	26k

Table 3. Peak-to-peak values of interference and noise voltages (mV)

Skin Pre-treatment		Subject Number									
		I	II	III	IV	V	VI	VII	VIII	IX	X
Clamp-electrode	(1)	5.16	3.18	3.15	5.14	2.4	3.87	6.13	4.39	4.4	3.87
	(2)	2.65	2.78	2.19	2.37	1.2	2.3	4.93	2.65	2.71	2.32
	(3)	1.58	2.48	1.17	1.4	1	1.28	4.32	1.4	2.33	1.36
	(4)	1.19	1.13	1.12	1	0.96	1.15	1.59	1.32	1.3	0.97
	(5)	0.89	1.09	0.65	0.94	0.95	0.75	1.56	1.14	0.99	0.51
	(6)	0.64	0.55	0.5	0.64	0.63	0.4	0.97	0.93	0.96	0.46
Ball-electrode	(1)	11.7	4.88	5.06	10.97	6.04	6.12	11.4	6.13	11.1	3.19
	(2)	6.16	3.06	4.4	5.06	4.92	3.9	5.08	5.2	8.9	1.58
	(3)	5.07	1.22	2.24	4.37	2.41	2.8	4.95	4.36	5.09	1.36
	(4)	4.38	1.17	2.01	3.89	2.35	2.21	3.2	2.35	2.45	1.29
	(5)	1.31	0.9	1.31	1.2	1.23	1.7	2	2.1	1.31	0.96
	(6)	0.76	0.75	0.95	1	1.1	0.78	1.35	1.36	0.95	0.85
Adhesive electrode	(1)	6.44	8.81	6.3	5.09	5.94	6.15	6.12	7.3	6.28	3.86
	(2)	5.08	6.07	5	4.98	4.07	6.11	6.06	5.11	4.3	2.63
	(3)	3.75	5.01	1.33	2.85	1.5	1.98	2.68	2.67	3.87	1.35
	(4)	1.17	1.23	1.12	1.99	1.22	1.38	2.66	1.43	2.31	0.98
	(5)	1.15	1.05	0.85	1.12	1.2	0.94	1.35	1.3	2	0.93
	(6)	1.02	0.77	0.6	0.78	0.99	0.5	1.3	1.17	1.23	0.65

This shows: (1) the skin-electrode impedances are much different for 6 pretreatment methods; (2) the average value of internal human body impedance in frequency 0.1 Hz to 1000 Hz must be smaller than 26 k Ω ; (3) the output impedance difference of 547 k Ω is mainly caused by the difference of skin-electrode impedance, which demonstrates that skin-electrode impedance among the human body output impedance may be much larger than internal human body impedance. Therefore, we must attach importance to the pretreatment of skin surface to ensure a good contact between skin and electrode.

Method two

Principle

Figure 4 gives equivalent interference and noise model respectively. According to the equivalent external interference model as shown in Figure 4(a), external interference sources, including high voltage grid, electrical equipment, radio, lightning phenomena of nature and so forth [18], leak into bioelectrical amplifier via voltage dividing of a parallel

impedance composed of the input resistance of amplifier (R_i) and HBOI (R+jX). Since R_i is always higher than 109 ohm, the interference received by the amplifier, at the input terminal, is proportional to the size of HBOI. According to the equivalent interior noise model shown in Figure 4(b), the interior noise current caused by the circuit itself passes through the HBOI and flows back to bioelectrical amplifier, which also produces an unwanted noise voltage proportional to the size of HBOI.

According to the above, we can evaluate different skin pretreatment methods by recording the interference and noise voltage in the biopotential acquisition system. Choose two test points which are close enough on the subjects' skin, then put an electrode on each point and connect them into the biopotential acquisition system. By now, the influences of body biopotential and human internal impedance on pretreatment evaluations are ruled out, since biopotential electrical potential difference between two close test points is approximately 0 and the human internal impedance is small when two test points are close enough

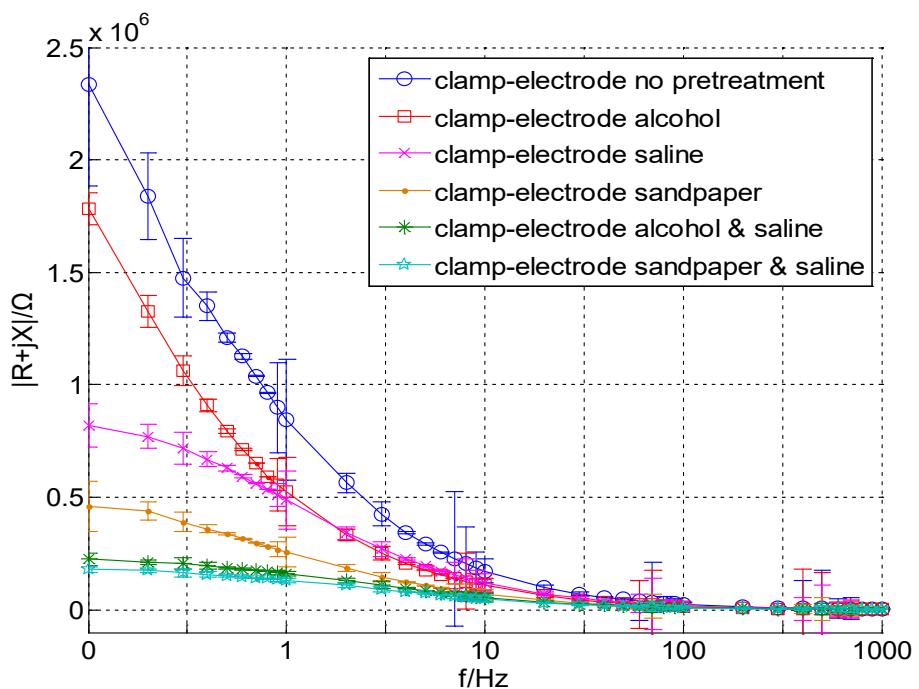


Figure 2. HBOI change curves for skin pre-treatments using clamp-electrode

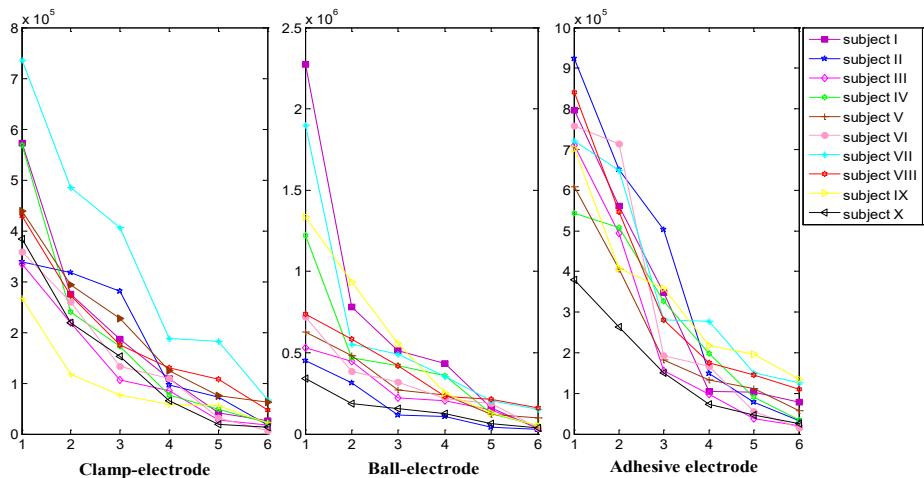
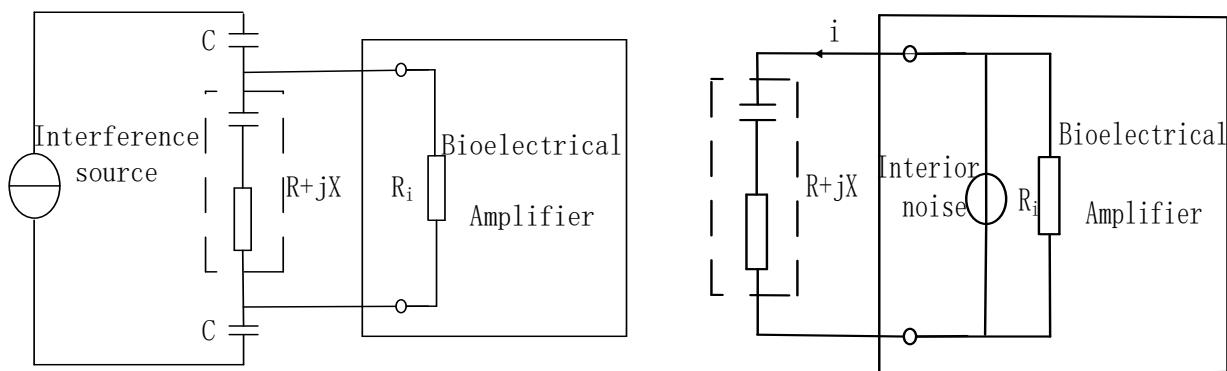


Figure 3. Line charts of average HBOI Amplitudes



(a) External interference model

(b) Interior noise model

Figure 4. Equivalent interference and noise model

Experiment

Here are the concrete implementation steps: (1) Seat a subject relaxed at the experimental desk with his/her inner forearm upward on the desktop, then choose two close points whose distance is about 5cm on the inside surface of right arm as measuring points and get a biopotential acquisition system ready; (2) Pretreat skin surface according to the skin pretreatment method awaiting assessment, then place an electrode to each measuring point selected in step (1), and access them to the Ai port of the biopotential acquisition system; (3) Record the voltage data for 24 s as txt format; (4) Calculate peak-to-peak value of the recorded voltage data for evaluation, and the smaller the peak-to-peak value means the smaller the interference and noise. In above steps, the biopotential acquisition system is constructed with NI PCI4461 card and a computer. Flow chart of this evaluation method is shown in Figure 5 and Figure 6. Following the scheme provided above, we tested 10 healthy adults in total.

Result

Interference and noise voltage signal, according to the principle mentioned above, increase with skin-electrode impedance. In this case, value orders of the recorded voltage of 6 different kinds of skin surface pretreatment should be constants with that of HBOI. Figure 7 showed the recorded voltage oscillogram of one subject using ball-electrodes. Six curves correspond to the skin pretreatment method (1) to method (6) in Table 1, respectively. Obviously, the interference and noise generated by different pretreatment methods are different.

The recorded voltage signals of each experiment situation were divided into 10 equal length groups. We calculated the peak-to-peak

values of each groups and then took the median of 10 peak-to-peak values as the final result, which is shown in Table 3. Comparing Table 2 and Table 3, with the correlation coefficient of two groups of data being 0.926, apparently, the rule of voltage values achieved in this method and the rule of impedance values in method one is fully consistent.

Discussion

Interference is mainly composed of 50 Hz signal and its harmonic waves, which are easy to be removed. However, other interference and noise signals are too complex to remove. Though the other interference and noise signals may be as small as only hundreds or even tens of μ V, as shown in Table 4, it certainly has little effects on adult ECG [19] whose amplitude is about several mV, nevertheless, for noninvasive fetal ECG [20] or EEG acquisition, this noise cannot be neglected, which will influence fetal ECG or EEG extraction severely.

Conclusion

With two particularly designed methods and a large amount of experiments for 6 skin pretreatments, we may safely draw the conclusions that: (1) skin pretreatment is vital to biopotential signal acquisition and should be given more attentions clinically and in experimental study; (2) The skin-electrode impedances for 6 skin pretreatments are quite different; some are as great as thousands of kilohms and some are only tens kilohms, (3) without considering the factors such as time-consuming, the descending performance sequence of 6 skin pretreatments is: smearing saline after gently rubbing with sandpaper, smearing saline after cleaning with alcohol, rubbing skin with sandpaper, spreading saline on skin, cleaning skin with alcohol, and lastly no pretreatment.

Table 4. Peak-to-peak values of residual voltages after removing 50 Hz signal and its harmonic waves (μ V)

Skin Pre-treatment		Subject Number									
		I	II	III	IV	V	VI	VII	VIII	IX	X
Clamp-electrode	(1)	517	600	373	684	224	425	562	107	691	532
	(2)	463	120	327	646	151	142	172	588	506	217
	(3)	256	91	241	173	603	178	160	147	136	143
	(4)	332	124	191	129	603	147	167	268	144	53
	(5)	77	114	131	164	603	101	117	164	40	102
	(6)	77	432	154	105	603	98	547	84	105	85
Ball-electrode	(1)	1500	1900	837	754	928	1000	880	954	303	435
	(2)	195	1600	706	689	306	480	269	520	266	367
	(3)	208	128	214	501	220	386	332	206	137	134
	(4)	249	595	524	246	441	317	662	414	297	114
	(5)	149	195	195	178	308	126	323	737	105	218
	(6)	118	162	181	80	226	130	303	180	105	126
Adhesive electrode	(1)	338	435	560	850	347	999	804	482	516	450
	(2)	204	839	479	726	281	258	468	481	826	759
	(3)	150	150	222	501	443	506	443	324	151	140
	(4)	280	136	348	190	438	218	425	497	96	118
	(5)	220	739	298	251	226	180	267	221	87	188
	(6)	109	181	209	213	345	123	345	313	142	62

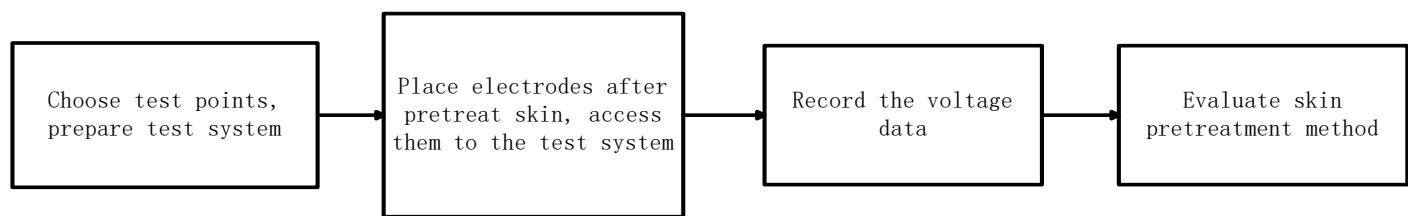


Figure 5. Flow chart of method two

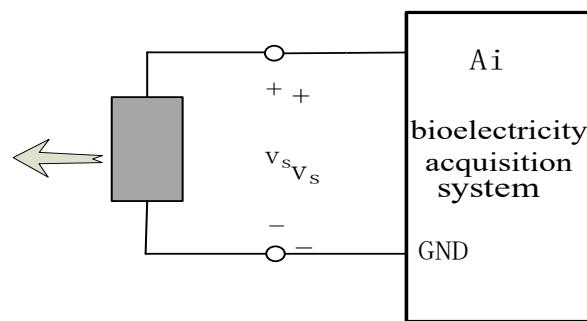
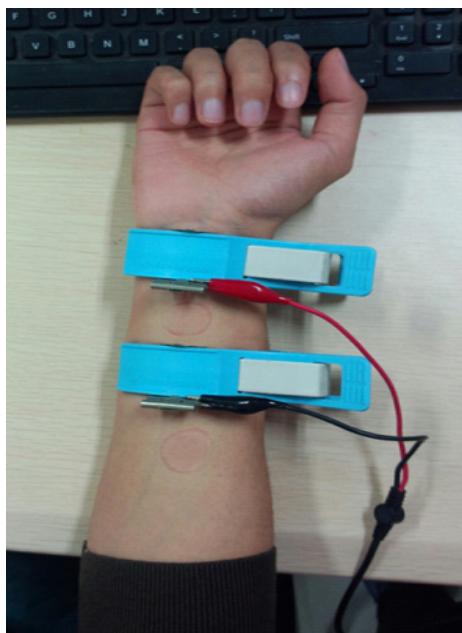


Figure 6. Schematic of interference and noise voltage measuring

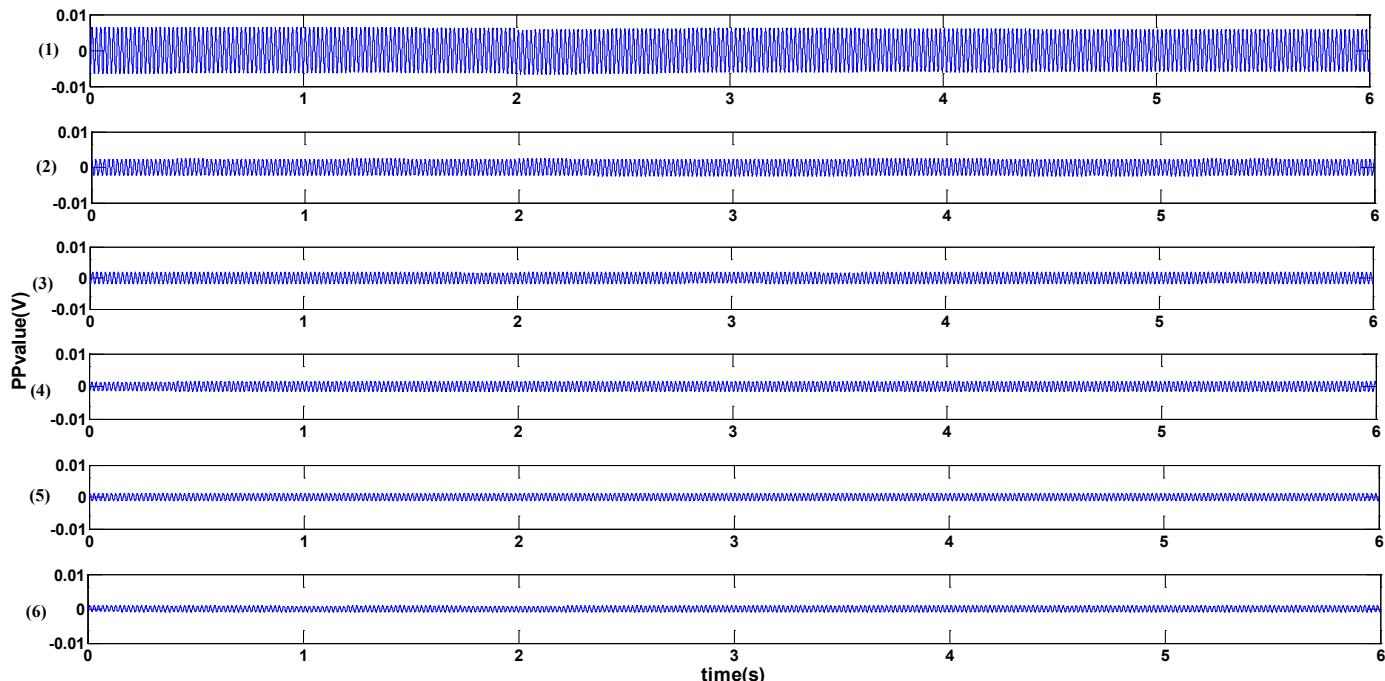


Figure 7. Voltage oscilloscope of one subject using ball-electrode

Conflict of interest

The authors have no conflict of interests to be declared.

Ethical approval

Ethical approval for experiment was given by School of Electronic Science and Engineering, Nanjing University.

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