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Application of Sphygmography to Detection of Dyspepsia and the Rhinitis

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Abstract: Diagnosis by radial arterial pulse is very important in Traditional Chinese Medicine (TCM). The objective of this study is to evaluate the effects of detection time and position on the parameters of time- and frequency-domain of radial pulse wave and to differentiate between Dyspepsia and Rhinitis by the statistical analysis of two signal types. A sphygmograph was developed to record radial pressure pulse for spectral analysis. The measurements were expressed as the pressure wave and its frequency. In this study, 135 subjects including the controls, Dyspepsias and Rhinitis were enrolled in this study. The signals were taken from three diagnosis positions of both wrists. Seven parameters of pressure wave and two parameters of spectrum analysis were evaluated by ANOVA test and Tukey's test. The results showed that the effects of detection time and position on the parameters taken from pulse wave were inconsistent. No regular rules or relationship could be established. The power spectra of 10–50 Hz and 13–50 Hz from sphygmography revealed a significant effect of health status, position and their interaction. There was a significant difference in the power spectra of 13–50 Hz between the control and Rhinitis, as well as between the control and Dyspepsia at right Guan position. The results of this study strongly suggest that the spectrum of sphygmogram might be more helpful than the pressure wave signals for detection of Dyspepsia and Rhinitis.

Keywords: Sphygmography; Spectrum Analysis; Pulse Wave; Dyspepsia, Rhinitis.

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Introduction

The radial pressure pulse (RPP) derived from the heart's pumping action and transmitted from the heart to the end of the radial artery is regulated by sympathetic nerve activity (SNA). Traditionally, Chinese doctors place their index, middle, and fourth fingertips on patients' skin over the radial artery of the wrist to palpate the pulse property for diagnosis. The relationships between the organs and the pulse are determined at the Chun, Guan, and Chy positions on the underside of the wrist. For example, gastric disease can be detected from the pulse at the right Guan position and the conditions of the cardiac system can be assessed at the left Chun position. A previous study has confirmed the quantitative characteristics of pulse signals from RPP (Lee *et al.*, 2008).

Pulse diagnosis methods could yield complex and important information. In modern Chinese medicine, pulse diagnosis techniques still play important roles. However, training in pulse diagnosis is time-consuming and some doubt this diagnosis method. Furthermore, many practitioners of Western medicine do not believe that three fingertips placed on the wrist can detect variations in pulse. This raises questions about whether a diagnosis could be confirmed by other means. Is the pulse information associated with the physician examination? What physical factors of humans could affect the pulse diagnostics? The factors affecting pulse wave analysis and parameters taken from pulse wave have been reviewed in detail by O'Rourke *et al.* (2001) and Korpas *et al.* (2008).

Radial pressure pulse originates from the systole and diastole of the heart. Therefore, the pulse signal carries the information of the heart ejection ability, vascular compliance and elasticity. The relationship between the pulse force and time is known as the pressure wave diagram or the time-domain method. Besides the use of time-domain analysis to evaluate the shape and dimension of arterial pressure waveforms, spectral analysis with the frequency-domain is used for analyzing periodic waves to represent the dynamics carried in the waves. In this method, the sums of the spectral energy are obtained. These signals then were treated with Fourier transformation and the pulse wave is expressed as the sum of several amplitudes and frequencies. The diagram expressing the association of amplitudes and frequency is called spectrum analysis signals.

Results of time-domain analysis usually reveal few specific characteristics. For example, Tyan *et al.* (2001) investigated the pulse signals of radial arteries for patients with Systemic Lupus Erythematosus. Chang (2005) and Yang *et al.* (2006) studied the difference between subjects with congestive heart failure and the controls. However, frequency-domain analysis often shows significant differences. For instance, Gorenberg and Marmor (2008) found that the central aortic pressure data obtained by non-invasive devices were highly correlated with traditional catheter measurements. Lu (2006) found that the harmonics of pulse spectrum revealed pathological status in the circulation. Liu *et al.* (2009) used the Skylark sphygmogram to evaluate the cardiovascular system of subjects under Zen meditation. Four parameters and normalized values were compared to observe the function of Zen meditation. To study the arterial pulse in the spectral domain, Huang *et al.* (2011a) defined a spectral harmonic energy ratio to evaluate the features of decreased spectral energy in different harmonics of the pulse wave and found that this parameter could be used to quantify the spectral harmonic distribution of the arterial pulse.

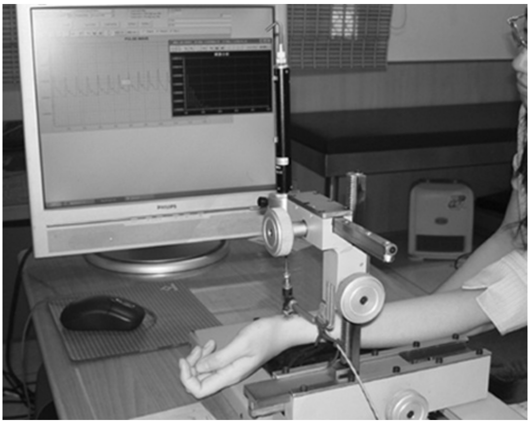
The peripheral pressure pulse transmits along the arterial tree and is reflected to become a retrograde wave when the pulse encounters the resistance of the arterial wall. Hence, the travelling pressure wave at the radial artery consists of forward- and backward-travelling waves. The increase in peripheral resistance may induce a higher degree of reflected waves which then results in a high amplitude augmentation index (AI) (Safar and Lacolley, 2007) and is influenced by higher-frequency components of the radial pulse waveform (Millasseau *et al.*, 2003; Fetics *et al.*, 1999). We have demonstrated in heat and cold tests that the AI and spectral energy of 10–50 Hz were significantly correlated (Huang *et al.*, 2011b). In normal individuals, the spectral energy of $0 \sim 10$ Hz contained more than 99.1 % of the total energy of the radial pressure waveforms, with less than 0.9% of energy contained over $10 \sim 50$ Hz, and patients with acute illness or under metabolic stress show large variations beyond 10 Hz (Wei *et al.*, 1984; Imperial-Perez and McRae, 2002). Therefore, radial pressure pulse always exhibits some specific characteristics in the spectral domain, especially in higher-frequency components.

The characteristics and significance of radial pressure pulse in time- and spectrum-domain analysis are not well documented. The objective of this study is to evaluate the use of sphygmography for detecting the status of Dyspepsia and Rhinitis by statistical analysis of time- domain and spectral-frequency signal. The signals of the pulse wave diagram were then transformed into a spectrum frequency diagram. The parameters taken from both diagrams were further analyzed statistically to evaluate the influencing factors.

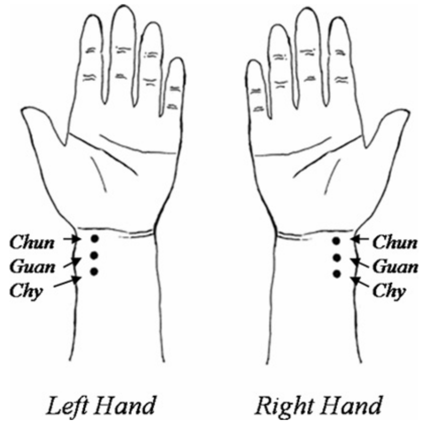
Materials and Methods

Subjects

We designed two experiments. The first experiment was conducted with nine healthy subjects (six men and three women, mean age of 22 ± 3 yr) to observe the effect of detection time on the parameters taken from pulse wave and spectrum frequency diagrams. The second experiment was conducted with 126 subjects. Three groups were selected, including 42 (20 men and 22 women, mean age of 35.3 ± 2.1 yr) normal healthy subjects not under medical treatment (Control), 42 (18 men and 24 women, mean age of 36.6 ± 11.8 yr) persons with Dyspepsia and 42 (21 men and 21 women, mean age of 34.1 ± 13.2 yr) persons with Rhinitis. The six detection positions for sphygmography were the Chun, Guan and Chy positions on both wrists (Fig. 1(b)). Patients in the rhinitis group had rhinitis symptoms, such as stuffy nose, nasal discharge, and sneezing. Subjects with other respiratory symptoms, such as headache, cough, fever, or aversion to cold were excluded. Dyspepsia was defined as intermittent or continuous epigastric pain or discomfort with fullness, early satiety, bloating, or nausea; those with other systemic symptoms were excluded.



(A)



(B)

Figure 1. The measurement of radial pulse. (A) The measurement on right radial artery with the subject in a sitting position. (B) The position of the Chun, Guan and Chy positions for both wrists.

Sphygmography

The pulse wave of the radial artery was detected at the wrist by use of the Huang-cwl type sphygmograph (designed by China Medical University, Taiwan). This device is comprised of a strain-gage pressure transducer, X-Y-Z axial moveable framework, amplifier, signal recording card and A/D conditioner. Pulse examination was performed as in Fig. 1(A), at the Chun, Guan and Chy positions on both wrists over the radial artery with the subject in a sitting position. The Guan position is located on the ventral portion of the styloid process of the radius. The Chun position is adjacent to the Guan position and distal to it, and the Chy position is proximal to the Guan position (Fig. 1(B)). The electrical pulse signal from the sensor was digitized and fed into a computer by processing through Fast Fourier Transformation to obtain the spectral energy of 0–10 Hz, 10–50 Hz and 13–50 Hz. The sampling rate was 4000 Hz.

Pulse Wave Diagram

A typical pulse wave diagram of a healthy subject in the first experiment is presented in Fig. 2. The first peak of the pulse wave diagram is called the Percussive wave (P wave). The crest of the P wave is derived by the blood from the left ventricle into the aorta. The height of the P wave is denoted h_1. The ejection time of the left ventricle is t_1. h_1 *or* h_1/t_1 is the index of the heart ejection ability (Feng, 2003).

The second wave, Tidal wave (T wave), is a backward-travelling wave that occurs when the travelling wave encounters the resistance of the arterial wall. The height of the T wave, h_3, indicates the resistance of the arterial system. In some cases, the T wave merges with the P wave. The lowest position between the T wave and the next peak (D wave) is called the Valley (V). The height of V is h_4. The h_4 value represents the peripheral resistance of

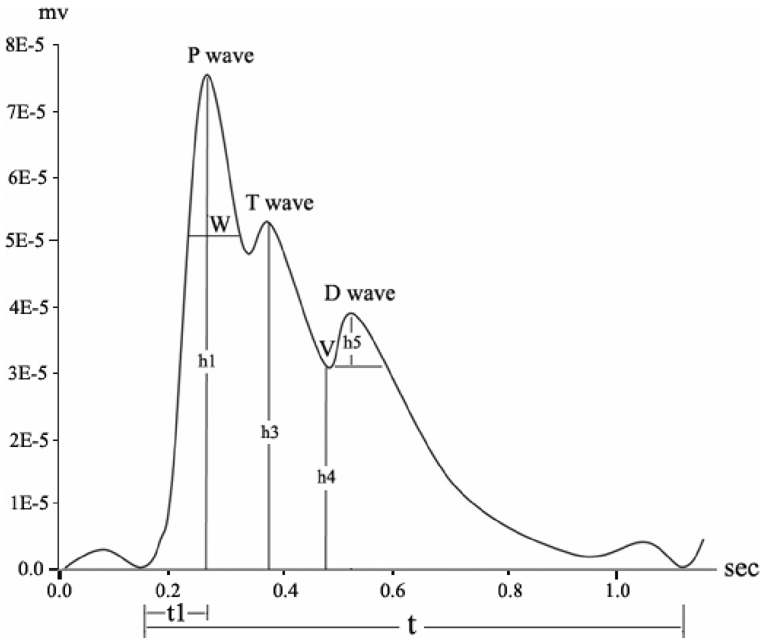


Figure 2. A typical radial pressure pulse waveform measured in this study.

vessels. As the aortic valve closes, the Dicrotic wave (D wave) is generated, which is a peak pressure in early diastole. The height of the D wave is named as h_5. The h_5 value expresses the stiffness of the aorta. The width of the P wave at the two-thirds height of h_1 is the interwave w. The w value is equal to the time to maintain maximum pressure values. The t value is total pulse duration.

Typical pulse waves and related spectrum analysis diagrams for the three health statuses in the second experiment are shown in Fig. 3.

Detection Procedure

All subjects were asked to refrain from drinking alcoholic or caffeinated beverages during the day the experiments were conducted, and each rested for 20 minutes before the initial pulse examination. The detection times were in the morning (9:00), afternoon (15:00) and night (20:00). The radial artery pulse was recorded with the subject in the sitting position. When the sphygmogram showed the greatest amplitude, the RPP was considered suitable to be recorded.

Parameters of Pulse Wave and Spectrum Analysis Diagram

The detection positions were denoted RI (right Chun), RB (right Guan), RC (right Chy), LI (left Chun), LB (left Guan), and LC (left Chy).

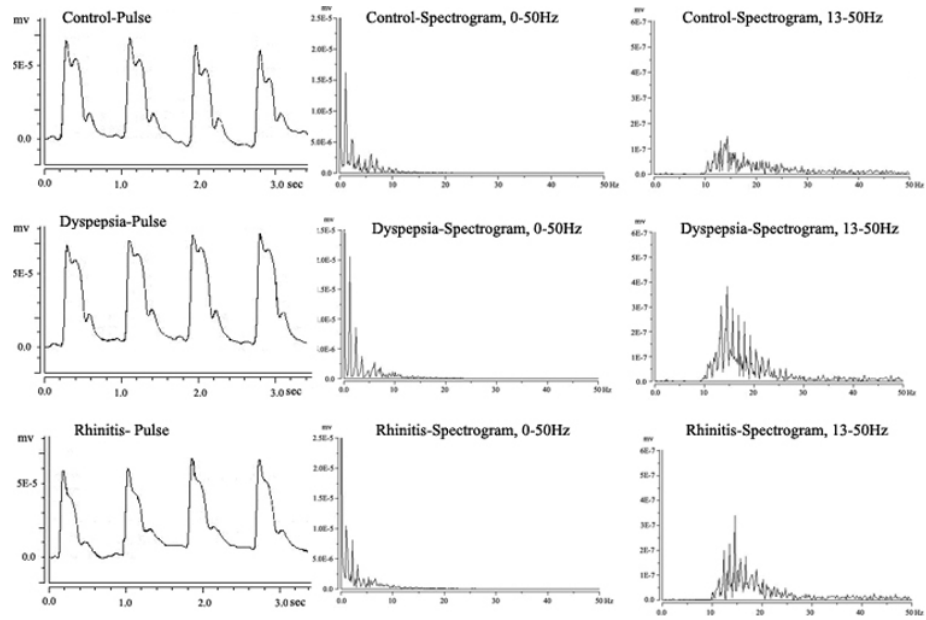


Figure 3. The typical diagram of pulse wave and the corresponding spectrograms, $0 \sim 50$ Hz bands and C, $13 \sim 50$ Hz bands for three health status. First row: control; second row: Dyspepsia; third row: Rhinitis. Right: diagram of pulse wave; middle: spectrograms of $0 \sim 50$ Hz bands; left: spectrograms of $13 \sim 50$ Hz bands.

The parameters of a set of pulse waves included h_1, h_4, t, and t_1 values. The normalized parameters selected in this study were $h_1/t, h_4/h_1$ and w/t values. These parameters were called pulse wave parameters.

The parameters of the spectrum analysis diagram were the spectrum energy between 10 and 50 Hz and the spectrum energy ranged from 13 to 50 Hz:

(a) Power spectrum between 10 and 50 Hz, denoted as P_{10-50}; and
(b) Power spectrum between 13 and 50 Hz, denoted as P_{13-50}

These parameters were called spectrum analysis parameters.

Experimental Design

The first experiment was designed to examine the effect of detection time and position. Only data of healthy subjects in the first experiment were analyzed. The measurements were performed for two weeks. Two-way analysis of variance (ANOVA) was used to analyze the influencing factors. The observed values for statistical analysis included the $h_1, h_4, t, t_1, h_1/t, h_4/h_1$, and w/t values of pulse wave. Three explicates of these parameters were taken from each pulse wave diagram. The spectrum energy, P_{10-50} and P_{13-50} was analyzed from the spectrum frequency diagram. Only one datum was taken from the spectrum frequency diagram.

The second experiment evaluated the effect of health status (Control, Dyspepsia and Rhinitis) on the pulse wave and spectrum analysis diagram. The pulse wave parameters, the h_1, h_4, *t, and* t_1 were analyzed. The effect of health status on these parameters at the six positions was further analyzed by two-way ANOVA test.

Statistical Analysis

Standard statistical methods were used to calculate means $\pm$ SD. The interactions of detection time and position on parameters of pulse wave and frequency were tested by two-way ANOVA and Tukey's post-hoc tests. The interaction of health status and detection positions was analyzed by two-way ANOVA and Tukey's post-hoc LSD tests. The difference between detection in the morning, afternoon and night in the first experiment and between health statuses in the second experiment were assessed by one-way ANOVA and Tukey's post-hoc test. All tests were two- sided. A $p < 0.05$ was considered statistically significant. Statistical analysis involved use of Sigma-stat 3.5 (Sigma SPSS Inc., Chicago, IL, USA).

Results

The parameters of time-domain and spectral energy at six diagnosis positions in the morning, afternoon and night from the first experiment are presented in Table 1. The parameters of time- domain and spectral energy at the six diagnosis positions for the control, Dyspepsia and Rhinitis groups from the second experiment are displayed in Table 2.

Experimental 1: *Normal Healthy Subjects*

Pulse Wave Parameters

h_1 Parameter: The ANOVA test showed no significant detection time effect for the h_1 parameter ($F(2,738) = 1.553$, $p = 0.1669$), a significant position effect ($F(5,738) = 45.2$, $p < 0.001$), and no significant interaction between detection time and position ($F(10,738) = 0.475$, $p = 0.4674$).

h_4 Parameter: The ANOVA test revealed that detection time ($F(2,738) = 7.17, p < 0.001$); detection position ($F(5,738) = 11.5, p < 0.001$), and interaction of time and position ($F(10,738) = 3.93$, $p < 0.0001$) all had significant effect on the h_4 parameter of pulse wave.

t Parameter: The detection positions revealed a significant effect on the t parameters (ANOVA, $F(5,738) = 4.336$, $p < 0.001$), but no significant effect for time (ANOVA, $F(2,738) = 2.743$, $p = 0.065$) or position and time interaction (ANOVA, $F(10,278) = 1.96$, $p = 0.105$).

t_1 Parameter: The detection positions had a significant effect on the t_1 parameter (ANOVA, $F(5,738) = 4.36$, $p < 0.0001$) and the position and time interaction ($F(10,738) = 1.96$, $p < 0.001$). However, no time effect could be found ($F\ (2,738) = 2.74$, $p = 0.895$).

Table 1. The Parameters of Time-Domain and Spectral Energy at Six Diagnosis Positions in the Morning, Afternoon and Night in the First Experiment

Position	Parameter	Morning	Afternoon	Night
RI	h1	7.66 ± 1.05 E−5	7.55 ± 1.66 E−5	7.88 ± 1.74 E−5
	$h4$	2.30 ± 0.93 E−5	1.96 ± 0.72 E−5	2.33 ± 0.91 E−5
	w	0.13 ± 0.02	0.12 ± 0.02	0.10 ± 0.02
	$t1$	0.13 ± 0.02	0.12 ± 0.02	0.13 ± 0.02
	t	0.88 ± 0.16	0.90 ± 0.11	0.87 ± 0.11
	$P_{10-50\,Hz}$	1.53 ± 0.73 E−12	5.06 ± 0.60 E−12	2.29 ± 0.44 E−12
	$P_{13-50\,Hz}$	0.14 ± 0.07 E−12	0.13 ± 0.09 E−12	0.16 ± 0.10 E−12
RB	$h1$	8.28 ± 2.19 E−5	7.93 ± 1.93 E−5	8.15 ± 2.15 E−5
	$h4$	1.57 ± 0.73 E−5	2.12 ± 0.33 E−5	2.48 ± 1.97 E−5
	w	0.17 ± 0.01	0.14 ± 0.02	0.11 ± 0.02
	$t1$	0.13 ± 0.03	0.14 ± 0.23	0.13 ± 0.03
	t	0.86 ± 0.15	0.92 ± 0.15	0.94 ± 0.06
	$P_{10-50\,Hz}$	0.25 ± 0.13 E−12	0.21 ± 0.18 E−12	0.23 ± 0.19 E−12
	$P_{13-50\,Hz}$	0.23 ± 0.20 E−12	0.19 ± 0.16 E−12	0.20 ± 0.25 E−12
RC	$h1$	5.83 ± 1.23 E−5	5.45 ± 1.14 E−5	5.54 ± 1.33 E−5
	$h4$	1.80 ± 0.89 E−5	1.12 ± 0.47 E−5	1.44 ± 0.68 E−5
	w	0.11 ± 0.02	0.12 ± 0.02	0.10 ± 0.02
	$t1$	0.13 ± 0.03	0.13 ± 0.03	0.12 ± 0.02
	t	0.84 ± 0.16	0.87 ± 0.10	0.83 ± 0.11
	$P_{10-50\,Hz}$	0.12 ± 0.15 E−12	0.10 ± 0.18 E−12	0.10 ± 0.14 E−12
	$P_{13-50\,Hz}$	0.11 ± 0.45 E−12	0.09 ± 0.02 E−12	0.10 ± 0.13 E−12
LI	$h1$	7.22 ± 1.34 E−5	7.12 ± 1.40 E−5	7.14 ± 1.32 E−5
	$h4$	1.77 ± 0.67 E−5	1.92 ± 1.33 E−5	2.08 ± 1.08 E−5
	w	0.12 ± 0.02	0.14 ± 0.02	0.11 ± 0.02
	$t1$	0.13 ± 0.03	0.12 ± 0.02	0.12 ± 0.02
	t	0.87 ± 0.09	0.84 ± 0.13	0.86 ± 0.11
	$P_{10-50\,Hz}$	0.18 ± 0.17 E−12	0.20 ± 0.18 E−12	0.16 ± 0.99 E−12
	$P_{13-50\,Hz}$	0.16 ± 0.06 E−12	0.18 ± 0.17 E−12	0.16 ± 0.09 E−12
LB	$h1$	7.30 ± 1.39 E−5	7.76 ± 1.83 E−5	7.78 ± 1.09 E−5
	$h4$	1.77 ± 0.67 E−5	2.13 ± 0.69 E−5	2.29 ± 1.16 E−5
	w	0.11 ± 0.02	0.12 ± 0.02	0.10 ± 0.02
	$t1$	0.11 ± 0.02	0.11 ± 0.02	0.12 ± 0.02
	t	0.80 ± 0.19	0.89 ± 0.10	0.89 ± 0.09
	$P_{10-50\,Hz}$	0.38 ± 0.99 E−12	0.36 ± 0.25 E−12	0.30 ± 0.29 E−12
	$P_{13-50\,Hz}$	0.33 ± 0.27 E−12	0.30 ± 0.20 E−12	0.26 ± 0.02 E−12
LC	$h1$	6.87 ± 1.28 E−5	6.04 ± 1.21 E−5	6.70 ± 1.38 E−5
	$h4$	1.89 ± 0.70 E−5	1.65 ± 0.62 E−5	1.90 ± 0.72 E−5
	w	0.11 ± 0.02	0.13 ± 0.02	0.11 ± 0.01
	$t1$	0.12 ± 0.03	0.12 ± 0.02	0.12 ± 0.02
	t	0.86 ± 0.11	0.85 ± 0.10	0.84 ± 0.16
	$P_{10-50\,Hz}$	0.23 ± 0.26 E−12	1.55 ± 0.17 E−12	0.10 ± 0.24 E−12
	$P_{13-50\,Hz}$	0.22 ± 0.02 E−12	0.13 ± 0.13 E−12	0.09 ± 0.05 E−12

Table 2. The Parameters of Time-Domain and Spectral Energy at Six Diagnosis Positions in the Control, Dyspepsia and Rhinitis in the Second Experiment

Position	Parameter	Control	Dyspepsia	Rhinitis
RI	$h1$	5.20 ± 1.98 E–5	5.71 ± 1.94 E–5	5.44 ± 1.45 E–5
	$h4$	1.52 ± 0.74 E–5	2.82 ± 0.64 E–5	1.84 ± 0.51 E–5
	$t1$	1.22 ± 0.15	1.23 ± 0.12	1.25 ± 1.19
	t	8.80 ± 1.40	9.09 ± 2.17	10.13 ± 2.49
	$P_{10-50Hz}$	8.78 ± 5.57 E–13	10.53 ± 15.10 E–13	15.74 ± 9.13 E–13
	$P_{13-50Hz}$	8.55 ± 5.38 E–13	10.18 ± 14.98 E–13	15.37 ± 18.03 E–13
RB	$h1$	5.32 ± 1.67 E–5	8.61 ± 1.95 E–5	7.79 ± 1.66 E–5
	$h4$	1.55 ± 0.72 E–5	2.96 ± 0.87 E–5	2.41 ± 0.75 E–5
	$t1$	1.24 ± 0.13	1.22 ± 0.12	1.29 ± 0.19
	t	7.85 ± 2.13	9.92 ± 2.85	10.93 ± 2.15
	$P_{10-50Hz}$	14.99 ± 9.70 E–13	60.81 ± 69.47 E–13	67.82 ± 61.42 E–13
	$P_{13-50Hz}$	14.59 ± 9.42 E–13	59.28 ± 58.70 E–13	57.30 ± 16.49 E–13
RC	$h1$	5.07 ± 2.06 E–5	6.48 ± 2.62 E–5	6.29 ± 2.58 E–5
	$h4$	1.57 ± 1.07 E–5	2.47 ± 0.95 E–5	1.72 ± 0.53 E–5
	$t1$	1.25 ± 0.16	1.22 ± 1.13	1.30 ± 0.19
	t	8.63 ± 2.20	8.41 ± 1.92	9.49 ± 2.03
	$P_{10-50Hz}$	8.63 ± 7.21 E–13	16.72 ± 15.49 E–13	18.02 ± 19.60 E–13
	$P_{13-50Hz}$	8.42 ± 6.95 E–13	16.20 ± 15.00 E–13	17.70 ± 19.33 E–13
LI	$h1$	5.83 ± 1.43 E–5	5.88 ± 2.32 E–5	5.49 ± 1.70 E–5
	$h4$	2.10 ± 0.86 E–5	2.25 ± 0.99 E–5	1.56 ± 1.66 E–5
	$t1$	1.22 ± 0.12	1.19 ± 0.12	1.28 ± 0.21
	t	7.88 ± 1.75	8.43 ± 1.97	8.97 ± 2.12
	$P_{10-50Hz}$	11.65 ± 8.58 E–13	8.18 ± 5.78 E–13	23.17 ± 3.07 E–13
	$P_{13-50Hz}$	11.37 ± 8.33 E–13	7.97 ± 5.64 E–13	24.34 ± 11.30 E–13
LB	$h1$	5.46 ± 1.49 E–5	6.89 ± 2.31 E–5	6.53 ± 2.27 E–5
	$h4$	1.71 ± 0.95 E–5	2.52 ± 1.01 E–5	2.10 ± 0.94 E–5
	$t1$	1.23 ± 0.11	1.20 ± 0.12	1.30 ± 0.22
	t	9.61 ± 2.82	9.20 ± 3.09	10.29 ± 2.78
	$P_{10-50Hz}$	19.17 ± 19.60 E–13	26.74 ± 24.06 E–13	34.36 ± 46.09 E–13
	$P_{13-50Hz}$	18.63 ± 19.34 E–13	24.96 ± 23.92 E–13	23.99 ± 18.00 E–13
LC	$h1$	4.37 ± 1.46 E–5	5.44 ± 1.72 E–5	5.15 ± 1.72 E–5
	$h4$	1.65 ± 0.63 E–5	2.19 ± 0.74 E–5	1.95 ± 0.81 E–5
	$t1$	1.22 ± 0.17	1.22 ± 0.13	1.28 ± 0.19
	t	8.80 ± 2.18	8.45 ± 2.85	9.40 ± 1.89
	$P_{10-50Hz}$	11.77 ± 13.12 E–13	15.19 ± 21.14 E–13	10.29 ± 11.66 E–13
	$P_{13-50Hz}$	11.50 ± 12.77 E–13	14.88 ± 11.02 E–13	9.95 ± 11.02 E–13

Pulse Wave Normalized Parameters

Three normalized parameters were analyzed by two-way ANOVA method.

h_1/t_1 Parameter: ANOVA tests showed a significant main effect of detection position ($F(5, 738) = 28.78$, $p < 0.0001$) on the normalized h_1/t_1 values, but no significant effect of time ($F(2, 738) = 1.553$, $p = 0.2123$) and position and time interaction.

h_4/h_1 Parameter: The ANOVA test indicated that a significant time effect ($F(2,738) = 3.904$, $p = 0.0201$), a significant position effect ($F(5,738) = 6.511$, $p < 0.001$) and the interaction of time and position.

w/t Parameter: Both the detection time ($F(2,738) = 13.94$, $p < 0.0001$) and position ($F(5,738) = 2.374$, $p = 0.0376$) had a significant effect on the normalized w/t values. However, had no significant effect on the time and position interaction ($F(10,738) = 1.075$, $p = 0.3817$).

From the above results, the effects of detection time and position on the parameters taken from the pulse wave were inconsistent. No regular rules or relationship could be established.

Spectrum Analysis Parameters

Spectrum Power between 10 and 50 Hz, P_{10-50}: The ANOVA test indicated a significant effect of detection positions on P_{10-50}($F(5,234) = 7.223$, $p < 0.0001$). Subsequent post-hoc comparison by Tukey's test showed that the parameter taken from the LB position had differed significantly from that at other positions. No significant difference could be found for detection time ($F(2,234) = 1.883$, $p = 0.1544$) and the interaction ($F(10,234) = 1.218$, $p = 0.2795$).

Spectrum Power between 13 and 50 Hz, P_{13-50}: The effect of detection position on P_{13-50} was similar to that of P_{10-50}. A significant effect of detection positions ($F(5,234) = 6.603$, $p < 0.0001$) is found. The LB position showed the significantly differed from other positions. No effect of detection time ($F(2,234) = 0.5049, p = 0.6042$) and interaction ($F(10,234) = 0.486$, $p = 0.898$) effect was revealed by ANOVA tests.

The above comparison indicated consistent results. The ANOVA results indicated that detection time did not influence spectrum energy P_{10-50} and P_{13-50}. Their values at the LB position were significantly higher than those at other positions.

Experiment 2: Effects of Detection Position and Health Status

Pulse Wave Parameters

In this statistical test, several parameters were taken from the pulse wave. The treatment included three health statuses and six positions. The ANOVA tests revealed a significant effect of detection position, health status and their interactions on all parameters ($p < 0.0001$). For example, the h_1 differed significantly by the health conditions ($F(2,168) = 132.2$, $p < 0.0001$), detection position ($F(5,168) = 58.35$, $p < 0.0001$) and their interaction ($F(10,168) = 34.23$, $p < 0.0001$).

To clarify the effect of health status on parameters of different detection positions, one-way ANOVA tests and the Tukey's test were applied. Inconsistent results could be found. The Dyspepsia and Rhinitis groups did not differ in h_1 at RB and LB positions, but both groups differed from the controls in this parameter. The three status groups significantly differed in h_4 at the RB and LB positions. However, the control and Dyspepsia groups had similar h_4 values for LI position. Inconsistent results were found for the two parameters (t_1, t) in the three health statuses.

The parameters taken from Dyspepsia pulse waves at six positions were analyzed by one- way ANOVA test and the Tukey's test. For h_1 and t parameters, a significant difference was found among the six detection positions. For h_4, the data sets suggest positions LC, RC and LI, and positions RI and LB as individual groups. No significant difference could be found for t_1.

The parameters taken from Rhinitis pulse waves at six positions were also analyzed. Inconsistent results were found for the four parameters. For example, for h_1, the data sets suggest positions RC and LI as one group with a significant difference from data for the other four positions. No significant difference could be found for t_1.

As seen from these results, the parameters taken from the pulse wave are significantly affected by health status and detection position, but no rules or relationships could be established. In other words, it was not easy to detect the health status of Rhinitis or Dyspepsia simply by analyzing parameters of pulse wave at different detection positions.

Spectrum Frequency Parameters

Effect of Detection Position and Health Status: The variables in this study included the health statuses (Control, Rhinitis and Dyspepsia) and six detection positions (RI, RB, RC, LI, LB and LC). The parameters taken from the spectrum frequency included P_{10-50} and P_{13-50}.

For P_{10-50}, a significant effect of health status $(F(2, 342) = 9.34,\ p < 0.0001)$, detection position $(F(5, 342) = 14.57,\ p < 0.0001)$, and their interaction $(F(10, 342) = 29.173,\ p = 0.0017)$ was found.

For P_{13-50}, a significant effect of health status $(F(2, 342) = 8.1415,\ p < 0.001)$, detection positions $(F(5, 342) = 14.143,\ p < 0.0001)$ and their interaction $(F(10, 342) = 3.067,\ p < 0.001)$ was also found.

From these results, the parameters taken from power spectrum frequencies could be adopted as a useful index to distinguish the health status of subjects with Rhinitis or Dyspepsia. The detection positions also could also serve as an index for further studies.

Effect of Six Detection Positions: In this study, health status was served as the variables to be evaluated by each detection position. Parameters P_{13-50} was tested by one-way ANOVA test and subsequent post-hoc comparison by Tukey's test and the results are listed in Fig. 4.

P_{13-50} values for three health statuses at RC position were evaluated and the result of one- way ANOVA indicated no significant difference for three health statuses $(F(2, 57) = 2.311,\ p = 0.1085)$. Similar results were also found for the positions of RI, LB and LC.

P_{13-50} values for three health statuses at RB position with one-way ANOVA test revealed significant difference between the three health statuses $(F(2, 57) = 5.122,\ p < 0.001)$. The subsequent post-hoc comparison by Tukey's test indicated significant difference between the control and Rhinitis groups, as well as between the control and Dyspepsia groups, but no significant difference between the Rhinitis and Dyspepsia groups.

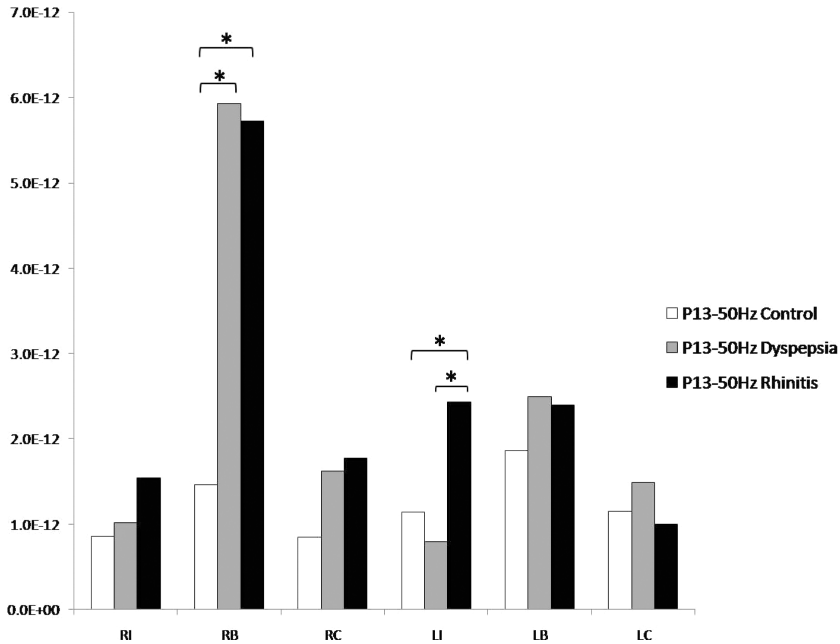


Figure 4. The results of one-way ANOVA tests and the Tukey's test for the P_{13-50} data of three health status. * $p < 0.05$.

The ANOVA test showed a significant effect of health status at LI positions $(F(2,57) = 4.912, p = 0.011)$. In this position, P_{13-50} values of the Rhinitis group show significantly different from the Dyspepsia and Control groups.

Discussion

Results of pulse wave analysis indicated that detection time and position had a significant effect on parameters of $h_4, h_4/h_1$ and w/t. Detection position had a significant effect on parameters of h_1, t, t_1 and h_1/t_1. However, the effects of detection time and position on parameters taken from pulse wave were inconsistent. No relationship could be established between these parameters. Conditions of detection time and position should be considered as the influencing factors in the research of pulses wave analysis. The adrenocorticoid hormone can regulate blood pressure and its secretion in humans is in a diurnal rhythm, the highest in the morning and the lowest at the night. Furthermore, the morning, noon and night temperature are different and thus affect vasodilatation. In addition, Lee *et al.* (2008) found that the distance between the epidermis and the upper wall of the radial artery increased in the order of Chun, Chy and Guan positions. All the above factors affect the radial artery pulse.

The detection time did not influence P_{10-50} and P_{13-50} parameters by spectrum analysis. However, detection positions significantly affected these parameters. The left Guan (LB) position was the only position from the six that showed significant effects in healthy subjects. Parameters of P_{10-50} and P_{13-50} belong to the higher-frequency pulse wave. In cardiovascular physiology, the vascular smooth muscles are innervated by nerve fibers and exposed to recurrent oscillated stimuli. The discharge of most sympathetic nerves is between 2 and 6 Hz to maintain a normal sympathetic effect and would be increased to 50 Hz during acute stress, which maximizes the arterial and arteriolar tension (Levick, 2003; Kenney, 1994). The increased impedance of vessels is proportional to the high natural frequency response (Kinefuchi *et al.*, 1999). When stress increases the sympathetic nerve activity, the higher-frequency pulse wave will be changed. The left Guan (LB) is the position for diagnosing stress in humans. People today are under high objective and subjective stress, and therefore, the pulse of LB pulse is affected.

Detection positions and health status significantly affected the parameters taken from the pulse wave, but no rules or relationship could be established. In other words, analysis of pulse wave at different detection positions could not distinguish Dyspepsia or Rhinitis. Therefore, the results of detection position and health status on the parameters from spectrum frequencies indicated that these parameters could be a useful index to distinguish the health status of subjects. P_{10-50} and P_{13-50} were both affected by the detection position and health status. Further study evaluating the effects of detection position on P_{13-50} at RB and LI positions could help to distinguish the health status of the control, Rhinitis and Dyspepsia.

In TCM, gastric disorders and yang brightness meridians connected to the nose (Jeon *et al.*, 2009) can be detected at the right Guan position (RB); therefore, the increase in sympathetic nerve activity with Rhinitis and Dyspepsia enhances the higher-frequency activity of RB. As a result, if lesions were in the nasal cavity or in the stomach, the pulse of RB would vary. The cardiac system can be detected at the left Chun position (LI). As a result of the increase in higher-frequency activity at LI, we inferred that Rhinitis reduces the supply of oxygen, which increases cardiovascular stress; therefore, the pulse of LI was affected.

The results of this study lead us to suggest that the spectrum signals obtained by sphygmography might be more meaningful than pressure wave signals analysis for detecting of Dyspepsia and Rhinitis. The results from statistical analysis also validate the reasonable citation of TCM books. Recent researches has found that the radial AI is influenced by higher-frequency components of the waveform (Huang *et al.*, 2011a; Safar and Lacolley, 2007), and higher- frequency components were found to be statistically different between Guan and the other positions (Jeon *et al.*, 2009). The present study revealed the importance of higher-frequency components in the radial waveform, which supports the major hypothesis of TCM that all three palpation positions reveal different clinical information. To our knowledge, this is the first study to use two analysis methods to quantitatively study the characteristics of the radial artery at the right and left diagnosis positions of Chun, Guan and Chy by use of a novel sphygmograph apparatus. The results indicated that the higher-frequency spectrum signals of the sphygmography could provide more meaningful results than pressure wave signals.

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Adherence to Ethical Standards

The measurement of pulse wave was a non-injuring, non-invasive technique. No harmful occur in experimental subjects. The methods we obtained written informed consent from the subjects. The experimental work corresponded with the legal requirements of the study country.

References

Chang, H. The association between left ventricular function and sphygmogram of heat failure patients. *Yearb. Chin. Med. Pharm.* 23: 375–424, 2005.

Feng, J. *Contemporary Sphygmology in Traditional Chinese Medicine*. People's Health Publishing House, Beijing, 2003, pp. 163–165.

Fetics, B., E. Nevo, C.H. Chen and D.A. Kass. Parametric model derivation of transfer function for noninvasive estimation of aortic pressure by radial tonometry. *IEEE Trans. Biomed. Eng.* 46: 698–706, 1999.

Gorenberg, M. and A. Marmor. Validation of a novel method to determine non-invasively the rate of central aortic pressure changes. *J. Med. Eng. Tech.* 32: 257–262, 2008.

Huang, C., H. Chang, S. Kao, T. Li, C. Wei, C. Chen, Y. Liao and F. Chen. Radial pressure pulse and heart rate variability in heat and cold-stressed humans. *Evid. Based Complement. Alternat. Med.* 2011: 751317, 2011a.

Huang, C., C. Wei, Y. Liao, H. Chang, S. Kao and T. Li. Developing the effective methods of spectral harmonic energy ratio to analyze the arterial pulse spectrum. *Evid. Based Complement. Alternat. Med.* 2011: 342462, 2011b.

Imperial-Perez, F and M. McRae. Protocols for practice: applying research at the bedside. *Critical Care Nurse* 22: 1–22, 2002.

Jeon, Y., J. Kim, H. Lee, J. Lee, H. Ryu and Y. Lee. A clinical study of the pulse wave characteristics at the three pulse diagnosis positions of Chon, Gwan and Cheok. *Evid. Based Complement. Alternat. Med.* doi: 10.1093/ecam/nep150, 2009.

Kenney, M.J. Frequency characteristics of sympathetic nerve discharge in anesthetized rats. *Am. J. Physiol.* 267(3 Pt 2): R830-R840, 1994.

Kinefuchi, Y., H. Fukuyama, T. Suzuki, M. Kanazawa and M. Takiguchi. Development of a new catheter-tip pressure transducer. *Tokai J. Exp. Clin. Med.* 24: 85–92, 1999.

Korpas, D., J. Halek and L. Dolezal. Parameters describing the pulse wave. *Physiol. Res.* 58(4): 473–479, 2008.

Lee, Y., J. Lee and J. Kim. A study on characteristics of radial arteries through ultrasonic waves. In: *30th Annual International IEEE EMBS Conference*, Vancouver, 2008, pp. 2453–2456.

Levick, J.R. *An Introduction to Cardiovascular Physiology*, 4th ed. Arnold Publications, London, 2003, pp. 211 and 217–250.

Liu, C., C. Wei and P. Lo. Variation analysis of sphygmogram to assess cardiovascular system under mediation. *Evid. Based Complement. Alternat. Med.* 6(1): 107–112, 2009.

Lu, W. Pulse spectrum analysis in primary hypertension patients. *Taipei City Med. J.* 3: 859–868, 2006.

Millasseau, S.C., S.J. Patel, S.R. Redwood, J.M. Ritter and P.J. Chowienczyk. Pressure wave reflection assessed from the peripheral pulse: is a transfer function necessary? *Hypertension* 41: 1016–1020, 2003.

O'Rourke, M., A. Pauca and X. Jiang. Pulse wave analysis. *Br. J. Clin. Pharmacol.* 51: 507–522, 2001.

Safar, M and P. Lacolley. Disturbance of macro- and microcirculation: relations with pulse pressure and cardiac organ damage. *Am. J. Physiol. Heart Circ. Physiol.* 293: H1–H7, 2007.

Tyan, C., H. Chang, J. Chen and Y. Hsu. A study of radial sphygmogram on Yin vacuity syndrome in patients with systemic lupus erythematosus. *J. Chin. Med.* 12: 145–154, 2001 (in Chinese).

Yang, Y., H. Chang, C. Wang, W. Lin, W. Wu and W. Cherng. A study of radial sphygmogram in heart failure patients. *J. Chin. Med.* 17: 85–94, 2006.

Wei, L. C. Lee and P. Chow. A new scientific method of pulse diagnosis. *Am. J. Acupunct.* 12: 205–218, 1984.