Pulse Spectrum Analysis in Primary Hypertension Patients

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Background and Purpose: Arterial pulse diagnosis is noninvasive and it is very popular in traditional Chinese medicine clinics. The aim of this study was to evaluate the possibility of using pulse diagnosis in patients with the primary hypertension. **Methods:** Noninvasive analyses of radial pulses were taken in primary hypertension patients immediately after their arrival at the physical examination room. They then underwent physical health examinations including measurement of blood pressure and heart rate, EKG, blood test, urine test, x-ray, ultrasound scanning, and recording medical history. We carried out pulse spectrum analysis on 110 patients with possible primary hypertension. We used five criteria for pulse diagnosis of blood pressure abnormalities to test for correlation. These were (1) C1≧2 (in intensity) and C4≦-3 (in intensity) or C4≦-2 (in phase), (2) C0≧4 (in intensity) and C4≦-2 (in intensity), (3) C0≧4 (in intensity) and C3≦-2 (in intensity) and C3≦-2 (in phase), (4) C0≧4 (in intensity) and C3≦-2 (in intensity) and C5≦-3 (in intensity), (5) C3≦-2 (in intensity and phase) and C6≦-2 (in intensity and phase). For the intensity, C1 (liver) every 5% above normal was given one "＋", every 5% below normal was given one "－". For C3 (spleen), C4 (lung), C6 (gallbladder), every 10% above normal was given one "＋", every 10% below normal was given one "－". For the phase, every 10% delay in the traveling speed of the pressure wave was given one "－". **Results:** Only the "＋", "N" (N = normal) and "－" states were considered, while quantities of "＋" "－" were not monitored. In the pulse analysis, there were 311 (from intensity) × 311 (from phase) ＝ 177, 147 × 177, 147 possible states (3 qualitative states and 11 harmonics). We considered only five criteria for blood pressure abnormalities and the correlation was very high, p < 0.001, Kappa = 0.701. **Conclusion:** The results strongly suggested that each harmonic of pulse spectrum has physiological and pathological importance in the circulation and it is worth further study. (Full Text in English)

Key words: Pulse diagnosis, spectrum, Fourier transform, harmonic

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Introduction

Blood pressure (BP) measurement is an integral part of medical examination. A number of factors affect the accuracy of its measurement. These include the subject's mental status and level of anxiety, position of the arm, and the size of the arm cuff, as well as observer bias and the instrumentation used.[1] Nearly 100 years have passed since Nicholai Korotkoff, a Russian army surgeon, defined the auscultatory measurement of systolic and diastolic BP.[2] Yet a century later, we still have not perfected the art of indirect BP measurement. There is also no easy assessment of how hypertension problems affect other parts of the body[3], such as the heart, stomach, lung, liver and spleen. In this article, we present patients who came to the hospital for physical examination, with the goal of using the pulse spectrum theory to diagnose primary hypertension and evaluate the possibility.

Palpation of the pulse is an ancient art. Determining pressure using pulse spectrum is comparatively newer method. It is reasonable to ask how well pulse spectrum correlates with indirect BP measurement, but data are lacking. In our previous report on pulse analysis of patients with liver problems and liver cirrhosis, we found that the spleen harmonic and liver harmonic were closely related to liver problems and cirrhosis, which might be induced by a virus or alcohol consumption.[4, 5]

It is well documented that the volume and contour of arterial pulses reflect a combination with cardiovascular function.[6] It follows that an analysis of the pulse wave should be a useful method with which to assess cardiovascular function.[7] One of the most powerful tools in signal processing is the frequency analysis technique involving the Fourier transformation. Bennett and Fischer[8] applied a spectrum analyzer to assess the diagnostic utility of plethysmographic waveforms in peripheral vascular diseases. Ting et al[9] resolved the pressure and flow signals into their harmonics to calculate the input impedance modulus and phase angle for each harmonic. Marble and colleagues [10] used similar techniques to demonstrate the correlation between the amplitudes of the 7-14th harmonics and the occurrence of coronary artery disease. Furthermore, in one animal study, Young and colleagues consistently demonstrated different harmonic patterns of pulse waveforms in the tail artery of rats when the left renal or superior mesenteric arteries were very briefly clamped.[11] Wang and colleagues[12] showed that the higher-frequency components of the PBP allowed blood flux in PVBs more efficiently.

We thought it appropriate to undertake this study to examine the frequency spectrum of arterial pulses in patients with primary hypertension as well as the possible mechanism responsible for such a special spectrum, if one occurred. We also hoped such a noninvasive technique would provide some diagnostic clues which would be helpful not only in the identification of the disease but also in providing further insight into our understanding of arterial pulses.

Material and Methods

Subjects

From August 1997 through July1998, 110 patients who came to the hospital for physical examinations were included in this study. Comparisons between the two groups of tests were carried out by the following studies (all tests were done at the Ho-

Ping Municipal Hospital). The two groups of tests compared in this study were:

Measurement of blood pressure

A Kenlu-model K-300 Sphygmomanometer (Di Tai Precision Ent. Co., Ltd. TAIWAN) was used for the detection of arterial blood pressure in this study. The patients were in the supine position for 30 minutes before measurement of arterial blood pressure. First, the arm cuff of the Sphygmomanometer was put on the left upper-arm and then the stethoscope was put under the arm cuff of Sphygmomanometer on the pulse position of the upper-arm to listen to the Korotkoff sound. The line of vision was vertical with the surface of the mercury column and the Korotkoff sound was heard as the surface of mercury column gradually went down. As the mercury column dropped down, the systolic blood pressure (SBP) was measured when the first Korotkoff sound was heard and the diastolic blood pressure (DBP) was measured when the last Korotkoff sound was heard. The mean arterial pressure was defined as DBP + (SBP-DBP)/3. Particular attention was paid to: (a) making sure the subject is at ease and in the supine position in order to reduce muscle tension. (b) The cuff around the arm was at the level of the heart. (c) The mercury column was lowered at a rate of approximately 2—3 mm/s. (d) And finally we reduced other environmental factors such as room temperature, noise, alcohol, caffeine, and recent cigarette smoking.

According to the Joint National Committee on Detection, Evaluation and Treatment of High Blood Pressure for the diagnosis of hypertension in individuals aged 18 years or older, the patients with the diastolic blood pressure between 90 and 104 mmHg are considered to have mild hypertension, those with diastolic blood pressure between 105 and 114 mmHg were considered to have moderate hypertension and those with diastolic blood pressure equal or greater than 115 mmHg were considered to have severe hypertension. The patients with the systolic blood pressure between 140 and 159 mmHg when the diastolic blood pressure was lower than 90 mmHg were considered to have borderline isolated systolic hypertension. The patients with the systolic blood pressure equal or greater than 160 mmHg when the diastolic blood pressure was lower than 90 mmHg were considered to have isolated systolic hypertension.[13] In the study, the 59 patients had primary hypertension because of unknown causes.

Radial Arterial Pulse Tests

Wang and colleagues[14] showed that to simulate a short segment of the aorta, they studied wave propagation in an elastic tube with a side branch balloon. The small balloon simulated the organ (group of arterioles). Ligation of this side branch reduced the moduli of the higher harmonics when the length of the side branch was appropriate. Electrical analogy of vessels was used to analyze this phenomenon. This simulation can explain the ligation results we found in rats. It may also clarify the discrepancies between the prediction of the Womersley equation and the experimental results. The aorta and the closely attached organ can produce coupled oscillation; theoretically, this structure is equivalent to a resonance circuit. The frequency properties of arterial beds in organs were studied by temporarily ligating the renal, gastric, splenic or superior mesenteric arteries of rats. Blood-pressure waves of the tail arteries were recorded before and during the ligations, and were analyzed using Fourier's transformation.

Their frequency spectra have been found to change profiles following specific patterns with the ligations of different arteries. Wang et al.[15] indicated that the results were significant with regard to the frequency selectivities of the organic arterial beds. Such frequency properties can be clearly explained when the circulation system is viewed as an electrical circuit network in which the organic arterial beds work as filters. Lin Pulsatile pressure wave is maximized. A pressure wave equation derived previously was used to predict this fundamental frequency. Wang et al.[16] demonstrated that the heart rate is proportional to the average high-frequency phase velocity of the pressure wave and the inverse of the animal body length dimension. The area compliance related to the efficiency of the circulatory system was also mentioned.

The subjects included in this study were instructed not to take caffeinated or alcoholic beverages or drugs for at least 24 hours prior to the tests. The radial artery pressure pulses of both hands were recorded using a pressure transducer (PSL-200GL, Kyowa Electronic Instrument Co. Ltd., Japan) fixed on the skin with tape and an adjustable belt with a small button to give suitable pressure on the transducer. The criterion of a good measurement was to seek the largest pulse amplitude. The subjects were first asked to rest for 20 minutes prior to the four consecutive pulse measurements being taken. The output of the pressure transducer was stored in an IBMPC after A/D conversion at a sampling rate of 430/sec. The pulse spectrum was analyzed by the Fourier transform using the period equal to 1 pules. This analysis gave spectrum readings up to the 10th harmonic. All procedures were performed in a bright and quiet room with a constant temperature of 24 to 25oC.

The intensity of the harmonics above the 11th was very small and thus not recorded. Intensity and phase were compared to a male standard (average of 100 male college students, ages 18 to 20 years) and a female standard (average of 100 female college students, ages 17 to 19 years). Normal was defined as those who had no known health problems. We had five criteria of pulse spectrum for primary hypertension:

1.C1≧2 (in intensity) and C4≦－3 (in intensity) or c4≦－2 (in phase)
2.C0≧4 (in intensity) and C4≦－2 (in intensity)
3.C0≧4 (in intensity) and C3≦－2 (in intensity) and C3≦－2 (in phase)
4.C0≧4 (in intensity) and C3≦－2 (in intensity) and C5≦－3 (in intensity)
5.C3≦－2 (in intensity and phase) and C6 ≦－2 (in intensity and phase)

A phase angle delay of 10% (i.e., the traveling speed of this harmonic) was mainly due to a structural change of its related organ.[17, 18] For the intensity, the definition was the same as we used before. For C0 (heart), C1 (liver), every 5% above normal gave one "＋" and every 5% below normal gave one "－". For C3 (spleen), C4 (lung), C5 (stomach), and C6 (gall－bladder), every 10% above normal gave one "＋" and every 10% below normal gave one "－".

Statistical Analysis

The blood test was used as the golden standard. The validity of the pulse spectrum analysis was analyzed using the kappa value and X2 test.

$$\text{Kappa value } (\kappa) = \frac{\text{Actual Agreement beyond chance}}{\text{Potential Agreement beyond chance}}$$

When κ = 0~0.2: slight agreement; 0.2~0.4: fair; 0.4~0.6: moderate; 0.6~0.8: substantial; 0.8~1.0: almost.

In the X2 test: X2 = Σ[(O-E)2/E], where O is the observed value; E is the expected value. From the X2 value, we found the p value, the chance of noncorrelation.[19- 21]

Table 1. Baseline characteristics of patients with primary hypertension.

Baseline characteristics	Primary hypertension (n=59)
Age (yrs)	60.1 12.3
Gender (M/F)	36/23
Body Height (cm)	164.3 7.6
Body Weight (Kg)	67.6 10.5
BMI (kg/m2)	25.7 4.3
Medication	
Beta-blocker(n)	11
Calcium antagonist(n)	19
Nitrates(n)	2
ACE inhibitor(n)	26
Diuretic(n)	12
Aspirin(n)	10

n: number of person.

Values are numbers of patients or mean ± standard deviation. BMI = body mass index; ACE = angiotensin-converting enzyme.

Results

The results for the 110 patients with possible primary hypertension (69 males and 41 females between 18 to 85 years of age with average 58.9±13.1 years), using the five pulse criteria in comparison with the blood pressure, are shown in Table 2. Baseline characteristics and medication of patients with primary hypertension are shown in Table 1. The results for the 59 patients with primary hypertension and pulse abnormalities, and the number of patients who fit into each criterion of pulse diagnosis are shown in Table 3. The results for the 59 patients with primary hypertension and pulse abnormalities, and the number of patients who fit into each harmonic spectrum of the pulse are shown in Table 4. The numbers (without parentheses) in the tables were the observed values where as numbers in the parentheses () were the expected value.

Discussion

Frequency analyses of cardiovascular signals were first carried out by Aperia in 1940[10]. Since then, the calculation of the Fourier series of varied hemodynamic waveform, e.g. femoral artery pressure gradient, arterial input impedance and flow waveforms, has been reported by several researcher pioneers. These offline studies emphasized the potential usefulness of frequency analysis in providing a better understanding of the dynamics of cardiac function and arterial wave transmission. With consideration of the medical ethics, it was unsuited to stop medication before testing the patients with primary hypertension. Thus, baseline differences were inevitable in this study. We need to perform further studies that use complete testing under ideal situations or controlled risk factors in the future.

Additionally, the results of the fast Fourier transform (FFT) of pressure and flow waveforms also allow the calculation of the pulsatile and steady components of fluid power and, consequently, the efficiency with which the arterial system transmits the output pressure and flows from the heart to the peripheral vascular bed.

Estimation of the power spectrum of arterial pressure has been obtained for humans and animals. However, the use of a noninvasive technique to record an arterial pulse, followed by Fourier analysis, has seldom been applied in clinical practice such that the successful application of Fourier transformation (FFT) to analyze certain hemodynamic data in patients with coronary artery disease, hypertension or peripheral vascular disease. This has provided us with the idea that the technique may also have some clinical value in monitoring patients.

As seen in Table 1, the p values corresponded very well with the values of Kappa. There were 11 harmonics (from 0 to 10th harmonics) in the pulse spectrum analysis. Each indicator may be in the "N", "＋" or "－" state, with different

Table 2. Agreement between pulse diagnosis and the standard tests.

Primary hypertension	Pulse spectrum		Subject total
	Abnormal	Normal	
Abnormal (n)	59 (40)	0 (19)	59
Normal (n)	16 (35)	35 (16)	51
Subject total (n)	75	35	110

n: number of person.

X2 = 60.902, P = 0.0000000157, Kappa = 0.701

Table 3. Number of patients who fit into each criterion of pulse diagnosis.

Criterion of pulse spectrum	Intensity	Phase	Subject total
1. (A)	C1>=2 , C4<=-3		21
1. (B)	C1>=2	C4<=-2	12
2	C0>=4 , C4<=-2		28
3. (A)	C0>=4 , C3<=-2		22
3. (B)	C0>=4	C3<=-2	10
4. (A)	C0>=4 , C3<=-2		1
4. (B)	C0>=4	C5<=-3	1
5. (A)	C3<=-2 , C6<=-2		10
5. (B)		C3<=-2 , C6<=-2	3

quantities. Even if we do not consider the quantity results, and just focus on the states, there are a total of 3^{11} (from intensity) $\times 3^{11}$ (from phase) = 177147×177147 possible states. We chose just a few criteria from the billions of possible states and obtained good correlation. WE concluded that there was a specific change in the power spectrum of the radial pulses, as recorded and analyzed in a noninvasive manner, in patients with primary hypertension.

A group of 59 of 110 patients showed primary hypertension. As seen in Table 3, 43 subjects possessed C0≧4 (in intensity) and 43 subjects also possessed C4≦−2 (in intensity and in phase). It seems that the frequency modulus of C0 (intensity) and C4 (intensity, phase) were very important in the hemodynamic changes of patients with primary hypertension. The question of what the C0 and C4 of the power spectrum of the arterial pulse indicate has arisen. We concluded that the C0 of the power spectrum indicated the average height of the power spectrum ($C0 = 1/T\int_0^t P\,dt$), which we believe is directly also proportional to the mean arterial pressure. We concluded that the lower C4 of the power spectrum is proportional to the lower blood flow of the lung. We believe that the differential blood flow of internal organs may affect the power spectrum of arterial pulse waves. Arterial hypertension is defined as elevated arterial blood pressure (BP). Since BP in the general population falls on a gaussian curve of normal distribution, it is impossible to define with precision the limits of "normal" BP. In addition, the BP of a given individual varies widely over time, depending on many variables, including sympathetic nervous system activity, posture, state of hydration, and skeletal muscle tone. Primary hypertension is arterial hypertension of unknown cause. More than 95 % of all cases of arterial hypertension are in this category. The primary function of the lungs is to act as a gas exchanger supplying oxygen to the tissues and removing the carbon dioxide produced by cellular respiration. The function of the lungs correlated with the concentration of the oxygen, and carbon dioxide of the circulation inside the body. [3] The function of the heart is to pump sufficient oxygenated blood containing nutrients, metabolites, and hormones to meet moment-to–moment metabolic needs and preserve a constant internal milieu. The heart has two essential characteristics, contractility and rhythmicity. The nervous system and neurohumoral agents modulate relationships between the venous return to the heart, the outflow resistance against which it contracts, the frequency of contraction, and its inotropic state.[3] From the results of this

Table 4. Number of patients who fit into each harmonic of pulse diagnosis.

Harmonic of pulse spectrum	Intensity	Phase	Subject total
C0	C0>=4		43
C1	C1>=2		33
C3	C3<=-2	C3<=-2	38
C4	C4<=-2	C4<=-2	43
C5	C5<=-3		2
C6	C6<=-2	C6<=-2	13

study, we thought that the primary hypertension correlated with the organs especial the heart and the lungs. This is consistent with the statement in Huang Ti Nei Ching that "The heart controls blood circulation, and the heart is connected with blood vessels. Blood flow of the whole body converges in the lung."[22] So this study should not be considered as merely a correlation study. It was a worthwhile project to thoroughly examine the possibilities of using this technique for something even more.

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原發性高血壓患者脈波頻譜之分析

呂萬安[1,2,3,4]

目的：寸口把脈是傳統中國醫學臨床上非常流行且非侵入性的方法，本研究之目的正是探討將寸口把脈作為診斷的可行性。**方法：**從醫院進行健康檢查的病患之中選取110位疑似原發性高血壓病患進行研究，以5個脈波頻譜指標作為原發性高血壓的脈診指標，分析這五項脈診指標與現代醫學各項健康檢查（各項健康檢查包括血壓、心跳速率、心電圖、常規血液檢查、常規尿液檢查、X光、超音波）以及過去疾病史的相關性，這五項脈診指標分別為（1）第一諧波強度≧2且第四諧波強度≦-3，或第四諧波相位角≦-2；（2）第0諧波強度≧4且第四諧波強度≦-2；（3）第0諧波強度≧4且第三諧波強度及相位角≦-2；（4）第0諧波強度≧4且第三諧波強度≦-2，且第五諧波強度≦-3；（5）第三諧波強度及相位角≦-2，且第六諧波強度及相位角≦－2。第一諧波（肝）之強度每高於正常值的5%則定量為一個 "＋"，反之每低於正常值的5%則定量為一個 "－"；第三諧波（脾）、第四諧波（肺）、第六諧波（膽）之強度每高於正常值的10% 則分別定量為一個　"＋"，反之每低於正常值的10%則分別定量為一個　"－"；至於相位部分，所有諧波之壓力波傳送速度每低於正常值的10%則分別定量為一個　"－"。**結果：**當不考慮 "＋"、"－" 的變化量而僅考量 "＋"、"N" 及 "－" 三種情況，那麼11個諧波總共可產生311 (強度) × 311 (相位) ＝ 177, 147 × 177,147個脈波頻譜，本研究僅選用6個脈波頻譜作為肝異常之指標，卻得到非常高之相關性，p值小於0.001，Kappa值等於0.701。**結論：**這個結果顯示脈搏諧波頻譜在循環系統具有生理與病理上的重要性，值得進一步去深入研究。

關鍵詞： 脈診，頻譜，傅立葉轉換，諧波

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