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Research paper

Differences in the radial pulse spectrum between the follicular and luteal phases of the normal menstrual cycle

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ABSTRACT

Introduction: Pulse spectrums measured from the radial artery carry hemodynamic and cardiovascular biosignals from the whole body. Many studies have shown different and special changes for specific diseases in the pulse spectrum analysis in accordance with Wang et al. who proposed that each harmonic is related to the energy of a corresponding organ. The specific aim of this study was to investigate the differences in pulse spectrum analysis between the follicular and luteal phases in healthy eumenorrheic women.

Methods: Biphasic healthy eumenorrheic female volunteers were recruited and pulse pressure waveforms from the left radial artery were recorded by a sphygmography in the follicular and the luteal phases. The indices of pulse spectrum, including the areas of the first five harmonics and the spectral energy ratio (SER (10)) were calculated and compared between the follicular and the luteal phases.

Results: According to the data from our 25 recruited women (aged 25.9 ± 0.9 years), the areas of the five major harmonics of the pulse spectrum, which were C0, C1, C2, C3 and C4, were all larger in the luteal phase than in the follicular phase, implying a higher energy state in the luteal phase than in the follicular phase. There were no differences in SER (10) between the two phases that were measured.

Conclusion: The data helps to understand the hemodynamic change within a menstrual cycle from the point of view of the pulse spectrum, establishing evidence-based literature for traditional Chinese medicine diagnosis.

1. Introduction

The history of diagnosis based on the radial pulse can be traced back to thousands of years ago. In traditional Chinese medicine, radial artery pulse taking is one of the diagnostic methods [1]. Blood pressure of the radial artery not only plays a role in cardiovascular function assessment [2], but also carries biosignals that reveal valuable internal physiological information about the entire body [3,4]. Using the technique of sphygmography, generally measured non-invasively, the texture and strength of the radial pressure waveforms can be faithfully recorded, with the parameters that can aid clinical diagnosis. The most common application of the pulse pressure waveforms analysis is to evaluate hemodynamic conditions in cardiovascular diseases [5–7], and to study some physiological processes that would alter hemodynamic conditions, such as pregnancy [8]. Besides, pulse pressure waveforms have been reported to help in monitoring certain diseases, such as atopic dermatitis [9], bipolar disorder [10], dyspepsia [11], and polycystic ovary syndrome [12].

The traditional method to analyze pulse waveforms is the time domain analysis, from which indices including the main wave, dicrotic wave, and rapid ejective time, have been demonstrated to be related to the blood pressure wave of the ascending aorta [6], the resistance, the compliance of vessels [4,13], and the endothelial functions [14,15]. However, time domain analysis can not reveal frequencies higher than the heart rate and therefore, have a limitation in detecting information in high frequency signals. Analyzing the "pulse spectrum", which has been used widely in analyzing the signals from the electrocardiogram, might be a solution to this problem [16,17]. The analytic process starts from performing Fourier transformation to the time domain waveform signals, and changing it into frequency-domain [18]. The power spectrum of the pulse pressure waveforms contains five main harmonics [19]. Wang et al. proposed that each harmonic is related to the energy of a corresponding organ, including the heart, liver, kidney, spleen, and lungs sequentially [20].

By analyzing time domain signals of pulse pressure waveforms from the radial artery, our previous study showed that the height of the main

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wave, the height of the dicrotic wave, the rapid ejection time, and the systolic area are larger in the luteal phase than that in the follicular phase [21]. Those differences could be explained by the hemodynamic changes within a normal biphasic menstrual cycle, including greater plasma volume, ventricular ejection volume, and vasodilatation in the luteal phase as compared to the follicular phase [22,23]. However, other physiological changes, e.g. sympathetic and body temperature differences within a cycle, cannot be observed in the time domain signals. We hypothesized that signals from pulse power spectrum would reveal and explain more regarding the physiological changes between phases than the time domain signals could.

The specific aim of this study was to investigate the differences in pulse power spectrums between the follicular and luteal phases. Healthy women were recruited and the pulse pressure waveforms were taken from the radial artery. The areas of the first five harmonics of the power spectrum were calculated and compared. Besides, the spectral energy ratio (10) (SER(10)), which is calculated by dividing the area higher than 10 Hz by the area lower than 10 Hz, was calculated to evaluate the degree of health in two phases [24].

2. Materials and methods

2.1. Subject selection

After receiving ethical approval from the institutional review board of China Medical University Hospital (CMUH), Taichung, Taiwan (protocol DMR97-IRB-241), 25 subjects were recruited through an advertisement at the CMUH. All subjects received a full explanation of the study and signed an informed consent form. The enrolled subjects met the following criteria: 1) eumenorrheic healthy women with regular, predictable menstrual cycles ranging from 28 to 35 days; 2) age from 18 to 40 years; 3) no oral contraceptive used within the last 6 months; 4) body mass index (BMI) within normal range (18.5–24 kg/m2); 5) no history of alcohol, drug abuse or smoking.

2.2. Experimental design

Pulse pressure waveforms were measured on the 12th or 13th day and on the 26th or 27th day of the menstrual cycle, representing the late follicular (LF) phase and the late luteal (LL) phase, respectively. The subjects' diet was free of caffeine and alcohol 24 h before pulse wave measurement. Basal body temperature (BBT) was measured sublingually everyday to ensure that our subjects were in the LF and LL phases of their cycles when the pulse waveforms were measured.

2.3. Pulse waveform measurement

The measurement was designed to be single blind. Radial pulse pressure on the left hand was recorded using sphygmography (WS 901, Skylark Device and Systems Co., Ltd.) after a 20 min rest. The technician who performed the sphygmography was blinded to the menstrual time points of the subjects. A pressure detector, in which the preload pressure could be adjusted, was placed onto the left radial artery located parallel to the radial styloid process as described previously [21]. Then the radial artery was compressed between the sensor and the underlying structures, allowing the arterial pulse pressure to be transmitted through the arterial wall to the sensor. Then the detector was held down until we measured the largest waveform, usually a preload pressure of more than 250 mg is needed. The resulting pressure waveforms were then digitalized and the data were displayed on the screen for visual analysis to confirm that the recorded waveforms were uniform and without artifacts. The room temperature was controlled at 21 ± 1 °C and all measurements were performed between 09:00 and 12:00.

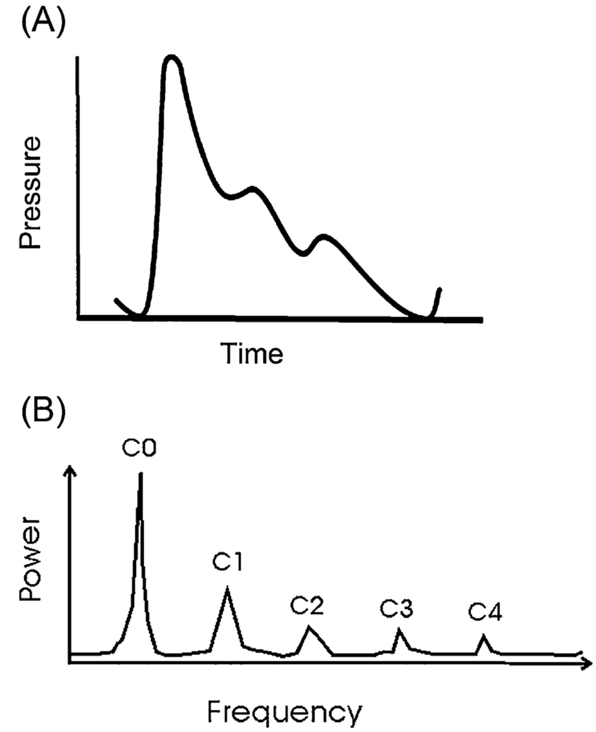

Fig. 1. Transformation of pulse pressure waveforms measured from the radial artery into frequency domain. (A) Time-domain feature of the pressure waveforms. (B) Frequency-domained signal and the five major harmonics.

2.4. Harmonic calculation

Fourier formula was used to transform the original time domain data of the pulse waveforms to a power spectrum (Fig. 1). The area of each harmonic from C0 to C4 was calculated. SER (10) was calculated by dividing the integration lower than 10 Hz by that higher than 10 Hz. All calculations were performed using MATLAB 7.2 software.

2.5. Statistical methods

All statistical analyses were performed using SPSS 13.0 statistical software. Results are expressed as mean ± SEM. C0, C1, C2, C3, C4, and SER (10) of the follicular and luteal phases were compared by paired *t*-test. A $p < 0.05$ was considered to represent statistical significance.

3. Results

3.1. Subjects

The mean age of the recruited 25 biphasic subjects was 25.9 ± 0.9 years (range, 18–35 years). They had a mean weight of 52.3 ± 1.5 kg (range, 42–66 kg), a mean height of 160.1 ± 1.1 cm (range 150–172 cm), and a mean menstrual interval of tested cycle of 30.0 ± 0.9 days (Table 1).

Table 1
The Baseline Characteristics of Study Subjects.

Height (cm)	Weight (kg)	Age (year)	Interval of menstrual cycle (day)
160.1 ± 1.1	52.3 ± 1.5	25.9 ± 0.9	30.0 ± 0.9

n = 25.