Effects of Glucose Ingestion on Acupoint Conductance

Shih-Tsang Tang, * # Ke-Feng Huang, ** Chia-Yen Yang, * Mei-Jung Chen *

** Abstract **

Traditional Chinese medicine considers the nutritive Qi—which is transported and regulated by the meridian system—to be the major source of energy for the human body. Modern medicine indicates that glucose provides the energy requirements of the body via blood circulation. The hypothesis examined in this study was that there is a correlation between glucose in modern medicine and nutritive Qi in traditional Chinese medicine, which was tested by measuring the changes in the Ryodoraku electrical conductances of acupoints during an oral glucose tolerance test. Twenty subjects drank a glucose solution after 10 hours of overnight fasting. Both acupoint conductance and blood glucose concentration were measured continuously at 30-minute intervals for a total of 2 hours. Since this study had a time-series design, data were analyzed using generalized estimating equations. The results demonstrated that the acupoint conductances varied following glucose digestion. Certain meridian vessels indeed appear to exhibit regular fluctuations: the conductances first decreased, indicative of energy consumption from glucose digestion, and then increased, indicating energy acquisition from glucose and its distribution. Glucose metabolism induces significant physiological responses in the meridian system, implying that the meridian vessels are the measurable indicators of energy distribution and transformation. These observations are very meaningful for clarifying energy regulation in traditional Chinese medicine.

** Keywords **: Ryodoraku, acupoint conductance, oral glucose tolerance test.


1. Introduction

In modern medicine it is accepted that glucose (1) is absorbed following digestion of food, (2) is the main source of body energy, and (3) is transported to various tissues and organs via blood circulation. In traditional Chinese medicine it is believed that nutritive Qi is transformed and delivered after ingesting and digesting food. Traditional Chinese medicine claims that nutritive Qi can enter five viscera, six bowels, and various tissues through the operation and regulation of the meridian system, and that it provides the required physiological energy. Thus, from the energy considerations, it is reasonable to assume that there is a correlation between “glucose” in modern medicine and “nutritive Qi” in traditional Chinese medicine.

According to the meridian theory of traditional Chinese medicine, life functions involve the coordinated operation of the meridian and Zang-Fu (viscera and bowels) systems. The meridian vessels connect the inside and outside of the body, operate Qi and blood, regulate the function of the viscera and bowels, and provide the nutrition for various tissues and organs. The operation of the Zang-Fu system starts after digestion, and traditional Chinese medicine has a primitive concept to describe the relationship between the digestion and Zang-Fu systems. In the treatise Suwen-Jingmai Bielun, Nei-Ching (a traditional Chinese medicine classic) states that “when food enters the stomach, it is digested and transformed. ... Then the refined, substantial portion of the food essence is transported to the heart, through the blood vessels, channels, and collaterals, then it converges at the lungs, whereby the lungs dispense it to the hundred channels of the entire body and finally to the skin and hair”[1]. The operation of the Zang-Fu system involves food ingestion, which is the major method for acquiring nutritive Qi. The meridian system then works as the pathway for nutritive Qi, and plays a core role in the regulation of the physiological functions of the viscera.

The status of the meridian system is known to vary with the operation and function of the viscera and bowels within the body, and its behavior relative to the electrical characteristics of acupoints on the meridians has been a subject of research since the 1950s. Dr. Yoshio Nakatani [2] discovered Ryodoraku acupuncture, and Dr. Reinhold Voll [3, 4] characterized the electrical activity of the meridians, which is better known as “electroacupuncture”. Many researchers have studied acupoints extensively, and major findings include that they have low impedances and high potentials. Reichmanis and colleagues [5] found that both the resistance and capacitance between acupuncture points varied significantly by external voltage perturbation. And then they discovered...
that the resistance at the meridian was significantly lower than at sites devoid of meridian [6]. Zhu [7] found that more than 90% of particularly low impedance skin points coincide with traditional Chinese medicine acupuncture points. Tsuei [8] introduced the Voll (EAV) electro-acupuncture system as a means to standardize the therapeutic effectiveness of acupuncture. Lu and colleagues [9] investigated the symmetry or preferred direction of electrical conduction of human meridians. Moreover, there is a strong correlation between the meridians and the viscera, and the strength of this correlation varies with the electrical characteristics of individual acupoints. The acupoint conductance would fluctuate from perturbation of the meridian system. Bao [10] conducted an analysis correlating the visceral disease with the change in resistance at the meridian points. Kobayashi [11] investigated cancer diagnosis by means of Ryodoraku neurometric points. The method can reveal not only a highly significant difference between cancer and non-cancer groups, but also provides a valuable evaluation of whether a cancer patient is improving or getting worse. Sullivan and colleagues [12] found a significant level of agreement between the lung electroacupuncture point measurements and subjects with confirmed lung cancer. Tsuei [13] and Chen [14] provided system reviews on the theory and practice of acupuncture and the electrical properties of meridians. Schmidt and colleagues [15] found that electroconductivity is a useful noninvasive technique for the evaluation of sympathetic nervous activity in cholecystectomy. Chun and colleagues [16] observed that the current on acupuncture spots changed before and after meal, and healthy persons showed a regular pattern while unhealthy persons showed irregular patterns of current changes. Lee and colleagues [17] investigated the differences in bio-potential in the stomach meridians between normal healthy control subjects and gastric disease patients. The response patterns of healthy control subjects were regular in both the left and right meridians, whereas the response patterns of gastric disease patients were irregular. Ingestion and digestion of food reportedly do not induce consistent changes in the electrical characteristics of acupoints [18]. However, this could be attributed to various factors including the presence of large variations in acupoint signals, the difficulty of controlling the baseline, fundamental differences between individuals, and the lack of standards against which to measure ingestion parameters [19].

Our previous study that showed a strong relationship between glucose metabolism and Qi vacuity [20]. Then we hypothesize that glucose metabolism may also correlate directly with the Qi status, regardless of the vacuity condition. The aim of the present study was to determine whether performing an oral glucose tolerance test (OGTT) induces variations in the electrical characteristics of acupoints. Various steps of the experimental procedure were normalized quantitatively, and potential errors were controlled as much as possible throughout the study. The behavior of the meridian system was examined relative to the distribution and regulation of energy.

2. Materials and Methods

2.1 Subjects

Twenty healthy adults (13 males, 7 females) ranging in age from 20 to 26 years (±1.2 years, mean ± standard deviation (SD)) participated in the study. Due to associated fluctuations in dermal impedance, women who were menstruating were excluded from this study. The criteria for being “healthy” were as follows: (1) a self-reported feeling of good health, (2) routine blood parameters within normal limits, and (3) no abnormalities found on a physical examination by a physician. The recruitment of subjects and the study design were approved by the institute research board (sponsored by National Yang Ming University, Taipei, Taiwan).

2.2 Study design

This study had a one-group comparison design. The electrical conductances of acupoints and the blood glucose level of subjects were measured at five discrete time points before and after ingesting a glucose solution. Before the OGTT, the subjects were requested to fast overnight for 10 hours, and their acupoint conductances and blood glucose were measured to provide baseline data. They then ingested a 75-g glucose solution. Sequential acupoint conductance and blood glucose measurements were made 30, 60, 90, and 120 minutes after glucose ingestion.

2.3 Measurement device and protocol

In this study, the electrical conductances of acupoints were measured using a Meridian Energy Analysis Device (MEAD ME-100, MedPex Enterprises, Taichung, Taiwan) operating at 12 VDC and from 0 to 200 μA. The active monopolar stainless steel probe electrode of this device is 1.1 cm in diameter and comprises a cup containing saline and moist wool. The pressure of the spring-loaded probe electrode was maintained constantly at 120–140 g/cm². The device takes measurements over a 2.5-second period, and presents the average value for that period. The device was recalibrated before each measurement. The stability and reliability of measurements obtained from this device have been demonstrated previously, by measuring 12 body meridians and presenting the minimum 79.9% and 93.2% of the highest reproducibility of confidence (p < 0.0001), while measuring up to 96 percent consistency of the meridian test results [21].

The acupoint conductance was measured using a Ryodoraku measurement tool with a reference electrode held in the right hand (Fig. 1). Ryodoraku values were recorded at 12 main acupuncture channels bilaterally and symmetrically on the hand and the foot (a total of 24 points) according to Nakatani [2]; lung (LU9), pericardium (PC7), heart (HT7), small intestine (SI4), triple heater (TH4), large intestine (LI5), spleen-pancreas (SP3), liver (LR3), kidney (KI3), urinary bladder (BL65), gallbladder (GB40), and stomach (ST42). The above acupuncture points are named according to the proposed standard
nomenclature of World Health Organization[22].

Blood glucose levels were measured from venous blood samples taken during the OGTT. However, since we were concerned only with relative changes, blood was collected from the fingertip for simplicity. The blood glucose concentration was measured using the ACCU-CHEK Advantage System (Roche Diagnostics, Rotkreuz, Switzerland).

2.4 The OGTT and experimental procedure
Experiments were conducted in all subjects between 8:50 a.m. and 11:00 a.m. after overnight fasting. The subjects were asked to lay flat and rest for 10 minutes without falling asleep. The acupoints and the fingertip were wiped and sterilized using 75% alcohol before making measurements. The baseline (first) acupoint conductance and blood glucose concentration measurements were made before glucose ingestion. Then glucose was ingested, and the second measurements were made after a 30-minute period before glucose ingestion. Then glucose was ingested, and glucose concentration was measured using the ACCU-CHEK Advantage System (Roche Diagnostics, Rotkreuz, Switzerland).

2.5 Experimental environment
The environmental conditions were controlled by maintaining the temperature at between 25°C and 27°C, and the relative humidity at 60–80%. To control for any variation in acupoint conductance with the recording time, all measurements were performed during the period 9:00–11:00 a.m. Furthermore, the subjects were asked to stay awake throughout the measurement process, since falling asleep could induce larger variations in the signals.

2.6 Data analysis
The variation in acupoint conductance during OGTT was quantified as a difference according to the following equation:

\[
\Delta(T_{a,s}) = \frac{C(T_a) - C(T_b)}{C(T_b)}
\]

Where \( \Delta(T_{a,s}) \) is the variation of the acupoint conductance between times \( T_a \) and \( T_b \) (the subscript \( a \) indicates the measurement interval, ranging from 1 to 4), \( C(T_a) \) is the Ryodoraku value (electrical conductance of the acupoint) measured at time \( T_a \) and \( T_b \) is the baseline (i.e., before ingesting the glucose solution).

2.7 Statistical analysis
In order to control for differences between individual subjects at time \( T \), variations in acupoint conductance during each time segment (between times \( T_{a,1} \), \( T_{a,2} \), \( T_{a,3} \), and \( T_{a,4} \)) was converted to percentage as described above. Since our experiments are repeated observations, cross-sectional time-series data are collected. As a result, the generalized estimating equations were used to determine whether the data were statistically significant.

3. Results
The mean (SD in parenthesis) electrical conductances of the 24 acupoints on the left and right sides are listed in Tables 1 and 2. The \( \Delta(T_{a,s}) \) values of the 24 acupoints were calculated; \( \Delta(T_{a,s}) \) varied with time for each acupoint, with the variations peaking during the interval \( T_{a,1} \), as shown in Fig. 3. Overall, the variations in \( \Delta(T_{a,s}) \) were large on the lung, pericardium, small intestine, large intestine, spleen-pancreas, liver, urinary bladder, and stomach meridians, and small on the heart, triple heater, kidney, and gallbladder meridians. Figure 4 shows the percentage differences in blood glucose concentration during intervals \( T_{a,1} \), \( T_{a,2} \), \( T_{a,3} \), and \( T_{a,4} \); the difference was maximal during \( T_{a,1} \) and decreased in the order \( T_{a,2} \), \( T_{a,3} \), and \( T_{a,4} \).

GEE statistical analysis revealed that some acupoints exhibited significant variations in \( \Delta(T_{a,s}) \) during the time intervals (Fig. 5). \( \Delta(T_{a,1}) \) decreased on the liver (\( p < 0.05 \)), stomach (\( p < 0.05 \)), kidney (\( p < 0.01 \)), and gallbladder (\( p < 0.01 \)) meridians; \( \Delta(T_{a,2}) \) decreased on the kidney (\( p < 0.05 \)) and right gallbladder (\( p < 0.05 \)) meridians; \( \Delta(T_{a,3}) \) increased on the left small intestine (\( p < 0.05 \)) meridian and decreased on the gallbladder (\( p < 0.01 \)) meridian; and \( \Delta(T_{a,4}) \) increased on the right pericardium (\( p < 0.05 \)), left small intestine (\( p < 0.01 \)), left large intestine (\( p < 0.05 \)), triple heater (\( p < 0.01 \)).
Table 1  Measured acupoint conductances [μA; mean and standard deviation (SD)] for the 20 subjects (S1–S20) at times $T_0$, $T_1$, $T_2$, $T_3$, and $T_4$.  

|   | S01 | S02 | S03 | S04 | S05 | S06 | S07 | S08 | S09 | S10 | S11 | S12 | S13 | S14 | S15 | S16 | S17 | S18 | S19 | S20 |
|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| $T_0$ | 22(11) | 9(4) | 15(5) | 50(24) | 26(9) | 37(29) | 40(14) | 88(19) | 8(3) | 14(2) | 19(10) | 21(9) | 29(13) | 12(6) | 46(26) | 63(22) | 94(13) | 29(7) | 15(7) | 35(8) |
| $T_1$ | 34(21) | 10(6) | 18(8) | 40(28) | 23(7) | 47(29) | 43(14) | 95(26) | 10(6) | 14(1) | 27(14) | 14(7) | 22(12) | 31(20) | 39(22) | 62(33) | 64(19) | 70(24) | 12(9) | 21(8) |
| $T_2$ | 38(16) | 13(7) | 23(12) | 36(20) | 25(13) | 51(22) | 44(15) | 80(25) | 16(10) | 13(5) | 54(19) | 46(20) | 9(5) | 11(5) | 44(19) | 53(21) | 99(17) | 30(21) | 36(18) | 38(17) |
| $T_3$ | 35(17) | 14(4) | 35(14) | 12(10) | 9(3) | 28(11) | 50(24) | 84(12) | 18(10) | 34(17) | 34(15) | 35(17) | 46(20) | 9(5) | 11(5) | 44(19) | 53(21) | 99(17) | 30(21) | 36(18) | 38(17) |
| $T_4$ | 35(17) | 14(4) | 35(14) | 12(10) | 9(3) | 28(11) | 50(24) | 84(12) | 18(10) | 34(17) | 34(15) | 35(17) | 46(20) | 9(5) | 11(5) | 44(19) | 53(21) | 99(17) | 30(21) | 36(18) | 38(17) |

Data are mean(SD) values.

Table 2  Measured electrical conductances [μA; mean and standard deviation (SD)] of 24 acupoints on the left and right sides for the 20 subjects.  

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Data are mean(SD) values.

Fig. 3  Percentage differences in the electrical conductance of the 24 acupoints. The first and second numbers in the two-number terminology represent the two end time points (e.g., $T_{0.1}$ represents the 30-minute time interval between points $T_0$ and $T_1$).
Chun and colleagues reported that "Qi opening" regulation of Qi in meridian vessels would be displayed in main matter in the meridian vessels. The operation and which are named defense Qi nutritive Qi by the middle heater and spleen-stomach, After food has been ingested it is transformed into and distribution of the Zang-Fu and meridian systems. Variations, individual differences, and ambiguous observations in this field due to several difficulties, including signal variations, individual differences, and ambiguous observations have been reported [19]. We aimed to improve the stability and reproducibility of measurements in our experiments, and to strictly control potential errors. The accuracy of the MEAD ME-100 device used in this study is far superior to its predecessors. The environmental conditions were controlled by maintaining ambient temperature between 25 C and 27CC, and relative humidity at 60-80%. The possible variation in acupoint conductance with the recording time was reduced by performing all measurements between 9:00 a.m. and 11:00 a.m. Moreover, larger signal variations that may occur in sleeping subjects were avoided by ensuring that the subjects remained awake throughout the measurement process.

Glucose metabolism represents the major energy supply to human organs and tissues, especially to the heart, lung, nervous system, and muscles. The standard OGTT procedure is now widely used to examine glucose metabolism and insulin response [24, 25]. In a healthy person, glucose is transported throughout the body via blood circulation after food digestion and absorption. The pancreas is stimulated to release insulin to aid the entry of glucose into histiocytes, after which it is transformed into energy or stored in the liver, muscle cells, and lipocytes. The glucose metabolism pathway is conceptually identical to the operation and regulation of the meridian system on "nutritive Qi" in traditional Chinese medicine. A high dose (75 g) of glucose was used in the present study to stimulate "nutritive Qi", which was expected to change the acupoint conductance due to excitation of the meridian and Zang-Fu systems. Observing changes in the behavior of the meridian system induced by this stimulation yields useful information on the energy distribution and regulation of the meridian system.

We found that blood glucose concentration increased rapidly during time interval $T_{1,1}$, and that there was a corresponding significant reduction in acupoint conductance $\Delta(T_{1,1})$ on the liver, stomach, kidney, and gallbladder meridians. This implies an increase in resistance of the associated acupoints. Nei-Ching states that the "food Qi enters the stomach and sends essence to the liver," which is consistent with our finding that the liver and stomach meridians exhibited changes associated with blood glucose during the first 30 minutes following glucose ingestion. In addition, some energy consumption is necessary to start the digestion mechanism after food enters the stomach. This will promote the functions of liver and stomach meridians as well as the associated acupoints. Nei-Ching states that the "food Qi enters the stomach and sends essence to the liver," which is consistent with our finding that the liver and stomach meridians exhibited changes associated with blood glucose during the first 30 minutes following glucose ingestion. In addition, some energy consumption is necessary to start the digestion mechanism after food enters the stomach. This will promote the functions of liver and stomach meridians as well as the associated acupoints.
Ingested glucose during the first time interval $T_{0,1}$ increased in whole-body energy through the distribution of energy. Therefore, variations in acupoint conductance on different meridian vessels apparently indicate the contribution of viscera and bowels to the body energy balance when blood glucose concentration increased rapidly during time interval $T_{0,1}$.

$\Delta (T_{0,2})$ on the kidney and right gallbladder meridians continued to decrease as the procedure continued toward time interval $T_{0,2}$. This means that the kidney and right gallbladder meridians were still active principally to regulate the energy during this time interval. However, the behaviors of the liver and stomach meridians became ambiguous because there were no consistent variations in acupoint conductance during this interval, $\Delta (T_{0,3})$ on the gallbladder meridian still decreased during time interval $T_{0,3}$, but that on the left small intestine meridian increased significantly. This behavior of the small intestine meridian lasted until time interval $T_{0,4}$. Whether this is related to the subsequent state of glucose digestion requires further investigation.

Blood glucose concentration was almost restored to normal during the final time interval $T_{0,4}$. $\Delta (T_{0,4})$ increased markedly and significantly on the right pericardium, left small intestine, left large intestine, triple heater, left lung, liver, and left stomach meridians, indicating that the energy of these meridian vessels had increased. Traditional Chinese medicine considers that “the liver governs unblocking and deflation”. The acupoint conductance on the liver meridian decreased during $T_{0,1}$, but finally increased during $T_{0,4}$, indicating that this meridian plays an important role in the distribution and regulation of body energy. The triple heater meridian is considered to be related to the functions of original Qi in traditional Chinese medicine, and is therefore closely linked to the body energy. $\Delta (T_{0,4})$ finally increased on most meridian vessels, suggesting an increase in whole-body energy through the distribution of ingested glucose during $T_{0,4}$. It is interesting that most of the acupoints that changed during this time interval are located on the hand.

Those acupoints that did not exhibit statistically significantly variations in conductance could still contribute to the responses to glucose digestion. The absence of an apparent variation might be due to differences between individuals. The body energy of the subjects would have decreased markedly during the 10 hours of overnight fasting in this study, leading to large differences in the initial state among individual subjects. This would result in individual variations in baseline electrical conductance of certain acupoints. Such individual differences could also be attributed to the “physical constitution” concept of traditional Chinese medicine, whereby the acupoint conductance during a particular time interval is dominated by a specific type of physical constitution and the combined contribution would increase the SD for all measurements. However, despite the presence of these differences, the electrical conductances of certain acupoints on the meridian system still changed significantly and consistently in response to glucose ingestion/digestion. In addition, although this pilot study was limited by individual differences and a small sample, the results revealed that it is possible to detect the distribution and transformation of energy related to electrical conductance of acupoints through the Zang-Fu and meridian systems.

5. Conclusions

In summary, variations in electrical conductance of acupoints were detected following digestion of glucose using the standard OGTT procedure. Certain meridian vessels indeed appear to exhibit specific variation patterns. The electrical conductances of certain acupoints on the hands and feet display regular fluctuations: the conductances of feet acupoints first decrease indicating energy consumption for glucose digestion, and then the conductances of hand acupoints increase indicating energy acquisition from glucose and its distribution to different organs. These observations are very meaningful for clarifying energy regulation in traditional Chinese medicine. It would also be valuable to study the changes in pathology and the effects on treatments induced by abnormal glucose metabolism (such as diabetes mellitus and impaired glucose tolerance) from the viewpoint of traditional Chinese medicine.

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