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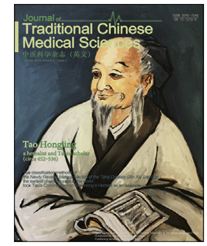

Micro-piezoelectric pulse diagnoser and frequency domain analysis of human pulse signals

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Pulse diagnosis;
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Abstract *Background:* The theory of pulse diagnosis is to assess the physiological condition of the human body using radial pulse. However, pulses can vary markedly from person to person. Further, pulse diagnosis is difficult to learn and requires one-on-one teaching.
Methods: To address this problem, we built a home-made pulse diagnoser and measured human pulses for studying the standardization of pulse diagnosis. Our pulse diagnoser was composed of a piezoelectric transducer, differential amplifier, data acquisition instrument, and a Matlab analysis program. The measured pulses were converted into electronic signals by a piezoelectric transducer and saved on a computer. The digitalized data were then refined and analyzed by fast Fourier transform for frequency analysis. Simulations were performed to assess the factors that affected the pulse, including phase shifts of reflected pulse waves (generate sub-peaks in pulses), inconsistent heart rates (deform pulse waves), the vessel stiffness (alter harmonic frequencies of the pulses), and the wave amplitudes (determined by the pulse strength).
Results: By comparing a published report and our simulation findings, we characterized the pulse types and the effects of various factors, and then applied the findings to study actual pulses in patients. Three types of pulses were determined from the frequency spectrum—choppy pulse (*Se mai*) without apparent harmonic peaks, the harmonic frequencies of wiry pulse (*Xian mai*) that are non-integer multiples of the fundamental frequency, and surging pulse (*Hong mai*) that exhibit strong amplitudes in the spectrum of frequency. A normal pulse and a slippery pulse were differentiated by a phase shift, but not by assessing the frequency spectrum.
Conclusion: These findings confirm that frequency domain analysis can avoid ambiguity arising in assessing the three types of pulses in the time domain. Further studies of other pulses in the frequency domain are required to develop a precise electronic pulse diagnoser.

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Introduction

Traditional Chinese medicine (TCM) has been used for over 3000 years. It mainly uses four diagnostic techniques: inspection, auscultation-olfaction, interrogation, and pulse.[1] TCM practice emphasizes all these diagnostic techniques, although healers prefer the exploiting pulse, which is simple, applicable, and precise.[2] Pulse diagnosis can also provide information that is unable to be verified by the other three techniques. For instance, interrogation may not work in infants or the deaf, while inspection may fail in patients who do not have obvious symptoms. Pulse diagnosis is therefore a highlight of TCM. Nevertheless, pulses vary markedly from person to person and are complicated. Successful pulse diagnosis also depends on the expertise of the healer in assessing variations of the pulses. Thus, pulse diagnosis is difficult to learn, and requires one-on-one teaching. To address this problem, many studies have attempted to standardize pulse diagnosis by development of objective instruments as a replacement for subjective conclusions.[3,4]

Piezoelectric is the most prevalent type of device, and utilizes a transducer to convert pulse pressures into electronic signals that are recorded for further analysis. Examples are the BYS-14 developed by Beijing Medical Devices, the MTY-A developed by Medical Laboratories of Tianjin, the ZM-1 developed by Shanghai University of Chinese Medicine, the HMX-4 developed by Shanghai Medical Instrument Company,[5] the BIOPAC-MP30,[6] the PSL-200GL developed by Kyowa Electronic Instrument,[7,8] and custom-built transducers.[9–15] The electro-optical technique uses a charged-coupled device camera to acquire the displacement of reflected light and diffraction grating resulting from the vibrations of the pulses, and the vibrations are shown on a chart. Various light sources have been reported, including laser,[16,17] halogen,[18] and fluorescence.[19] The electro-optical methodology is non-invasive and economical, although it has two major limitations (frame rates and resolution) that limit its use in pulse measurements. The acoustic and ultrasonic methods are used to detect the acoustic waves from blood travelling in blood vessels with a microphone[20,21] or a Doppler ultrasonic sensor.[22,23]

Data analysis is also essential for pulse diagnosis, as previously reviewed.[24] In principle, data analysis in the time domain examines the geometric shapes of pulses, while analysis in the frequency domain extracts the frequency information behind the pulses. The main difficulty in time domain analysis relates to the indistinctness of the pulse shapes. For example, a normal pulse has a similar shape to an intermittent pulse, while a surging pulse is similar to a knotted pulse.[9] Thus despite widespread use of various numerical methodologies, computing algorithms, and statistical techniques such as fuzzy neutral networks,[5] inter-rater agreement,[8] curve fitting,[6,9] and Bayesian network,[10] there is no consensus on the optimal technique for pulse diagnosis.

Analysis in the frequency domain can also be used to examine fundamental properties of the pulses, such as the resonance of mechanical waves generated by the heart via the radial pulse. This physical characteristic is a direct sign of physiological status in the human body, as the radial pulse is one of the main arteries connected to the heart and other main organs.[25] Further, frequency domain analysis provides numerical data, which are more specific than those from the time domain. Thus, frequency domain analysis is more reliable than that for the time domain. Power spectrum, fast Fourier transform (FFT),[8,15,16,19,20,23] and the Hilbert-Huang transform (HHT)[21] are typically used to analyze pulses.

Wang et al[7,13,14,23] previously reported that the resonances of pulse signals in the spectrum correspond to organs in the human body. For example, the first resonance relates to the liver, the second resonance relates to the kidney, and the third resonance relates to the spleen. This innovative hypothesis may provide physiological status in detail for human body compared with pulse analysis itself. However, this theory conflicts with the description of pulse diagnosis in *The Pulse Classic* (*Mai Jing*) written by Shuhe Wang 2000 years ago. In the Classic, he indicated that the radial pulse can be separated into three parts on both hands. These six points are then defined corresponding to the main organs. By contrast, Wang et al measured and analyzed the entire radial pulse without dividing into the six points described in *The Pulse Classic*. Thus, the findings in that study remain controversial.

In the present study, we simulated and measured pulse signals at the six points mentioned in *The Pulse Classic* using our novel pulse diagnoser, and then analyzed the signals based on the eight principles in TCM with FFT. Our results were similar to the pulse theories described in *The Pulse Classic*. Thus, our device may help in the standardization of pulse diagnosis for TCM healers.

Methods

Hypothesis of pulse diagnosis

Pulse diagnosis has been used for thousands of years. However, TCM classics such as *The Pulse Classic* solely describe the applications of pulse diagnosis, but not the rationale of pulse diagnosis. Pulse diagnosis can be nevertheless used to evaluate physical conditions in the human body in TCM practice, but TCM healers do not understand the basic theory behind pulse diagnosis. Up to date, there are no convincing explanations to support pulse diagnosis. In this paper, we will establish our own hypothesis, and discuss our findings based on our hypothesis as follows.