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Reliability of AcuGraph system for measuring skin conductance at acupoints

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Abstract

Objective—There are many commercially available instruments for measuring electrical conductance, but there is little information about their reliability. The aim of this study was to quantify measurement variability and assess reliability of the AcuGraph system—a commonly used electrodermal screening device.

Methods—Four experiments were conducted to measure variability in electrical conductance readings obtained by the AcuGraph system. The first involved measuring known resistors. The second measured non-human organic matter. The third was a test–retest assessment of the Yuan-Source and Jing-Well points in 30 healthy volunteers who were measured by a single operator. The fourth was an interoperator reliability evaluation of seven acupuncturists at the Yuan-Source and Jing-Well acupoints on four individuals at two time points.

Results—Against known resistors, the AcuGraph had an average coefficient of variability (CV) of 1.8% between operators and test–retests. On non-human organic material the AcuGraph had an average CV of 0.9% and 2.8%. When a single operator tested 30 participants, the average reliability for the Yuan-Source points was 0.86 and 0.76 for Jing-Well points with a CV of 23.2% and 25.9% respectively. The average CV for the seven acupuncturists was 24.5% on Yuan-Source points and 23.7% on Jing-Well points.

Conclusions—The AcuGraph measures known resistors and organic matter accurately and reliably. Skin conductance at acupoints recorded by one operator was also reliable. There was less consistency in electrodermal recordings obtained by seven different operators. Operator training and technical improvements to the AcuGraph may improve consistency among operators.

INTRODUCTION

Electrodermal activity (EDA) has been one basis for research into the nature of meridians and acupoints.¹ Based on the pioneering work of Nakatani,² Voll³⁴ and Niboyet,⁵ electrodermal screening at acupoints is currently used by clinicians worldwide, as a

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diagnostic aid and to monitor therapeutic effectiveness. Recently its potential usefulness as an outcome predictor in a clinical trial of acupuncture was also demonstrated.⁶ A variety of commercially available instruments are used to measure EDA through skin conductance (admittance), skin resistance (impedance) and skin potentials at acupoints. Although custom-made devices are evaluated for precision and reliability of recordings, only a small minority of devices on the commercial market have been tested for their ability to obtain reliable skin impedance measurements at acupoints.^{7–11} Three of the major sources of variability in skin impedance measurements are: the instrument itself (device, electrodes and skin probe interface), the operators and the physiological variability over time of persons being measured.¹² The objectives of this study were to determine the accuracy of measurements obtained with the commercially available AcuGraph 3 Digital Meridian Imaging System (Miridia Technology, Meridian, *Idaho*, USA); to evaluate the repeatability of test–retest measurements and to assess the interoperator agreement of skin conductance measurements at the Jing-Well and Yuan-Source acupoints.

In order to clarify, throughout this paper we will be using the terms 'accuracy', 'precision' and 'variability'. Accuracy refers to the ability of the machine to take a true measurement and will only be used to describe the instrument. Precision is used in a similar manner. Variability will be used in the statistical sense and refers to the extent to which the measurements differ from each other.

INSTRUMENTATION

The AcuGraph 3 Digital Meridian Imaging System (figure 1) is a computer software and hardware system developed by Miridia Technology. The system, which consists of software, an electronic control unit (ECU) and a probe set (ground and probe), electrically measures galvanic skin resistance at acupuncture meridian points on the body. The software then calculates and reports the conductance at each measured point. The software program allows data collection at the 24 Jing-Well acupoints, and the 24 Yuan-Source points. The 12 paired Jing-Well (*Ting*) points (see figure 2) are located at the beginning or end of the meridians on the fingers and toes and are needled to prevent the penetration of 'perverse energy' into the meridians. The 12 paired Yuan-Source points (see figure 3) are located on the wrists and ankles and are believed to serve as reservoirs for the 'energy' produced in their affiliated organs.¹³

Typical usage consists of gathering patient identifying data, applying a water-moistened cotton electrode probe to the acupoints to collect data, and interpreting that data with charts, graphs and recommendations produced by the software.

The software, running on a standard personal computer (PC), provides all user-interface functions and controls the system. During the exam, the software guides the operator by illustrating which point is to be measured. When the measurement cycle is complete for that acupoint, the next acupoint to be measured is displayed and so on until all points have been measured. The exam, which takes 4–6 min to complete, consists of measuring all Yuan-Source and Jing-Well acupoints on each of the 12 primary meridians bilaterally, for a total of 48 skin sites. The software stores de-identified patient data, including age, gender and time and date of AcuGraph examination.

The electronic control unit (ECU) interfaces with the PC through a universal serial bus (USB) port. Commands from the software are received and the ECU responds accordingly. The ECU contains all the measurement, interpretation and communication circuitry, as well as a micro-controller to control all the system functions.

The probe set consists of a handheld plastic probe used by the operator, and a metal hand mass held by the subject. The hand mass provides a return path for the measurement current. Both the probe and hand mass are connected to the ECU by 18-gauge, vinyl insulated test lead wires and a removable plug. The probe has a hollow, cylindrical, gold-plated metal tip (~3 mm diameter), designed to accept the end of a cut cotton swab. The cotton swab, in turn, makes contact with the subject's skin. The cotton swab is moistened with standard tap water to facilitate flow of electrical current and provide a better probe-skin interface. The probe is held steadily at a 90° angle on the point during the measurement cycle, while the probe controller provides auditory feedback to the operator indicating measurement and completion of the measurement cycle.

Measurement parameters on the AcuGraph are as follows: voltage=5 V direct current, current=0–40 μ A; resistance—measurement range=75 k Ω to 20 M Ω ; duration is user-selectable, but typically set for 3.0 s per measurement. The measurement circuit captures approximately 10 measurements per second and maintains a running average of the prior 10 readings. Upon completion of the measurement cycle, the final five readings are discarded and the average of the 10 readings prior to the last five is captured by the computer software and recorded as the reading for the point being measured. This running average function smoothes fluctuations in the readings and prevents interference that is typically encountered at the end of the reading cycle when the probe is being removed from the skin.

Skin resistance is measured by a voltage divider circuit in comparison with a known reference resistance. Because the microcontroller can measure both sides of the divider circuit, the device is self-calibrating. The analogue resistance information is then converted to a digital signal and quantified by the microcontroller, then relayed to the PC through the USB. The subroutines for measurement and averaging run on the microcontroller within the ECU. The unit is powered by the 5-volt USB on the computer.

Reading scale

The original Ryodoraku system of measurement and treatment developed by Dr Yoshio Nakatani¹⁴ expressed the conductance of each skin point on a scale of 0–200 μ A. For patient comfort and reliability, modern systems use much less current, but most have retained the original 0–200 scale of Ryodoraku. Using a current of 0–40 μ A, the AcuGraph reports transformed resistance data in normalised conductance units (conductance = 1/resistance) on a scale of 0–200.

METHODS

For all experiments, either the CV (a normalised measure of dispersion defined by the SD divided by the mean and generally expressed as a percentage) or the reliability coefficient (a measure of how close multiple measurements are to each other).¹⁵ A CV value of 0 indicates no variation. The reliability coefficient has a range of 0–1.0 and is interpreted similarly to a squared correlation, where 0 indicates that the measures have no relationship to each other and 1.0 indicates that all of the measures are the same.

All experiments were conducted under the approval of the National College of Natural Medicine Human Subjects Review Board.

We conducted four experiments with the AcuGraph:

Experiment 1: against known resistors

Three operators took six measurements on each of four known resistors (560 k Ω , 1 M Ω , 2.2 M Ω and 5 M Ω). The CVs of these data are reported.

Experiment 2: against non-human organic matter

A single operator measured electrical conductance on a summer squash, a carrot, a potato and a ham. This experiment was conducted to examine whether the AcuGraph was equally reliable when tested on organic matter that was not human. Measurements were taken at four different sites on a summer squash and four different sites on a carrot. The AcuGraph was unable to measure the ham (conductance readings were too high) or the potato (readings were too low). CV was reported.

Experiment 3: variability among 30 healthy participants

Thirty healthy volunteers were recruited by web postings, flyers, classroom announcements and word-of-mouth from the National College of Natural Medicine staff, students and faculty. Potential participants had to be 21 years of age or older, have no implanted electronic devices and be willing to refrain from caffeinated beverages for 3 h before being tested.

Participants completed an eligibility questionnaire and prior to enrollment in the study underwent an examination of the skin on their fingers, toes, wrists and ankles to assure that the skin over the acupoints to be measured had no obvious visible lesions such as cuts or cracks, moles or tattoos. Participants were asked to list their current medications and supplements in the Eligibility Questionnaire in order to track any potential correlations with the study results.

In this test–retest design, we evaluated the mean reliability of a single measurement at 48 acupoints (24 Jing-Well points and 24 Yuan-Source points). Participants were comfortably seated in an upright chair for 10 min prior to beginning skin conductance recordings. A single examiner (HS), using the AcuGraph 3 Digital Meridian Imaging System measurement system, recorded three sequential sets of skin conductance measurements at the 24 Jing-Well (figure 2) and the 24 Yuan-Source (figure 3) acupoints. These acupoints were chosen for their clinical importance, their use in previous trials, their different anatomical locations and because of AcuGraph software compatibility.

All measurements took place at the Helfgott Psychophysiology Laboratory. Testing was not limited to certain times of the day because reliability of skin resistance measurements rather than absolute values was the focus of this study. Ambient temperature was kept between 70°F and 72°F.

During the examination, participants sat quietly in an upright chair. The skin at the Jing-Well acupoints and the Yuan-Source acupoints was cleansed with ethyl alcohol. For consistency of electrode placement in the three sets of recordings, circular adhesives with 5 mm diameter centre cutouts were placed over each of the 48 acupoints to be measured. During testing, participants held the cylindrical reference electrode in the right hand while testing the left hand, and in the left hand while testing the right hand and both feet. The Yuan-Source *points* were tested first. The order of acupoints tested was left wrist/hand, then right wrist/hand followed by left ankle/foot, and right ankle/foot. After completing the three sets of Yuan-Source measurements three sets of measurements were obtained from the Jing-Well points in the same order as the Yuan-Source points. Recording three consecutive readings at the 48 acupoints, took approximately 20 min for a total of 144 measurements on each volunteer.

Test–retest reliability was calculated on all points and the average reliability coefficient of the right and left is reported.¹⁶

Experiment 4: variability among practitioners

Seven operators using the AcuGraph measurement system recorded skin conductance measurements at the 24 Jing-Well and the 24 Yuan-Source acupoints during two test sessions separated by one week. Using a random-number-generated pattern, examiners were assigned an examiner number. Each of the four volunteers underwent testing by six examiners in random order.

Prior to testing, the examiners had a 30 min training session that consisted of viewing a 5 min video tape and practice recording measurements on each other. Each of the examiners was blinded to the results of the reading at each point. One of the examiners managed the technical aspects of the study, ensuring that the protocol was followed, conditions in the laboratory were controlled and the AcuGraph instrument settings were appropriately set up for each data collection.

Acupoints on the volunteers were not marked, but examiners were allowed to consult the charts illustrated in figures 2 and 3. Each operator used his or her standard technique to locate the Jing-Well and the Yuan-Source acupoints. Each operator recorded 48 measurements on four volunteers on the two test days for a total of 2304 skin site recordings (288 measures on each subject on each day).

At the second test session, a week later, at the same time of day, the same volunteers were examined. All examinations took place in the Helfgott Research Institute Psychophysiology Laboratory. No one had access to the previous data on the second study day. A standardised AcuGraph protocol as described above was followed.

Coefficients of variability were calculated on all Jing-Well and Yuan-Source points and the average is reported.

RESULTS

In the first two experiments (known resistances and non-human samples), there was little variability among measurements. In Experiment 1, which involved measuring standard resistors, the average CV was 1.4% with the mode being 0%. In Experiment 2, the average CV for the carrot was 0.9% and for the squash 2.8%.

In Experiment 3, the range of test–retest reliability for the Yuan-Source points was 0.78–0.95 with an average reliability coefficient of 0.86. The range of reliability coefficients for the Jing-Well *points* was 0.56–0.91 with an average coefficient of 0.76. The CVs ranged from 16.8% to 30.3% on the Yuan-Source *points* and 15.5–39.4% on the Jing-Well *points* (see table 1).

In Experiment 4, the CVs between practitioners varied to a high degree. The range of coefficients for the Yuan-Source points was 19.4–34.8% with an average of 24.5%. The range and average CV of the Jing-Well points was 17.7–29.4% and 23.7% (see table 1). The results were not due to relatively high variability among one or two practitioners but rather inconsistency among all practitioners. While these CVs have similar values to the CVs in Experiment 3, it is important to remember that they can not be directly compared as CVs are the within-person SD divided by the mean measurement (usually multiplied by 100). Therefore one can compare CVs of different measurement processes in the same circumstances, but it makes no sense to compare the same process in different circumstances.

DISCUSSION

We found that the AcuGraph 3 Digital Meridian Imaging System measures standard resistors and organic materials accurately and reliably as demonstrated in Experiments 1 and 2. In addition, Experiment 3 indicates that when the same skin site (acupoint) is measured in three consecutive recordings by a single operator, over a period of 20 min, the AcuGraph demonstrates a high level of reliability. This level of reliability is comparable to that found with other electrodermal screening devices, such as the Prognos device⁷⁹ and the AMI device.⁸ This finding will provide a degree of confidence for solo practitioners who use these devices in their clinics. Although a single set of three readings taken with the AcuGraph was highly repeatable, we are unable to say anything about the repeatability of these measures over a longer time period than 20 min. For example, we cannot say conclusively that week to week differences recorded from the same individual are solely the result of changes in that individual over time because our measurements were taken on a single day only.

To our knowledge there are no other published studies that assessed the interexaminer variability of operators using the same device to record skin conductance at acupoints on the same patients. In Experiment 4 we found a high level of variability in AcuGraph readings obtained by seven practitioners who had received minimal training with the current iteration of the AcuGraph system. As a comparison, interexaminer variability of blood pressure readings typically have a CV of 9.9% systolic and 9.2% diastolic.¹⁷ This finding has ramifications for using the AcuGraph (or any other electrodermal screening device) in a clinical trial in which multiple operators record skin conductance measurements on multiple participants.

A limitation of Experiment 4, however, is that the acupuncturists were novice AcuGraph operators. Prior to recording electrodermal measurements, they watched a 5 min videotape instruction and were then told simply to locate the acupoint using their own point location technique, and hold the probe perpendicular to the acupoint for measurements. The novice operators practiced obtaining readings on each other for approximately 20 min prior to the experiment. It is possible that with more consensus training on acupoint location and probe handling interoperator agreement might be higher. In our previous work of developing consensus among acupuncturists for traditional Chinese medicine diagnoses we found that a single day session of training, with feedback to the acupuncturists following pools of diagnoses, led to an acceptable level of diagnostic agreement among practitioners for a clinical trial.¹⁸ Future operator training in the use of the AcuGraph system will include further instruction and practice on consistent acupoint location among examiners and probe handling with the express goal of obtaining greater agreement among operators. In such a training session individual operators will observe and critique each other's techniques. They will be instructed to obtain similar recordings to each other and will continue to practice until a desired level of agreement was reached.

Another limitation of Experiment 4 may be our use of the AcuGraph 3 Digital Meridian Imaging System which does not have a pressure sensor. Since conducting our experiments in February, 2010 the AcuGraph system has undergone a crucial change for the better: a pressure sensor has been incorporated into the measuring probe so that recordings are now acquired only at a specific pressure, thus controlling a well-known source of variability—pressure control. Potential effects of this change have not, however, been evaluated. As another technical improvement, in future studies we will experiment with placement of the reference electrode on a single midline skin site rather than changing from hand to hand during the testing.

CONCLUSIONS

Electrical conductance measurements with the AcuGraph 3 Digital Meridian Imaging System provide repeatable readings on known resistors, non-human organic material and on human acupoints when recorded by a single operator. However, an unacceptably high level of inter-rater variability was found among minimally trained AcuGraph operators, which provides a cautionary note regarding the use of this system in a clinical trial that requires multiple users. We are optimistic, however, that adding a pressure sensor to the AcuGraph system and providing in-depth consensus-training to the operators will lead to a level of interoperator variability that is acceptable for use in clinical trials.

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Summary points

- ▶ Skin conductance instruments are used to identify acupuncture points
- ▶ Their reliability is unknown
- ▶ We tested Acugraph on different materials and with different operators
- ▶ A single operator was consistent, but multiple operators were not

Figure 1.
AcuGraph 3 Digital Meridian Imaging System.

Figure 2.
Jing-Well Points.

Figure 3.
Yuan-Source Points.

Test-retest reliability and interexaminer agreement for AcuGraph measurements of skin conductance at Yuan-Source and Jing-Well acupuncture points from Experiment 3 and 4

Table 1

Location	LU	LI	ST	SP	HT	SI	BL	KI	PC	TE	GB	LR
Experiment 3: test-retest reliability of a single practitioner—fixed locations (n=30) reliability												
Yuan-Source	0.81	0.94	0.88	0.76	0.87	0.91	0.85	0.93	0.86	0.95	0.78	0.78
Jing-Well	0.81	0.70	0.65	0.72	0.56	0.70	0.90	0.91	0.80	0.68	0.86	0.86
Experiment 4: interexaminer agreement of seven practitioners—no fixed locations (n=4) coefficient of variability (%)												
Yuan-Source	19.4	34.8	26.1	20.2	22.6	22.8	22.5	23.6	22.9	27.2	27.5	24.6
Jing-Well	24.8	23.3	20.7	21.1	29.2	28.6	22.4	19.5	27.3	29.4	20.8	17.7