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TCM Pulse Contour Analysis Correlate First-Derivative to Frequency Domain: on Dr. Wang's Stringy (xian) Pulse

Yee-Guang Chen*

School of Post-Baccalaureate Chinese Medicine, Tzu Chi University, Hualien, Taiwan

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Dr. SY Wang being a cardiologist, who used to study TCM pulsology clinically forty years ago, had been summarized six important category of TCM pulse contours in his publications and it is my honor to have his latest pulses morphological map is released in this manuscript. I used to work on the computer programming for pulse contour analysis (PCA) under Dr. Wang's tutorial and instructions. Applied our previous experiences to this study, a series of computer procedures was solved for mining a variety of harmonics which had strong impact on the bisferiens waveform only but not the whole curve. Finally, evidence showed the 5th harmonic be an important factor to probe on. Results from the first-derivative function, there is a 'W' shaped on the slope curves which appeared to be very sensitive to the P1, P2 waves. Through the slope derivative and 5th harmonic-reduced results which may help us to quantify the bisferiens waveform and categorize into IV types (strong bisferiens to dicrotic). Another important contribution of this study is being a clue for PCA automation and demonstrating the different levels of *Xien* pulse. Empirically, this study may give some efforts to Dr. Wang's TCM pulsology interpretation with numerical analysis capability which may enrich PCA automation functions. In future, we want to accumulate more clinical cases for studying the PCA and verifying evidences which may raise new challenges on Dr .Wang's hypothesis and let truth become evidence. This work probably can provide a prospective research on pulsological automation evidence.

Key words: TCM pulsology, harmonic, derivative, PCA, bisferiens, evidence-base

Introduction

Forty-year ago, Dr. Shu-Yu Wang had been a cardiologist in the (*Tri-Service General Hospital, Taipei*) who dedicated his efforts on TCM sphygmography, carried out a bundle of scientific radial pulse studies[1-4]. Likewise, he wanted to probe pulse studies from hemodynamics into TCM pulsology that is now known as 'Evidence-base'. There once was an experiment described in his manuscript

***Correspondence to:** Yee-Guang Chen, Department of Traditional Chinese Medicine, Tzu Chi Medical Center, No. 707, Chung Yang Rd., Sec.3, Hualien 970, Taiwan, Tel: +886-3-8561825 ext. 2158, E-mail: tcmet.chief@msa.hinet.net

, which he wanted to study pulse changes under anaerobic status, testers were installed in an air-force hypobaric chamber (低壓艙) for pulse recordings[4]. Besides experimental studies, Dr. Wang shared his time to intervene electronic sphygmogram which succeeded on the 8748, APPLE II, IBM PC 8088 microcomputers[5-9]. In 1987, Dr. Wang led us to build the computerized TCM pulsology laboratory at the TCM diagnostic department in China Medical University affiliated Hospital (*CMUH*), Taichung. Next year, a three-channel IBM PC sphygmogram with (a) pulse waveforms, (b) dp/dt functions and (c) EKG was accomplished and served as a medical device for pulse recording and reading. In December 1988, a TCM pulsology symposium which was held at CMUH collected 17 manuscripts from all over Taiwan including honorable pioneers such as (*Ling-Yun Wei*[11],*Wei-Kung Wang*[12,13]).

In 1990, YG Chen (author) was encouraged by Dr. Wang to further his graduate studies at the (*Health Informatics department in University of Minnesota*) to claim his second M.S. degree. His advisor, Dr. Stanley Finkelstein, who has been a distinct scientist in studying arterial compliance based on Ohms law and advance C1 and C2 capacitance issues[10], gave him advices on finding the solution of reflected waveforms through the frequency domain. Therefore, both of the time domain and frequency domain on pulse waveform analysis (PCA) were tutored by his two former masters. Objective of this study is to introduce a method of time-frequency analysis based on our previous experiences and focused on *Xien* (弦) pulse as an example. *Xien* ,which is a pulse of bisferiens in nature, it used to be appeared both in 實證 (*Overloading*) or 虛證 (*Deficiency*) relating to *Liver-Xien* pulse. In TCM, *Eastern-Wind-Wind* gives out the *Liver-Xien* pulse (東方風木 ── 肝脈弦) [8].

Nowadays, National Health Insurance (*NHI*) system in Taiwan covers the payment for TCM sphygmographic examination so it is a good time to continue Dr. Wang's work which had already given evidence-base in TCM pulsology. It does not mean that Dr. Wang's saying is a golden rule but it really is clinical-experimental bare facts and directions which may lead people to the era of Evidence-based TCM pulsology from clinical perspectives. Moreover, there were so many valuable laboratory data sets available from Dr. Wang that we may use them for references.

As early as 1946, Projé wrote down the Fourier series deduction step by step, which applied to arterial pulse wave analysis with outstanding simplicity in his manuscript [14]. In 1950s , *Blood flow in Arteries* which was written and summarized the early works from Donald McDonald and John Womersley preluding PCA studies in the western country [15]. Concurrently, incident and reflected waveforms has been a popular topic which is based upon the early experimental work on vascular, PCA and hemodynamics studies such as pulse wave velocity (PWV) and augmentation index (AI)[24]. These two most commonly use non-invasive PCA able to deduce those reflected waves and reconstruct waveforms from peripheral to the central aorta which may promote clinicians to give better treatment in hypertension [23]. Apparently, vascular hemodynamics study as well as PCA had a strong research and developmental foundations in science. Definitely, Dr. Wang and early TCM pulsologist in Taiwan had done a great job which meets the interdisciplinary prerequisites for biomedical researchers and clinicians.

Dr Wang had summarized six essential TCM pulse patterns and made it disclose publicly from his studies since the '70s [5,8]. There are two basic pulse contours are mentioned which is the bisferiens and dicrotic waveforms (as shown in Figure 1) [9]. In this study, radial arterial pulse signals were taken from 27 patients with *Qi deficiency* and 24 as normal control. The bisferiens/dicrotic waves were put on the same scale for judgment which can be leveled in Type I to IV (as shown in table 4). Tactically, the following steps led PCA a way to mining the 5th harmonics: *Firstly*, DFS was applied to figure out harmonics as frequency as shown in (Figures 2, 3) which overviews data between two groups. *Secondly*, amplitude and phase curves are compared (Table 2, 3). *Thirdly*, filtering out the harmonic waveforms which had significant differences between (G1, G2) and giving the results (as in Table 3). *Fourthly* , based upon the above results keep tracking on the 5th harmonics and finding a method to mapping the systolic bulging P1, P2 into the frequency domain (as in Figure 4). *Fifthly*, a slope inter $\angle \theta$ comparison was made between the original and 5th harmonic-subtracted waveforms (Figure 4, Table 4). *Finally*, there was a trend of slope $\angle \theta$ changes among those waveforms which may lead a conclusion that the 5th harmonics is closely correlated to pulse contour analysis (PCA) giving a clue to Type I to IV levels.

Actually, time-frequency domain analysis had been applying to vascular flow (including TCM pulsology) with a long period of history that pulse contour can be broken down into harmonics and reconstructed by integrals[15,17]. This study took the advantages of the time-frequency analysis on differentiating the P waves into 4 levels and may give some insights on penetrating TCM-PCA studies. Type I and II with strong evidence of bisferiens, Type III is in boundary and Type IV no evidence at all that should be dicrotic in nature. Whatsoever, through this preliminary TCM pulsology analytical trial, it may give some intuition of pattern recognition to clinician or on machine reading.

Material and Methods

I. Patient and Instrumentation

Patient Collection

A questionnaire based on TCM signs/symptoms were designed to collect subjective and objective present-illness of the patients. This questionnaire used to be a standard worksheet in CMCH[7] to collect data from patients and analyzed through the eight principles in TCM diagnosis in order to explore the *Qi deficiency* (氣虛) cases. There were 51 examinees, who met the needs of the study, 27 cases with *Qi deficiency* while 24 in the normal *control group*, average age is 52.25.

Radial Pulse Recordings

The standard procedures for examining the radial pulse signals of the patient had been proposed by Wang (1998) at the TCM department, CMUH [6-8]. Pulses of the patients were recorded by Dr. Wang's sphygmography which was produced by the medical devices manufacturer (Skylark Device, Taipei, Taiwan). Pulse signals were digitalized and stored in the PC computer.

II. Discrete Fourier Series Analysis and Hypothesis Testing

Discrete Fourier Series

Projé summarized his early work for analyzing arterial pulse wave with the Fourier Series. Under the section of mathematical-physical methods in his paper, he illustrated the DFS analysis step by step with precise mathematical proof [14]. Thereafter, the function of Fourier Series, which based on the periodic pumping characteristic of the heart (pulsatile flow), has being used to solve the pulse wave contours in the frequency domain [15]. In this study, the DFS was solved based on the Fast Fourier Transform (FFT) by using the technique on numerical programming [16]. Outputs of this program contain essentially the real and imaginary parts for the DFS which encounter the amplitude, phase angle and fundamental frequency ($\omega_o = 2\pi f$) . These three parameters are required to construct the basic patterns of the sine-cosine wave functions with integer multiplication of the fundamental frequency which is usually given by the heart rate. Generally, a series of harmonics (f_1, f_2, f_3, f_4……)can be solved by the DFS programming (as shown in Figure 3).

Amplitude and Phase Angle

The real and imaginary part from multiple harmonics, which can be expressed as two vectors on a plane $C_n = a_n + ib_n$, are orthogonal to each other. Therefore, the amplitude C_n and phase angle θ_n from each harmonic can be calculated by the DFS function from following:

Fourier series induction functions as follows:

$$f(t) = 1/2a_0 + \sum_{n=1}^{\infty}(a_n \cos n\omega_o t + b_n \sin n\omega_o t)$$

$$= C_0 + \sum_{n=1}^{\infty}(C_n \cos(n\omega_o t - \theta_n))$$

Fourier in Complex form the real and imaginary part

Thus

$$e^{ix} = \cos x + i\sin x$$

$$f(t) = \sum_{n=-\infty}^{n=\infty} C_n e^{jn\omega_o t}$$

Mapping Harmonics to Pulse Contours

Harmonics distribution from the pulses was analyzed to reconstruct pulse waveforms (as shown in Figure 3). The result in (Figure 2) showed that amplitudes were decayed exponentially and harmonics (1 to 7) were encountered in this study. Actually harmonic with higher frequencies , usually beyond the 7th, is negligible in most of the PCA studies [17]. A trial of harmonics subtractions ,which ran through the first to tenth harmonic, were tested for their reconstruction power. Finally, the 5th harmonic was chosen to further our study mapping it to the bisferiens contour.

Based upon the time and frequency domain mapping, a derivative function f'(x) was elicited on both the original and 5th harmonic reduced waveforms. Apparently, the 'W' shape slope change (Table 4) is very sensitive to P1, P2. This 'W'-shaped which had found as an important landmark for tracing the P waves by Dr. Wang about 25 years ago[6] is also applicable for this time-frequency domain analysis.

Statistical Analysis

The H_o: $\mu_1=\mu_2$ such that amplitudes of each harmonics from patients with Qi deficiency G1 and normal control G2 are being compared (Figure 1). The probability to reject the H_o between the two groups is given by the two-tailed t-test.

Chi-Square is used in the 2x2 table comparing with frequencies of bisferiens and non-bisferiens (defined in Table 4) waves between our groups. Pearson value is used.

Results

Subject and Objective Clinical Findings

Table 1. Major top 6 signs & symptoms (S/S) of *Qi deficiency* patients (n=27).

S/S	Thirsty	Fatigue	Chest Tightness	Eye Blurred Vision	Absent Minded	Dizziness
Percentage(%)	60.0	59.9	49.01	45.1	41.17	39.2

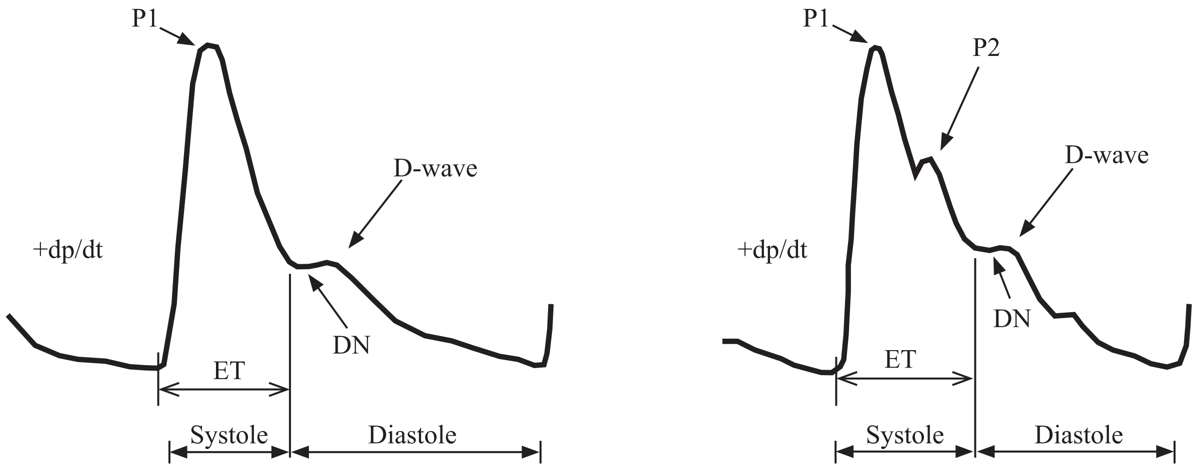


Fig. 1 Pulse contour recognitions—dicrotic and bisferiens waveforms. Left: Dicrotic wave with smooth curvature during systole , free of P2. Right: Bisferiens wave with P2 during systole. (Master thesis of Chen, 1987)[9].

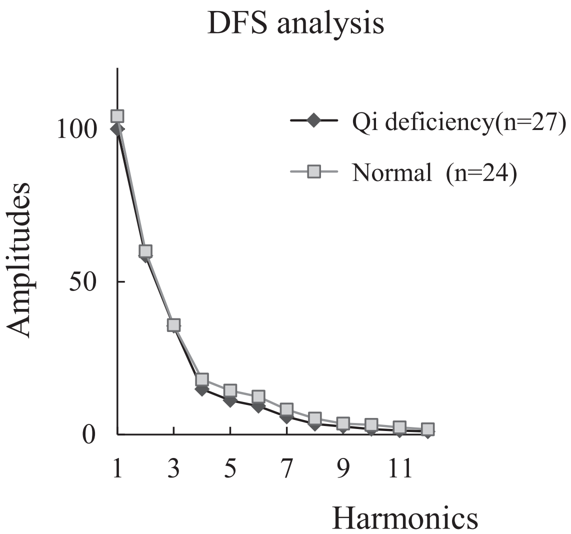


Fig. 2 Harmonic Analysis. Amplitude DFS with the average of the first 12 harmonics between two groups (G1: *Qi deficiency*, G2: *Normal control*) are decayed exponentially. A two-tail t-test with P-value = 0.8 showed no significant differences between both groups.

Table 2. Frequency of waveforms with P2-prominent and P2-negligible between groups G1 and G2, Chi-X^2= 14.8, P=0.00013 with significant differences.

	P2-Prominent	P2-negligible	
G1:Qi deficiency	8 (14.82)	19 (12.18)	27
G2:Control	20 (13.18)	4 (10.82)	24
	28	23	51

Table 3. Averages of the amplitude between G1 (n=27) and G2 (n=24) groups are compared to their matched-pair harmonics (1 to 7).

Harmonic	1st	2nd	3rd	4th	5th	6th	7th
P Value	0.975	0.329	0.706	0.102	0.020*	0.009**	0.01*

* P<0.05 ** P<0.01

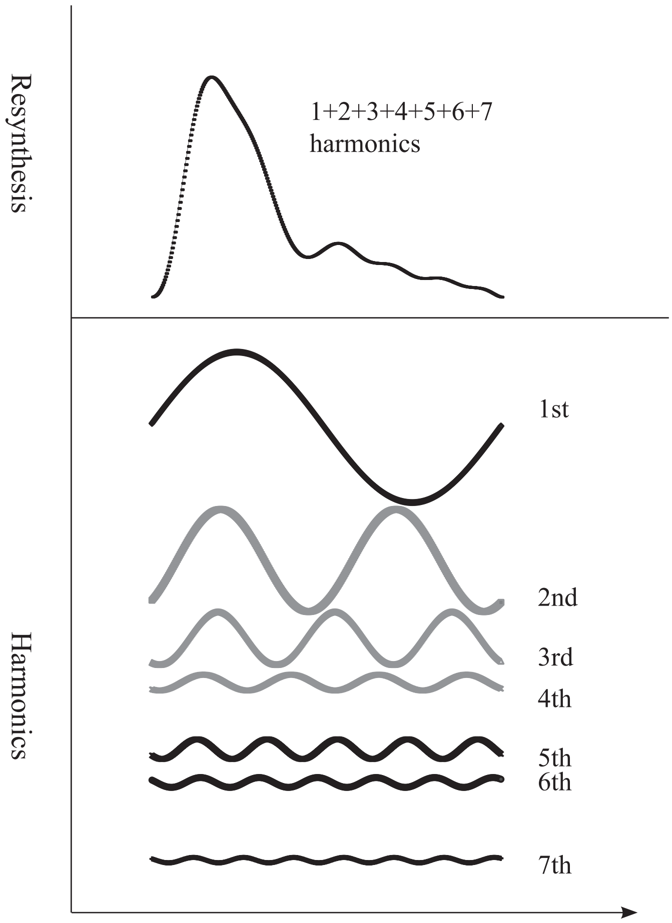


Fig. 3 Demonstration of original waveform which is reconstructed by the first 7 harmonics. Notice that the amplitudes are diminished exponentially. Amplitudes beyond the 7th harmonic is so small that it is negligible (N.B. 1st harmonic of this pulse is 1.2 Hz (72 beat/min), 5th harmonic will be 6 Hz).

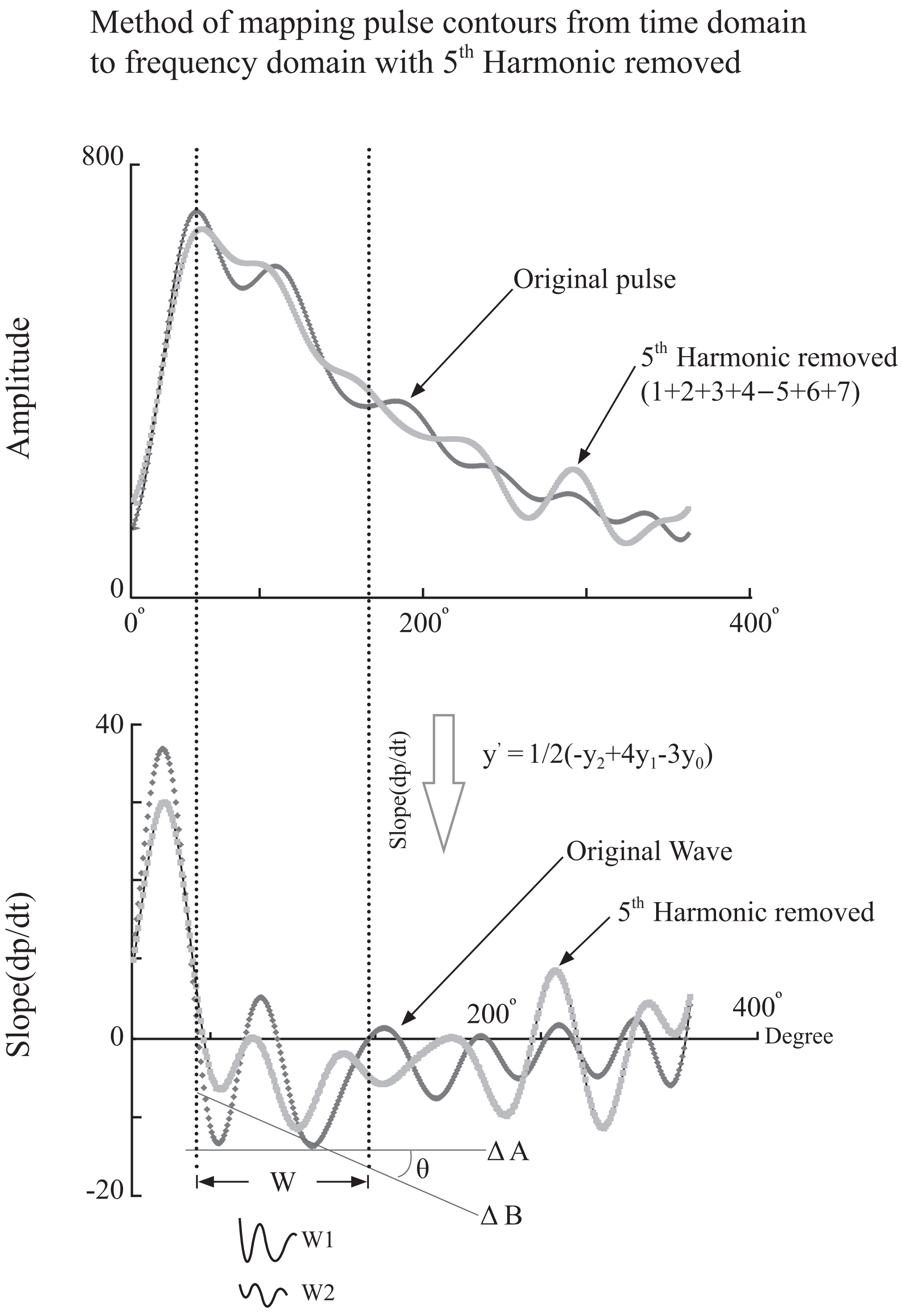
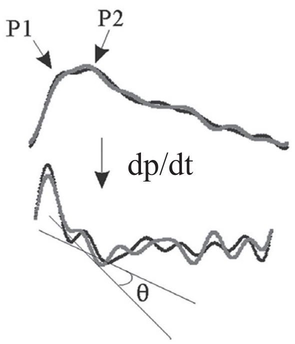
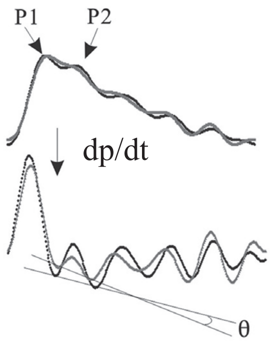
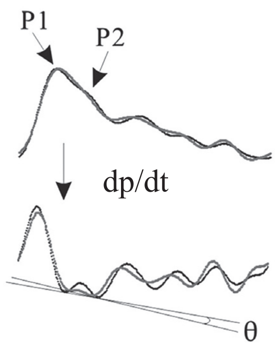
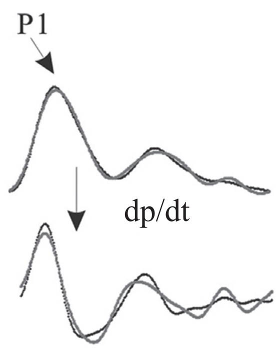


Fig. 4 Top: Overlapping curves are a) the original pulse are summed by the 1 to 7 harmonics, b) the 5th harmonic removed from the original and during the 'W' systolic time interval whereas the SR bulging is diminished. Bottom: A first derivative (dp/dt) with 3 points forward are being calculated and an obvious 'W' shape is found on those two f'(x) curves while w1 from the original and w2 from 5th harmonic-reduced. The angle θ is formed by slopes ΔA and ΔB. Correlate the slope curves onto the harmonic-reduced and original curves give further slope-angle comparisons.

Table 4. I~IV types applies to SR strength. I ,II are Stringy (弦), III weakly Stringy, IV no Stringy occurrence (dicrotic in nature) can be explained by the ∠ θ differences. Type I: w2 (5th harmonic reduced) anterior limb of the *'w'* flattened compared to w1 (original), it gives larger ∠θ = 22°. Type II: w2 with *'w'* shape conserved, it gives ∠ θ =9°. Type III: *'w'* shape of w1 and w2 do not change too much with ∠ θ less than 5°. Type IV: ∠ θ no change at all.

Class	Harmonic-time analysis	Characteristics	Descriptions
Type I SR++		Bisferiens Wave With P1<P2 ∠ θ = 22° SR ++ => **S**ystolic **R**etraction (**SR**) Prominent	Type I is characterized by P2 > P1 Case A: patient suffered from fatigue, thirsty, and poor appetite. *G1: Qi deficiency*
Type II SR++		Bisferiens Wave P1>P2 (Reverse to Type I) ∠ θ =9° SR ++	Type II is characterized by P1 > P2；P1, P2, w1, w2 are prominent. Case B: This case is in the normal control group. *G2: normal control*
Type III SR+/-		Bisferiens Wave P1>P2 ∠ θ less than 5° SR+/- =>obscured SR	Type III: P2 wave barely seen by eyes; w1 and w2 are remain prominent but nearly overlapped. Case C: *G2 control group*
Type IV SR -		Dicrotic Wave P1 only SR – =>SR None	Type IV is characterized by P1 only: i.e. dicrotic in nature Case D: patient suffered from fatigue, dizziness, thirsty, and poor appetite. *G1: Qi deficiency*

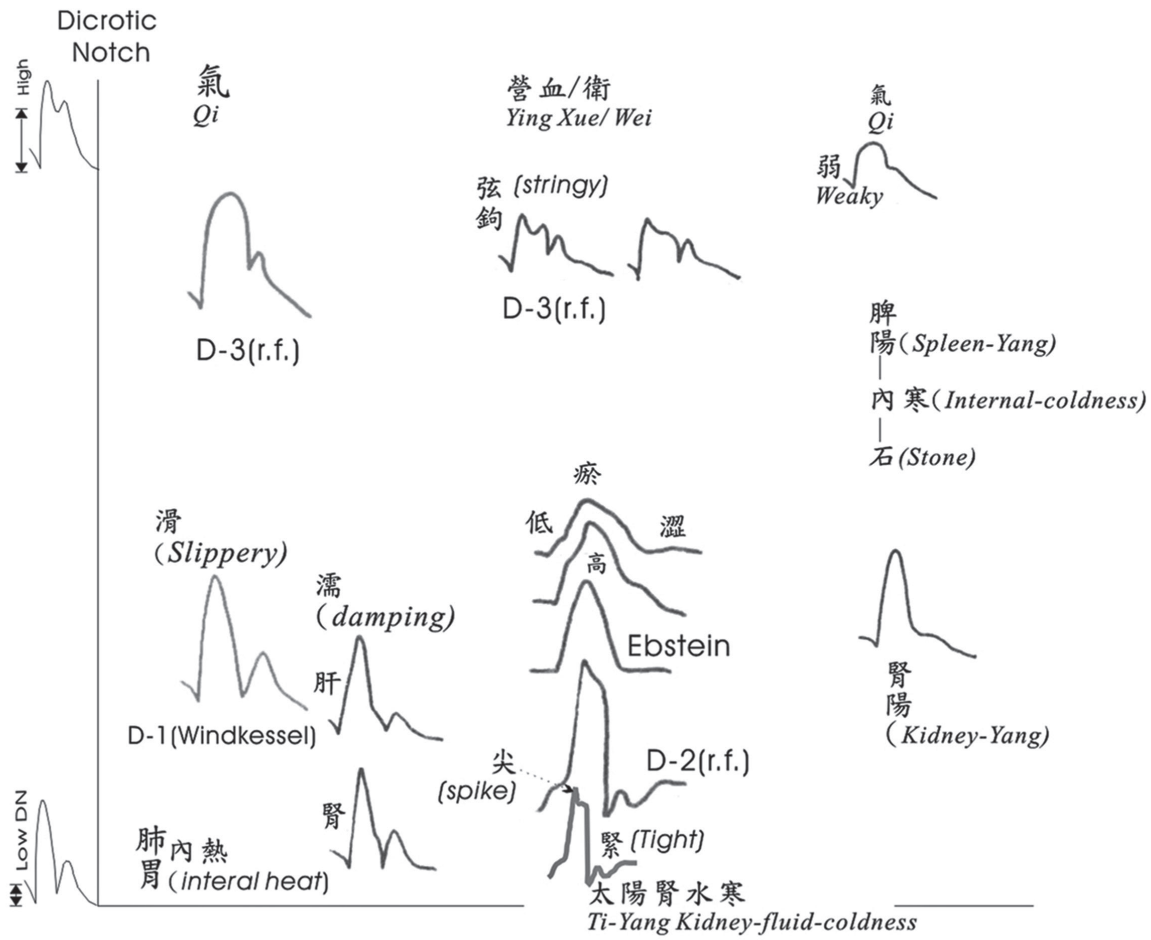


Fig. 5 Dr. Wang' TCM Pulsology morphological map. A map of TCM pulse morphology released by Dr. Shu-Yu Wang (Canada) NB: This map should be learned as a companion on Dr. Wang's manuscript (*J Chin Med* 4(3): 177-190, 1993)[8].

Discussion

Time Domain

Qi deficiency used to be one of the hot topics in all kinds of TCM studies. The top six signs and symptoms of G1 (*Qi deficiency*) were showed in Table 1. The result of the P2-wave available was compared with G1 and G2 (Table 2) which showed that (P2-Prominent; G1 = 8/27, G2=20/24) while (P2-negligible; G1=19/27, G2= 4/24) may conclude bisferiens occurred more in G2 (*control*) than G1 (*Qi deficiency*). This outcome may be due to the insufficient wave-reflection strength which shifting from systole to diastole so that it gave a weaker reflected-wave with P2-negligible as in (Table 2). The legend of bisferiens used to be occurred in aortic regurgitation clinically[19] and the concepts of reflections physiologically[23]. The aim of his study is not working on pulse pattern so that further explanations will be vulnerable. Back to the mathematical theme of this study, slopes dp/dt was calculated on the original and harmonic-subtracted curves. The 'W' shape on the f'(x) (as in table 4) could be insolated through the derivative function curves. Obviously, Type I and II had an inter-slope angle $\angle\theta$ bigger than 5 degree, while Type III and IV less than 5. This f'(x) 'W' had been located as a point of interest and interpreted by Dr. Wang[6] thoroughly which was related to the appearance of P1, P2 and systolic retraction changes during systole. In 1987 after writing a computer program by the 3 points forward derivative approximation function and reapplied as (in Figure 4), I had found that f'(x) gave its effort on stabilized the baseline of a fluctuated pulse so that it is very useful on filtering out cardiac rhythms accurately and applies to pulse contour recognition as described by others[20]. In the early stage of experimental studies from Dr. Wang, there were a lot of well-controlled experiments which had already had confirmed results on these pulse waveforms such as: the hypobaric chamber study, epinephrine / inderal injection to rabbits, femoral / hepatic artery clamping of the dogs and etc, these studies are invaluable in the history of TCM pulsology development[1-4]. When I worked with Dr. Wang in Taichung, I had found that most physicians are fond of reading pulse patterns through the time domain because it can be explained by physiological evidences. In this study, taken the bisferiens wave as a sample because it meets the criteria of stingy (弦) in Chinese medicine and the need of experimental peripheral pulse wave studies in the western country which will be discussed in the next section.

Time-Frequency Domain Analysis has Long been a Trend

Biomedical engineer are familiar with Discrete Fourier Analysis (DFS) so well and also applicable to TCM pulsology. As mentioned in the section of introduction, Womersley and McDonald carried out arterial pressure and blood flow research projects in the early 50s'. Integration of hemodynamics, frequency domain analysis, computer programming (puncture tape era) and human physiology studying which gave a steadfast research foundations on vascular blood propagation exclusively in the western country. Concurrently, the P1, P2 waves (figures 1, table 4) appear on the bisferiens wave used to be interpreted as an evidence of reflections formed by peripheral vascular impedance[15,17]. During the time of 60s', McDonald's team had already deduced the reflected and incident waveforms ,they regarded dp/dv as a *'windkessels (風箱)'* which generated by the inlet and outlet of the aorta. Applying *windkessel effect* on pulsatile pressure and flow, people can deduce the characteristic impedance (Zo) and input impedance (Zi) by solving each harmonics ratios[15]. When vascular impedance variables were available, the shape of the reflected and incident waveforms can be reconstructed[15]. It is difficult to take pressure and flow within the aorta and people found that the bisferiens (*P1 , P2*) surely are formed by the reflected waves and can be deduced by applying the concept of pulse wave velocity (PWV) [24] or Augmentation index (AI)[23] for approximation through peripheral pulse contours. Reflected wave may partly explain the P1 , P2 appearances to the pulse bisferiens waveform. These descriptions may also explain that the DFS functions has already been a basic tool in looking for transforming time signals into the frequency domain. In the introduction section which showed the steps had been planed for the 5th harmonic and mining. (Figure 2) showed that there were no amplitude differences in the first 12 harmonic between G1, G2 by averaging the 51 cases with the (P = 0.8). Nevertheless, pairing harmonic comparisons of the first 7 harmonics individually was proceeded which showed significant differences (P<0.05) from harmonic 5^{th} to 7^{th} (Table 3). It is really true when compared to harmonic re-synthesized waveforms all evidences were pointed to the 5^{th} harmonics which had the highest impact factor.

Dr. Wang's Stringy (*Xian*) Pulse Interpretation[8]

一、「從春秋 (或漢朝) 之《內經》及《難經》到清朝之《醫宗金鑑》，歷代文獻所提示之六個最基本之提綱，竟然都缺少了弦脈，所謂「緩急大小滑濇」或「浮沉遲數滑濇」俱未列入弦脈，但弦脈在臨診上卻是甚多見之脈。尤其是收縮期主峰，不論是沉石或浮滑皆是搏堅之水鎚脈體，惟有弦脈之主體峰中分為兩，成為疊波（F 及 P）－（bisferiens），而且在西醫動脈導管學上弦鼓是代表主動脈瓣內外兩面，內面是左心室在收縮後期之張力；外面是動脈管之周邊阻力，又稱「後負荷」，其出現是代表身體需氧（oxygen demand）之清況，與浮滑脈之重搏波代表供氧（oxygen supply）兩者前後互為相映，故決不能列於次級而忽視之。」

First of all, Dr. Wang mentioned that stringy (bisferiens) pulse is commonly found and it is one the most important patterns (bisferiens, dicrotic and water hammer) in TCM pulsology. Bisferiens (P1,P2) is the event occurred at systolic ejection time period which gives the late systolic left ventricular tension through the aortic valve proximally and the arterial peripheral resistance distally (also called the afterload). Oxygen demand and oxygen supply of the body is relevant to bisferiens and dicrotic waves, respectively.

二、「重搏脈（dicrotic pulse) 之具有胃氣（熱能－從重搏波可看出）為氧之提供無缺及主動脈弓之順應力良好。弦脈（bisferiens）之肝氣是缺氧之初對氣之需求狀態，乃小動脈之收縮增加了後負荷，誘發了左心室之張力。弦急鼓之脈是反應性充血之血流（RHBF）是缺氧之後進而有了氧債，氫離子之過多使酸鹼值減低所致，是微血管前微動脈之擴張。」

Secondly, Dr. Wang mentioned that dicrotic pulse is related to *Stomach-Qi* (heat energy , the dicrotic pattern) and given by adequate oxygen supply and good compliance around the aortic arch. Contrarily, stringy (bisferiens) refers to *Liver-Qi* is in the status of oxygen demand while our body is in the early stage of oxygen deficiency. During this event, the arteriolar constrictions gives increment of the afterload and increases left ventricular tension which is frequently occurred in oxygen demanding status. Apparently, Dr. Wang wanted to interpret pulse contours from the point view of hemodynamic and classical TCM theory. Finally, three basic patterns are founded which is dicrotic, bisferiens and water hammer[8].

Learning bisferiens clinically and physiologically relating to stringy (弦脈)

Pulse palpation is a physical examination skill both in TCM and western with long history. Medical terminology such as *bisferiens* (aorta regurgitation), *water hammer* (aortic insufficiency), *parvus tardus* (aorta stenosis), *pulsus alternans* (oxygenation deficiency), *pulses paradoxus* (cardiac tamponade) all these pulses could be sensed by finger palpation[21,22]. TCM had a history of radial pulse palpitation since *Han* dynasty (200 AD). Bisferiens wave often refers to a double peak feeling to the finger which is a stringy (弦) pulse[19] and also concluded by Dr. Wang[6]. Upstroke of the systolic wave mainly correlated with left ventricular pumping is preload dominant enriched by venous return. Cardiac physiology used to refer the systolic phase to fast ejection and slow ejection phase. Most time, P2 occurs around the slow ejection period. Obviously, P2 is coming from preload and/or afterload which is peripheral resistance related. In contrast to bisferiens is the dicrotic (單脈) wave as (in Figure 1). Being a cardiologist and after thousands of pulse contour readings[1-6], consequently Dr. Wang made a conclusion on yang (陽)-part in the diastole and yin (陰)-part in the systole (Figure 5). There are 6 basic patterns emerged in Dr. Wang's manuscript: *slippery (hua), stone (shi), weak (ruo), stringy (xian), apical-type (lei xi li)* and *faint fine (wei xi)*[8] and those waveforms are illustrated in his textbook[5]. Bisferiens (*xien* 弦). It gives us a clue that if the bisferiens P2 wave appears in the systolic descending limb , it is usually but not always given by arterioles constrictions which commonly occurred in anxiety, fight-or-flight status and is compatible with the theory in TCM (hepatic stringy pulse, 肝脈弦) too.

Fitting TCM Theory to Modern Sphygmography and Cooperation

There are so many different approaches to TCM pulsology: time domain, frequency domain, computerized pattern recognition, clinical correlation, etc. In my opinion, the best way to solve the problem in TCM pulsology is the theory of TCM itself. This is the reason why Dr. Wang wanted to seek the answer from *Neijing* as the reasons explained in the following paragraph. The pulse contours ,which is drawn by pressure transducer, can only partially be interpreted with human finger sensations. Multidisciplinary, science, classical TCM should be worked together in order to meet the needs of scientific purposes.

If you cannot measure it, then it is not science. —Sir W.T. Baron Kelvin (1907). It is a good way to follow the footprint of the modern science to meet the need of *evidence-base*. Nevertheless, there are so many unknowns in TCM as well as in the western medical world too that has to be explored. When I was a graduate student in CMU, *prof*. Wang gave us lessons on (五運六氣). I think it is the keystone for traditional Chinese medicine because most of the honorable ancient physicians (like 金元四大家) applied this theory to extend their thinking. A book title with (內經形氣論傷寒、溫病)[25], which had been published last year, hopefully may provide us a profound view on TCM pulsology. The ancient philosophy in *TCM literature* is a treasure which we have to follow. Measurement can not solve our own problems but TCM itself.

Thankfully, there had been so many engineers in Taiwan to dedicate their expertise to develop so many sophisticated models such as '*Resonance theories*' to explore the frequency domain analysis for TCM pulsology[12,13]. Unlike clinical science, experimental science always confines to a closed system or a model with controlled variables sometimes it is difficult to duplicate when conditions are being changed. For instance, cardiovascular system hemodynamics follows the Ohms law in nature: *pressure = flow x resistance*, minor changes of the pulse waveforms may come from any of those three variables. Clinically, when we talk about bisferiens, it mostly refers to cardiac regurgitations[22] while from PWV's aspect sometimes it refers to peripheral impedance. My point is both the preload & afterload , which may attenuate waveforms to bisferiens, is hard to distinguish between the cause and effectiveness. Furthermore, I would like to make a remark here about arterial wave spectral analysis as Taylor mentioned in his manuscript about power spectrum whichever is good for irregular heart rate but not the normal rhythm[26]. Engineering always emphasis on measurement that fits into science.

Donald McDonald who used to be a neurosurgeon and led his team (M. Taylor, MD PhD; M. O'Rourke, MD; W. Westerhof, MD PhD) to study vascular hemodynamics is a sample from the (medical mathematical physiological) *interdisciplinary* aspect. To allow TCM pulsology fidelity and blossom, multidisciplinary and team co-work is a rule of the thumb. There is boundary in between science and clinical interventions which sometimes refer to the jargon '*interdisciplinary*' by people.

Nowadays, TCM medical devices research and developmental team work has already been crewing in Taiwan and promoting services to human health is our great expectations. TCM pulsological analysis is complicated and necessarily to integrate the knowledge from the aspects of tradition, science and interdisciplinary.

Limitations

Although so many eminent biomedical engineer works for PCA, there are plenty of unknown even conflicts left behind in science. For instance, the contour on the bisferiens waveform may vary from preload to afterload. The afterload may vary from arteriolar bifurcations, windkessel's effect, vasoconstrictions, vascular diameter changes, pressure differences, etc. TCM talks about liver probably is not referring to the solid hepatic organ, booster unknowns is raised. Modern is not always better than the old. Fourier series was a mathematical induction invented by J.B. Fourier in 1801. Euler's formula is still a trigonometric complement that we commonly apply to the frequency domain functions and do not have so much other choices remain. Abundant numerical tools are available but no one knows which will be applicable to TCM studies. The question is not on the tool but clinical observations, TCM theories and finally given by the analytical tools. If we reviewed the PCA history from Womersley and McDonald , we will find that all the waveforms analytical methods and directions were raised by vascular physiological results. It is also true for TCM pulsology as DFS, PCA, time-frequency domain analysis is no more than a companion for clinical observations. Reiterate here that, experimental study is still the golden standard for TCM pulsology if someone wants to claim pulse contour evidences from numerical tools then preliminary clinical observations should be studied intensively or it will be leading astray.

Problem orientations still meet our need on exploring morphology of the Stringy pulse and transform it into Evidence-base. The 5th harmonic filtering procedures can fit into bisferiens analysis as in this study but it may or may not be applied to other data set. First derivative has been taking a part in PCA for decades and mostly applied to automation purposes[18,20]. Thereafter, I believe that the mathematical method described in this study surely helps on the pulse wave analysis and further applies to waveforms autocorrelation. Nevertheless, in order to make Dr. Wang's pulsology work, more samples ,experiments and clinical studies are required. There are so many unknowns and questions from TCM pulsology await, it really takes time to exploring and finding evidences. This never-ending TCM research issues should pass onto the next generation for further explorations.

Conclusion

Stringy (*Xien*) is the bisferiens waveform in nature. There are so many numerical tools available for both of the frequency and time domain analysis. First derivative is applicable whenever pulse baselines are fluctuated and also good for automation purposes. Frequency domain can interpret pulse wave individually so that it may apply to internal organ resonances as in W.K Wang's team-work[12-13]. The 'W' shape of first-order derivative appears to be the landmark of bisferiens even very tiny changes of the curves so that it consider to be very 'sensitive'. Basically, bisferiens pulse is a medical term which widely applied to pulse reflections and arterial compliance as known as the Augmented Index (AI). By Dr. Wang's definition, Stringy (*Xien*) is equivalent to bisferiens and *liver-qi* in TCM. It should spend more time on correlating the stringy pulse (Type I , II , III as in table 4) to the Qi-deficiency group. Apparently, the classifications may lead to bisferiens waveforms measurement quantitatively. The harmonic mining was deduced by a series of computer procedures and concluded the 5th harmonic is one of the best options applied to this study. Integration of harmonic reduction and the first-order derivative, which is introduced in this study , is a method to analysis the bisferiens contours and especially applies to automation purposes. TCM pulsological analysis emerges to be a new challenge and a chance to put Chinese medicine to the world of evidence-based.

However, multidisciplinary is given to science a bright future. It is quite an interesting issue to put Fourier series, pulse pattern recognition, numerical analysis, computer programming, vascular physiology and TCM pulsology all-to-one and works it out. It takes time and manpower to keep TCM pulsology in the pace of evidence. Recalling our history, those evidence-based TCM developers in field of pulsology, pharmaceutics, TCM literature-database recollections, clinical studies, theory explorations and etc in Taiwan, had already had brilliant contributions to science. I had helped Dr. Wang to develop computerized sphygmogram, since I was a student. I would like to pass our TCM pulsological logs to young medical physician who wants to dedicate their career on multidisciplinary purposes.

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中醫脈波分析利用一次導函數與頻域互驗：應用在汪教授之弦脈上

陳逸光 *

慈濟大學士後中醫系，花蓮，台灣

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四十年前，汪叔游教授還是一位心臟科醫師的時候，就決心投入中醫臨床脈診研究的工作，他將中醫脈象大致分為六類，曾發表在各類文獻中，今能獲得汪氏之第一手脈圖資料並已置入本文中乃筆者之無比榮幸。當筆者還是研究所學生之時，汪老師就有吩咐吾人將重點放在脈圖之電腦程式開發上。基於過去之經驗，本研究將進行一連串的脈圖數據運算，目的在找尋對應在脈圖上的諧波，條件是它只對 Bisferiens（複脈）有反應，但不會對圖形的整體性產生劇變。結果，從數據中得證第五諧波的貢獻最大，複脈波形在傅立葉函數加減重組下，脈圖數據能提供弦脈 IV 型的量化資料。過去我們曾經在脈波的一次導函數斜率曲線上，發現一‘W’變化，此現象對 P1,P2 波辨析很靈敏，而今運用在原波圖形及諧波折損圖的分析上仍然有效。這項結果，無疑是提供了時域╱頻域脈圖分析的線索，提昇了脈波圖形之自動化及量化判讀。本研究之初衷是用數據分析方法，協助汪教授的脈圖作分析，並盼能為未來的自動化運算作出貢獻。日後，若能在此自動分析方法基礎上，累積更多的臨床病例，將可與汪教授的中醫脈証學作比對，從統計中便可考驗各種假設，使真理成為證據。本研究將可為中醫脈診帶來預期的自動化之實證。

關鍵字： 中醫脈波學、諧波、導函數、脈波圖形分析、複脈、實證醫學

* **聯絡人：** 陳逸光，慈濟醫學中心中醫部，970 花蓮市中央路三段 707 號，電話：03-8561825 分機 2158，電子郵件信箱：tcmet.chief@msa.hinet.net