The use of time-domain analysis on the choice of measurement location for pulse diagnosis research: A pilot study

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Received January 22, 2018; accepted July 11, 2018

Abstract

Background: Pulse diagnosis researches acquiring pulse waves from the wrist radial artery has not yet addressed the issue of whether this information is affected by differences in the hemodynamic characteristics of pressure waves derived from different locations. This study aimed to clarify whether the blood dynamic states are identical with regard to the “three positions and nine indicators” (三部九候) listed in traditional Chinese medicine (TCM).

Methods: A total of 37 participants of CAD group and 20 participants of healthy group were recruited, and pressure pulse waves were measured at 18 locations on both hands. A multivariate analysis (MANOVA) was performed with a “randomized block design” using SPSS 22.0 and R 3.4.1 to examine the time-domain parameters that represented certain hemodynamic characteristics.

Results: In CAD group, the results showed significant differences ($p < 0.05$) among the $h_1$, $h_2$, $h_3$, $h_1/t$, and $h_3/h_1$ measurements of the pulse waves using different indicators at the same position; the $h_1$, $h_2$, $h_3$, and $h_1/t$ measurements of the pulse waves at different positions using the indicator “Superficial”; and the $h_1$, $h_2$, $h_3$, $h_1/t$, and $h_3/h_1$ measurements of the pulse waves at different positions using the indicator “Medium”.

In healthy group, the results showed significant differences ($p < 0.05$) among the $h_1$, $h_2$, $h_3$, and $h_1/t$ measurements of the pulse waves using different indicators at the same position; the $h_1$, $h_2$, and $h_1/t$ measurements of the pulse waves at different positions using the same indicator.

Conclusion: Because of the differences in the hemodynamic characteristics among the different positions and indicators, the article might provide a new opinion for future pulse diagnosis investigations to carefully consider the measurement location to ensure the completeness of the information.

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Keywords: Hemodynamic; Measurement; Pulse diagnosis; Time-domain; Traditional Chinese medicine (TCM)
1. Introduction

The “pulse diagnosis” of traditional Chinese medicine (TCM) refers to the diagnosis reached when a physician uses three fingers at three positions, i.e., Inch (寸), Bar (尺), and Cubit (尺) of the patient to perceive the pulse by pressing on three indicators, i.e., Superficial (浮), Medium (中), and Deep (沉), to simultaneously observe the physiological or pathological conditions of different organs from different levels and depths. This method is derived from the positioning method of the “three positions and nine indicators” of TCM.

Modern pulse diagnosis researches have been performed using a “pulse wave instrument” that applies a pressure sensor on the skin surface of the radial artery at the wrist to sense the pulse to analyze the physiologic or pathological condition. Different ways coexist to choose the measurement location: (1) single location, e.g., Inch or Bar; (2) three locations; (3) shallower locations; and (4) deeper locations. However, there is still doubtful about whether the pulse obtained at a single or three locations could represent the others.

Because the changes in the sphygmograms and the time-domain parameters reflect the signals of blood pressure waves, a time-domain analysis can address patients’ physiologic or pathological states at different locations of the wrist radial artery are consistent at different locations, we recruited two groups of participants.

2. Methods

2.1. The time-domain parameters of the pulse wave and their hemodynamic meanings

As the left ventricle contracts to pump blood into the aorta, it enters the “rapid ejection period” in which the blood affects vessels, and the first pulse pressure wave formed is the percussion wave (P-wave). The P-wave has the highest amplitude in the entire sphygmogram. The partial blood reflux then affects the vessel to create the second pressure wave called the tidal wave (T-wave). When the aortic valve suddenly closes during the early stage of ventricular diastole, blood reflux affects the aortic valve and generates rebounding blood flow to affect the blood vessels so that the vessels expand slightly, forming a pressure wave called the dicrotic wave (D-wave). The descending branch of the T-wave and the ascending branch of the D-wave constitute a downward waveform called the valley wave (V-wave), the bottom of which is the boundary of systolic and diastolic blood pressure.

In a time-domain analysis, in addition to h1, h2, h3, and h4, other common parameters include the following:

(1) The rising slope of the P-wave. The ratio of the height of the P-wave to the time of the rapid ejection period is represented by h1/t. Studies showed that h1/t is related to the pumping capacity of the heart, blood vessel elasticity, and blood viscosity.

(2) Radial artery augmentation index. The ratio of the height of the T-wave to the height of the P-wave in a percentage is represented by AIX, which indicates the sclerosis level of the blood vessels.

(3) Relative height of the V-wave. The ratio of the height of the V-wave to the height of the P-wave in a percentage is represented by h3/h1. Studies have shown that h3/h1 reflects peripheral vascular resistance and blood viscosity.

(4) Relative height of the D-wave. The ratio of the height of the D-wave to the height of the P-wave in a percentage is represented by h4/h1, which can reflect the elasticity of the arterial wall and the function of the aortic valve.

The pulsation changes recorded at the wrist radial artery are shown in Fig. 1.

2.2. Recruitment of test participants

In order to verify whether the hemodynamic characteristics are consistent at different locations, we recruited two groups of participants.

2.2.1. CAD group

This part was conducted from July 2011 to October 2012 as a sub-project under the “Pulse Spectrum Analysis to Aid Diagnosis of Coronary Artery Disease” study. For inclusion, the participants had to be at least 18 years of age, male or female, who sought treatment for chest pain or angina and needed to be hospitalized for further examination. Patients with acute myocardial infarction, arrhythmia, heart valve disease, cancer, severe infection, pregnancy, severe mental illness, or those for whom radial artery pulse could not be measured were excluded. The Institutional Review Board (IRB) for human subjects approved the content of this research project (Case #: TSGHIRB 100-05-016).

2.2.2. Healthy group

This part was conducted in June 2018. For inclusion, the participants had to be at least 20 years old, male or female, and disease-free (No hypertension, no diabetes, no medication, no chronic disease.) The IRB approved the content of this research project (Case #: CMUH107-REC2-088).

2.3. Instrument

The instrument used to measure pulse waves was the PDS-2010 Skylark Pulse Analysis System (developed by Cologne Technology Co., Ltd., Taiwan; Ministry of Health and Welfare medical equipment license number 003627). The main components of the instrument included the measurement and signal units. By measuring the horizontal and vertical sliding on X-, Y-, and Z-axes of the measurement unit, the pulse
waves on the horizontal and vertical planes were determined based on the analogous electrical signals of the wrist artery waves acquired through a single probe with a high-fidelity pressure sensor that was vertically pressed on the wrist. Then, the analogous electrical signals were converted into digital data and stored on a computer.

2.4. Operational definition of the “three positions and nine indicators”

According to the theory of pulse diagnosis, the “three positions and nine indicators” refer to those at the pulsating location of the wrist radial artery in the direction from the wrist to the elbow. The wrist area is divided into three positions, i.e., Inch (寸), Bar (關), and Cubit (尺), whereas each position is divided into three indicators, i.e., Superficial (浮), Medium (中), and Deep (沈) in the vertical direction, thereby giving rise to nine indicators. Together, these elements are called the “three positions and nine indicators.” A total of 18 indicators exist across both hands (see Fig. 2).

Following the idea of the “three positions and nine indicators”, the operational definitions for the three positions (i.e., Inch, Bar, and Cubit) mean the full length of the forearm is equally divided into 100 units. In the direction from the wrist to the elbow, starting from Unit 2, the Inch, Bar, and Cubit each sequentially occupy 6, 6, and 7 units, respectively, stopping at Unit 20. For the operational definitions of three indicators (i.e., Superficial, Medium, and Deep), pressures

![Fig. 1. Time-domain diagram and parameters of the wrist radial arterial wave.](image)

![Fig. 2. Schematic diagram of the “three positions and nine indicators”.](image)
across three weight ranges (i.e., 0–50 g, 50–90 g, and 90–120 g) were exerted downward by the instrument probe, and the depth that led to the most distinct pulse wave was assigned to each of the indicators.

2.5. Research procedure

All of the procedures were conducted in a bright and quiet room, and the room temperature was kept between 25 °C and 26 °C. A well-trained researcher conducted all of the procedures using the same instrument to avoid the measurement error. The researcher described the experiment process to the participants and asked them to sign the consent form. All participants were allowed to rest for 10 min before the pulse measurement. Then, the researcher marked “Inch”, “Bar”, and “Cubit” on both arms of the participants. Next, the participants’ hands were placed on the platform of the instrument, and the X-, Y-, and Z-axes were slid according to the operational definition. Measurements on a total of 18 locations were sequentially performed of the SRI, MRI, DRI, SRB, MRB, DRB, SRC, MRC, DRC, SLI, MLI, DLI, SLB, MLB, DLB, SLC, MLC, and DLC, and the data were saved to the computer. The following step was to process the data. The actual measurement condition is shown in Fig. 3.

2.6. Statistical analysis and method

Two types of statistical analysis software, SPSS 22.0 and R 3.4.1, were used to analyze the data. The basic information of the participants is presented in the form of descriptive statistics, including qualitative indicators such as age, height, weight, and so on. Continuous variables are presented as means ± standard deviations (ranges). Because the various unknown differences present among different participants might affect the test results, in examining whether the time-domain parameters are similar for different indicators at the same position and different positions using the same indicators, a randomized block design was implemented to facilitate a multivariate analysis (MANOVA) in which different participants were regarded as a “block” (i.e., as an independent variable), whereas each of the time-domain parameters was viewed as another independent variable, so that the parameters of the time-domain could be compared between different “subject blocks”, different positions, or different indicators. p-value <0.05 was considered as significant.

3. Results

3.1. Basic information

3.1.1. CAD group

A total of 37 participants who met the inclusion criteria were included and received pulse wave measurements over the three positions and nine indicators on both hands. Participant age, height, weight, and body mass index (BMI) were 59.54 ± 10.22 (36.25–78.25) years old, 166.59 ± 8.62 (150–194) cm, 71.96 ± 10.87 (54–100) kg and 25.91 ± 3.24 (20.19–32.66) kg/m², respectively.

3.1.2. Healthy group

A total of 20 participants who met the inclusion criteria were included. Participant age, height, weight, and body mass index (BMI) were 44.00 ± 13.27 (25.00–65.00) years old, 166.40 ± 8.80 (149–183) cm, 66.95 ± 11.40 (48–91) kg and 24.10 ± 3.04 (18.10–29.71) kg/m², respectively.


Fig. 3. The actual measurement condition (e.g., “Superior indicator within the left Bar [SLB]”).
3.2. CAD group: analysis of the time-domain of different indicators at the same position

In Table 1, take the first row as an example: The first straight column indicates the time-domain parameter items (h1). The second straight column includes two items. The upper item means after the randomized block design, each participant is treated as a "block", so 37 participants have a total of 37 blocks. The lower item “S/M/D” refers to the three indicators (i.e., "superficial", "medium" and "deep") at the same position, so there are three variables. The third straight column: The item in the upper half is the degree of freedom of the “block”; and the item in the lower half is the degree of freedom of the three indicators (S/M/D). The fourth to the ninth straight columns present the data at the positions of the “right inch” to the “left cubit”.

As Table 1 shows in the case of the right Inch, significant differences were found with regard to the subject block for h1, h2, h3, h1/t, and h4/h1. Regarding the three indicators (i.e., Superficial, Medium, and Deep) of the right Inch, significant differences were found for h1, h2, h3, and h1/t. These results indicate that in the right Inch, 37 subject blocks exhibited differences with regard to h1, h2, h3, h1/t, and h4/h1, whereas for the three indicators (i.e., Superficial, Medium, and Deep), the participants' time-domain parameters were not all the same; therefore, the pulse waves of the right Inch at the indicators Superficial, Medium, and Deep showed different time-domain characteristics. Similarly, neither the subject blocks nor the time-domain parameters of the indicators Superficial, Medium, and Deep, the results of MANOVA were not identical at right Bar, right Cubit, left Inch, left Bar, or left Cubit in CAD group.

3.3. CAD group: analysis of the time-domain of different positions with regard to the same indicator

As Table 2 shows, in the case of the indicator Superficial with regard to the subject block, significant differences were found for h1, h2, h3, h1/t, Alx, h3/h1, and h4/h1. Regarding the six positions of the indicator Superficial (i.e., right Inch, right Bar, right Cubit, left Inch, left Bar, and left Cubit), significant differences were found for h1, h2, h3, and h1/t, indicating that there were differences in terms of the indicator Superficial for h1, h2, h3, h1/t, Alx, h3/h1, and h4/h1 among the 37 subject blocks, whereas the time-domain parameters of the participants were not identical with regard to the six positions (i.e., right Inch, right Bar, right Cubit, left Inch, left Bar, and left Cubit). Therefore, the indicator Superficial did not exhibit identical time-domain parameters at the six positions. Regarding the indicator Medium, similarly, some of the time-domain parameters were not identical among the subject blocks or the six positions. Regarding the indicator Deep, some of the time-domain parameters showed significant differences among the subject blocks, but the eight time-domain parameters did not exhibit significant differences among the six positions of any participant.

3.4. Healthy group: analysis of the time-domain of different indicators at the same position

As Table 3 shows in the case of the right Inch, significant differences were found with regard to the subject block for h1, h2, h3, h1/t, Alx, h3/h1, and h4/h1. Regarding the three indicators (i.e., Superficial, Medium, and Deep) of the right Inch, significant differences were found for h1, h2, h3, and

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Table 1

<table>
<thead>
<tr>
<th>Time-domain parameters</th>
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<th>Degrees of freedom</th>
<th>Right</th>
<th>Left</th>
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<td>F-value</td>
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In CAD group, the data of 37 participants who composed one block were entered into a MANOVA, and the differences among the means of the time-domain vectors of the three measurements (i.e., Superficial, Medium, and Deep [S/M/D]) at the right Inch, right Bar, right Cubit, left Inch, left Bar, and left Cubit were tested. F-values were calculated for each variable. *p < 0.05.
These results indicate that in the right Inch, 20 subject blocks exhibited differences with regard to $h_1$, $h_2$, $h_3$, $h_4$, $h_1/t$, $AIx$, $h_3/h_1$, and $h_4/h_1$, whereas for the three indicators (i.e., Superficial, Medium, and Deep), the participants’ time-domain parameters were not all the same; therefore, the pulse waves of the right Inch at the indicators Superficial, Medium, and Deep showed different time-domain characteristics. Similarly, neither the subject blocks nor the time-domain parameters of the indicators Superficial, Medium, and Deep, the results of MANOVA were not identical at right Bar, right Cubit, left Inch, left Bar, and left Cubit at the Superficial, Medium, and Deep positions (CAD group).

3.5. Healthy group: analysis of the time-domain of different positions with regard to the same indicator

As Table 4 shows, in the case of the indicator Superficial with regard to the subject block, significant differences were found for $h_1$, $h_2$, $h_3$, $h_4$, $h_1/t$, $AIx$, $h_3/h_1$, and $h_4/h_1$. Regarding the six positions of the indicator Superficial (i.e., right Inch, right Bar, right Cubit, left Inch, left Bar, and left Cubit) at the Superficial, Medium, and Deep positions, the data of 20 participants of healthy group who composed one block were entered into a MANOVA, and the differences among the means of the time-domain vectors of the three measurements (i.e., Superficial, Medium, and Deep (S/M/D)) at the right Inch, right Bar, right Cubit, left Inch, left Bar, and left Cubit were tested. F-values were calculated for each variable. *$p < 0.05$.

In CAD group, the data of 37 participants, each treated as a block, were entered into a MANOVA, and the differences between the means of the time-domain vectors of six measurements (i.e., right Inch, right Bar, right Cubit, left Inch, left Bar, and left Cubit) at the Superficial, Medium, and Deep indicators were tested. F-values were calculated for each variable. *$p < 0.05$.
Table 4
Differences between the time-domain vectors of right Inch, right Bar, right Cubit, left Inch, left Bar, and left Cubit at the Superficial, Medium, and Deep positions (Healthy group).

<table>
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</table>

In healthy group, the data of 20 participants, each treated as a block, were entered into a MANOVA, and the differences between the means of the time-domain vectors of six measurements (i.e., right Inch, right Bar, right Cubit, left Inch, left Bar, and left Cubit) at the Superficial, Medium, and Deep indicators were tested. F-values were calculated for each variable. *p < 0.05.

Table 5

Bar, right Cubit, left Inch, left Bar, and left Cubit), significant differences were found for h1, h2, h3, and h1/t, indicating that there were differences in terms of the indicator Superficial for h1, h2, h3, h4, h1/t, h3/h1, and h4/h1 among the 20 subject blocks, whereas the time-domain parameters of the participants were not identical with regard to the six positions (i.e., right Inch, right Bar, right Cubit, left Inch, left Bar, and left Cubit). Therefore, the indicator Superficial did not exhibit identical time-domain parameters at the six positions. Regarding the indicator Medium and Deep, similarly, some of the time-domain parameters were not identical among the subject blocks or the six positions in healthy group.

4. Discussion

Pulse diagnosis researches acquiring pulse waves from the wrist radial artery have not yet addressed whether wrist radial artery waves are identical across different positions and indicators. Although previous studies have shown that the conditions of the three positions were not the same across the wrist’s Inch, Bar, and Cubit, but they did not consider the variables of different hands or different depths. To sum up, the differences in hemodynamic characteristics between the left and right hands as well as among the three indicators (i.e., Superficial, Medium, and Deep) have not yet been completed investigated. The choice of measurement location for pulse diagnosis studies is still lack of consensus, so the results of the studies of time-domain analysis could not be integrated and further practiced. Therefore, this study attempted to use experimental data to make a formal clarification.

Our aim is to clarify whether the hemodynamic characteristics at 18 locations are the same, this phenomenon should theoretically not be differentiated by people who are with disease or disease-free. So we analyzed the data from the study of “Pulse Spectrum Analysis to Aid Diagnosis of Coronary Artery Disease”. Since the results showed that the hemodynamic characteristics obtained at 18 locations were actually not the same in the CAD group, the main question of this study has been answered. However, to avoid potential bias for misleading, we include healthy individuals to repeat the experimental procedure. The results showed that whether in the CAD group or in the health group, the hemodynamic characteristics are not identical at 18 locations of both group. These results also strongly explains that the hemodynamic characteristics at 18 locations are indeed inconsistent.

In CAD group, according to the result listed in Table 1, the time-domain parameters of the pulse waves were not identical across the different indicators at the same position. Also, the results showed in Table 2 indicated that the time-domain parameters at different positions using the indicators Superficial and Medium were not identical, either. In healthy group, the hemodynamic characteristics showed the similar conclusion. Combining the results of Tables 1–4, we conclude that although not all of the parameters were found significant difference across different positions and indicators, the data collected in this study explained the following three results.

First, with regard to selecting the measurement location for pulse diagnosis research using a time-domain analysis, given the hemodynamic differences among the three positions and nine indicators of both hands, if only a single location is selected, then the pulse wave information of other locations is likely to be missed. Therefore, when choosing a single location, it is necessary to provide a rigorous theoretical basis to ensure the collection of more complete pulse wave information for the time-domain analysis.
Second, given the different hemodynamic conditions at the different depths of the three positions (i.e., Inch, Bar, and Cubit) of both hands, when performing a time-domain analysis on pulse diagnosis study, we must also reach a theoretical consensus to determine the depth of the measurement of the pulse waves at the three positions (i.e., Inch, Bar, and Cubit) simultaneously or sequentially (see Tables 1 and 3). This topic is seriously neglected and worthy of more in-depth investigations.

Third, Tables 2 and 4 show that the time-domain parameters of Inch, Bar, and Cubit differed between the right and left hands, which echoes the rationality of the TCM pulse-diagnosis practice that when taking a pulse, it is necessary to simultaneously place the fingers on the Inch, Bar, and Cubit of both wrists to feel the pulse state so that the hemodynamic signals of different organs can be accessed and diagnosed, while also manifesting the uniqueness of the pulse wave signals of the six positions of both hands. Therefore, future time-domain analyses of pulse diagnosis require more in-depth investigations to determine how to select the measurement location and when to use the right hand, left hand, or both. There is so far no other studies focus on the discussion for this issue.

As Tables 1 and 3 show regarding the three indicators (i.e., Superficial, Medium, and Deep) across the six positions (i.e., the Inch, Bar, and Cubit of both the left and right arms), two participants’ time-domain parameters, h4 and h4/h1, which represent the height and the relative height of the D-wave, respectively, did not show any significant differences. Studies have shown that h4 and h4/h1 are related to blood vessel elasticity and the state of the aortic valve.5,16,17 Our results indicate that regarding hemodynamic statuses such as blood vessel elasticity and the state of aortic valve, regardless of the pressure intensity that was exerted, no significant differences were observed among the six positions.

Table 2 shows that the indicator Deep did not show any significant differences across the six positions (right Inch, right Bar, right Cubit, left Inch, left Bar, and left Cubit) with regard to any of the eight time-domain parameters. Does this finding suggest that the indicator Deep is a representative measurement location? As Table 1 shows, the time-domain parameters of the indicator Deep were not consistent with those of the indicators Superficial or Medium at the same position, which indicates that sufficient evidence is currently lacking to use the indicator Deep as a representative location to measure the other locations of the three positions and nine indicators.

A previous study showed that the characteristics of blood vessels differ depending on the degree of obesity.28 In Taiwan, the definition of overweight is 24.0—26.9, and the definition of obesity is ≥27.29 The BMI of the participants in our research is 26.9, and the definition of overweight and obesity is the same, and directly analyzing the data would ignore the possible differences and cause errors.

In conclusion, the pilot study adopting a time-domain analysis on the choice of measurement location for pulse diagnosis research verify the wrist radial artery waves are not identical across different positions and indicators whether it is in CAD group or healthy group. Future studies which apply time-domain analysis should be careful to choose the measurement locations instead of any one or three points to ensure the completeness of the information to be analyzed.

Acknowledgments

This work was supported by the Committee on Chinese Medicine and Pharmacy, Department of Health, Executive Yuan, Taiwan [grant numbers CCMP 100-RD-024].

References


