# Design and application of pulse information acquisition and analysis system with dynamic recognition in traditional Chinese medicine


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**Abstract**

**Background:** To design the pulse information which includes the parameter of pulse-position, pulse-number, pulse-shape and pulse-force acquisition and analysis system with function of dynamic recognition, and research the digitalization and visualization of some common cardiovascular mechanism of single pulse.

**Methods**: To use some flexible sensors to catch the radial artery pressure pulse wave and utilize the high frequency B mode ultrasound scanning technology to synchronously obtain the information of radial extension and axial movement, by the way of dynamic images, then the gathered information was analyzed and processed together with ECG. Finally, the pulse information acquisition and analysis system was established which has the features of visualization and dynamic recognition, and it was applied to serve for ten healthy adults.

**Results**: The new system overcome the disadvantage of one-dimensional pulse information acquisition and process method which was common used in current research area of pulse diagnosis in traditional Chinese Medicine, initiated a new way of pulse diagnosis which has the new features of dynamic recognition, two-dimensional information acquisition, multiplex signals combination and deep data mining.

**Conclusions**: The newly developed system could translate the pulse signals into digital, visual and measurable motion information of vessel.



**Keywords:** Visualized pulse information; Radial artery; B mode ultrasound; Traditional Chinese Medicine

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## Background

Pulse diagnosis is an important part of the four diagnosis in traditional Chinese medicine. Before the doctor made judgments of pulse, they mainly used their finger to feel the pulse information of radial space perception when they are in the process of pulse diagnosis. Pulse contained much information in the health of human body [1].

The doctor could understand the pathological changes of internal organs by pulse diagnosis. Traditional medicine theory thinks that man is an organic whole one, pulse is one of them which is the body's physiological reaction. Qi and blood are the material basis for the formation of pulse. Heart is the leader of blood and pulse, so it is the major organ of pulse [2].


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Modern physiology thinks that the pulse is an oscillation between blood and the vessel wall. which caused by a blood heart ejection activity .The wave which came from the oscillation starting from the aortic root spread along the arterial tree to the peripheral vascular[3]. The blood injected into the blood vessels which formed the pulse by the heart beating. The heart beating and the movement of blood in the blood vessels affected the whole body under the coordination of various organs. The cardiovascular system and the blood laid the material foundation for the pulse diagnosis [4].

The development of cardiovascular imaging technology provided a significant methodological platform for the development of pulse diagnosis. The cardiovascular imaging technology made it possible to fully get the activities of heart、vessel, to directly observe the movements and shapes of the pulse position， and also to clearly track the cardiac activity[5].However till today, the major imaging technology applied in the pulse diagnosis area was still based on the pulse graph acquisition, which has big disadvantages and lack of much important pulse information. Actually, the radial artery not only had the activities of the radial expansion and contraction of the blood vessels, but also had the axial movement of the blood flow pulsation cycles, which was concluded in our research results. The axial movement of the blood flow pulsation cycles was a significant sense information which was one part of the pulse diagnosis of traditional Chinese medicine. In our research, we used some flexible sensors to catch the radial artery pressure pulse wave, and utilized the high frequency ultrasound B-type scanning technology to synchronously get the information of the radial extension and the axial movement,in the format of dynamic images. We analyzed such gathered information together with ECG., Finally, we established the pulse information acquisition and analysis system which had the features of visualization and dynamic recognition. This pulse diagnosis method and system were innovative and had great significance for the development of pulse diagnosis.

In our research project, we analyzed the latest development of clinical medical diagnosis and new requirements of studies on pulse diagnosis, we designed a pulse information acquisition and analysis system which had the dynamic recognition feature. This system could get diverse information and present the pulse characteristics from multi-perspective and multi-physiological indicators, it could also do the digitalization and visualization of some common cardiovascular data, creating a healthy human model.

**Materials and methods**

1) Pressure sensors: Pressure sensor could imitate the finger activities acted by Chinese medico, and it was a kind of very important material in area of pulse diagnosis. We chose the bionic flexible sensor, this sensor could correspond the basic characteristics of TCM doctors' fingers , this sensor could obtain the optimal method of pressure according to the height and the pressure changes of the main wave of pulse. At the same time this sensor could draw a vein of fugitive dust properties, but also could realize the detection of the pulse position, the pulse shape, pulse potential properties. In our project, we combined the pulse pressure sensor and the ultrasonic sensor, the bladders worked as a device of sounds coupling, as well as an important equipment to catch the pressure pulse wave of radial artery. During the measurement, three-level pressures were used on each volunteer in order to imitate the activities of pulse diagnosis, and the pulse images were recorded at the same time.

2) Ultrasonic sensor: The probing depth of B-mode ultrasound scanning technology was related to the image resolution and the ultrasonic frequency [6]. It required the use of high frequency ultrasound according to the anatomical characteristics of the radial artery (superficial parts from the epidermis was less than 10 mm) and accuracy requirements needed for the analysis of the radial artery movement (less than 0.5mm).The dedicated A / B-type ultrasonic diagnostic apparatus developed by Chinese Academy of Medical Sciences Institute of Biomedical Engineering ,which frequency was of 10MHz, the vertical resolution was of $\leq$ 0.2mm, the lateral resolution was of $\leq$ 0.4mm; frame rate was of 10 to 16 /s; 256 gray scale, the cursor measurement accuracy was of $\leq$ 0.25mm, basically meet the technical requirements of the ultrasonic pulse signal sensor.

On the basis of this work, we developed the ultrasonic pulse signal sensor to solve several basic problems of visible pulse diagnosis, and we took the following process:

(1)Bladders acoustic coupling: Our group intended to install bladders before the ultrasound probe. This could provide the required acoustic coupling with the reason that the bladders were located just above the measured radial artery, achieved with the measured area of the flexible contacts.

(2)The system also complied with the basic characteristics of the flexible multi-sensor system (Chinese medicine practitioners finger), broke through the currently widely used rigid single sensor mode.

(3)We extracted the radial artery pressure pulse wave by the bladders, which ensured the time synchronization of the pressure pulse wave and the ultrasound vascular image.

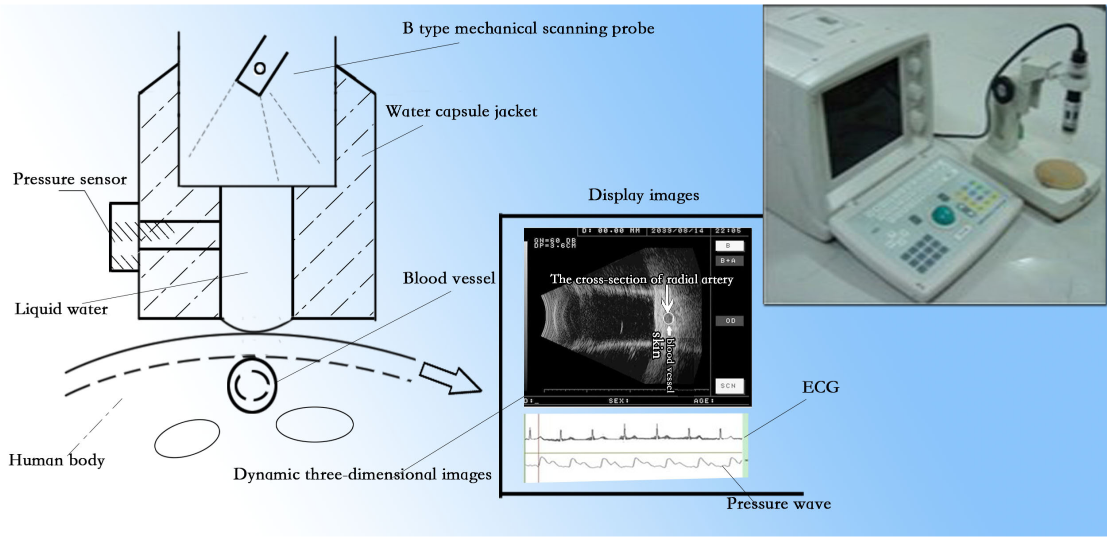
The water sac of ultrasonic sensor became an important device for extraction of the radial artery pressure pulse wave. Using the ultrasonic pulse signal of sensor can take real-time, dynamic and quantitative analysis of traditional Chinese medicine radial movement, it could obtain four properties of pulse of traditional Chinese medicine. According to the present study, no single sensor can complete solve the acquisition work of four properties of pulse of traditional Chinese medicine, What we did can solve the shortage of the single sensor at present.

3) ECG sensor: Some pulse were closely linked to the pathological ECG [7].We could get the important parameters of pulse wave velocity by analyzing the pulse diagram combined with the ECG, which could reveal the vascular elasticity, resistance to blood flow and other medical index [8].

Pulse power fluctuation is mainly composed of the heart, the human body physiology also reveals that the cardiac cycle at different stage has important influence on pulse waveform. Electrocardiogram (ecg) is the familiar diagnostic method for the doctor, some traditional Chinese medicine pulse condition, such as/knot, generation is closely associated with pathological ECG. At the same time combined with electrocardiogram (ECG) and pulse diagram analysis of traditional Chinese medicine, can get pulse conduction velocity, and other important parameters, so as to reveal the clinical vascular elasticity of care, medical indexes such as blood flow resistance.

The device adopted the pulse acquisition technology of integrating the signals of ultrasonic, pressure and ECG. It used the transformation of the domestic Department of ophthalmology B ultrasound, and FSG- 15 type pressure sensor, which could collect standard II ECG signal as a time marker, and synchronously collected pressure, B ultrasound, and ECG signal. The sensing acquisition probe which could collect pulse information combined a bionic flexible pressure sensor, a high-frequency ultrasound probe and liquid water. They were fixed on a water capsule jacket. The water capsule in which the pressure sensor was located lied in front of ultrasound; which achieved a flexible contact between the probe and the object to be measured (radial artery), and provides a necessary acoustic coupling condition for ultrasound [9].(Fig1)

**Figure 1: Pressure B super integrated pulsation information acquisition device**




**Participants' recruitment**

10 healthy young volunteers (5 females,5 males, aged 20-30 years, mean age 24.3 ± 2.6 years) were recruited. Two experienced Chinese medicine practitioners took the volunteers' pulses by the double-blind method and chose the results which were both normal pulses for building the pulse model.

Pulse diagnosis model: (1) The method of floating pulse model: To make the volunteers' limbs immerse into the bucket with 40 ~ 45℃ water , to stop soaking when skin flush, and complained of a slight fever. Two experienced Chinese medicine practitioners took the volunteers' pulses by the double-blind method and chose the results which were both floating pulse for detecting [10].

(2) The method of deep pulse model: To make the volunteers' limbs immerse into the bucket with 4℃ water, to stop 1 minute later. Two experienced Chinese medicine practitioners took the volunteers' pulses by the double-blind method and chose the results which were both deep pulse for detecting [10].

(3)The method of slippery pulse model: To make the volunteers drink 100 grams liquor, after 15 minutes, two experienced Chinese medicine practitioners took the volunteers' pulses by the double-blind method and chose the results which were both slippery pulse for detecting [11].

(4)The method of veins hollow pulse model: To make the volunteers do the Valsalva's test, two experienced Chinese medicine practitioners took the volunteers' pulses by the double-blind method and chose the results which were both veins hollow pulse for detecting [12].

### Detection indicators

Regarding the detection of a normal pulse, we detected the indicators as follows:

(1) Homax: Vasomotor cycle, the blood vessel cross-sectional view of the axial movement to the maximum distance from skin.

(2) Homin: Vasomotor cycle, the blood vessel cross-sectional view of the axial movement to the minimum distance from skin.

(3) T: Vasomotor cycle to reach the maximum area and back to the time between the minimum area.

(4) R—Amax: The time from the ECG R-wave to the Amax

(5) amax: The maximum value of the long diameter of vasodilatation.

(6) amin: The minimum value of the long diameter of vasoconstriction.

(7) bmax: The maximum value of the short diameter of vasodilatation.

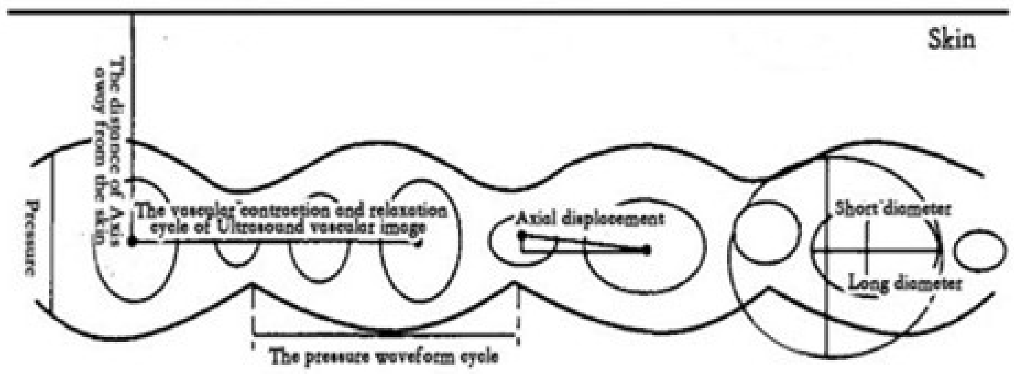
(8) bmin: The minimum value of the short diameter of vasoconstriction.

(9) Amax: Vasodilatation to the maximum cross-sectional area.

(10) Amin: Vasoconstriction to the minimum cross-sectional area (Figure 2)

(11)：Axial displacement

**Figure 2: Detection of indicator diagram**

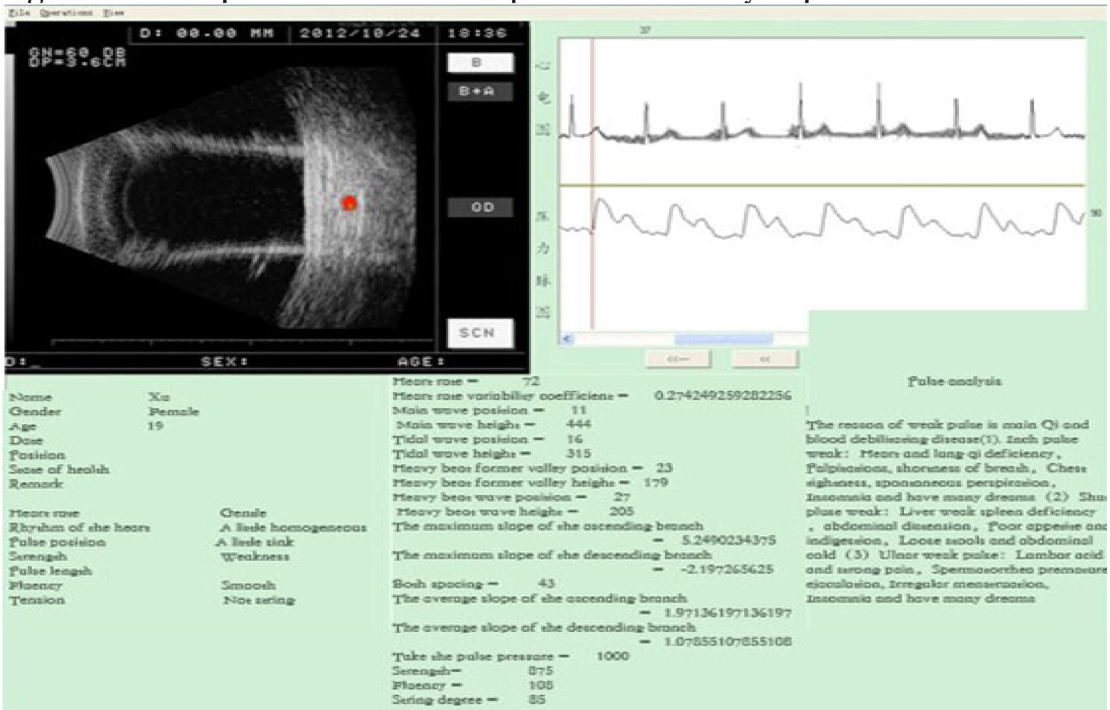



We chose length parameter, the time parameters, area parameters in order to calculate and obtain the 'position, number, shape, and the potential' properties in pulse diagnosis of TCM. Specific as follows: (1) Pulse position parameter: amax、amin、bmax、bmin、Ho max、Homin、Axial displacement；(2) Pulse number parameter: T、R-Amax; (3) Pulse shape parameter: am ax、amin、bmax、bmin、Amax、Amin；(4) Pulse potential parameter: (Amax-Amin)/T、T、(Amax-Amin)/Amax、Amax。

### Operation

1) Information collection: Setting the parameter values after the subjects settleed down, and feeling the pulse of left hand then they are hooked up to ECG II. It required special operation. We must adjust coupling probes before them fully attached on the hands. If the white mark on one side of the probe, it meaned that transverse section of radial artery could be scanned; if the white mark on one side of the probe, it meaned that longitudinal section of radial artery be scanned. Under ultrasound coupling guidance by startup acquisition system of pulse and regulated pressure, researchers could observe pulse picture and the change of radial artery motion in real-time. When finding the optimum pulse pressure and various indexes were relatively stable, we started to record the pressure pulse picture, standard II leading ECG and ultrasound image of radial artery[13].(Figure 3)

**Figure 3: Visual pulse information acquisition and analysis process**




2) Information analysis: We detected the volunteers' ECG while we detected the pulse. marked by the R wave of the ECG, cardiac cycle was selected to determine the serial number of images collected within the cardiac cycle by B-probe, generally for 10 consecutive ultrasound images, Apply Image Pro plus5.0 to analyze the ultrasound image index [14].We selected 5 cardiac cycles with the parameters vary depending on the variations of the average. (Figure 4, 5, 6)

**Figure 4: ECG, pulse pressure diagram**

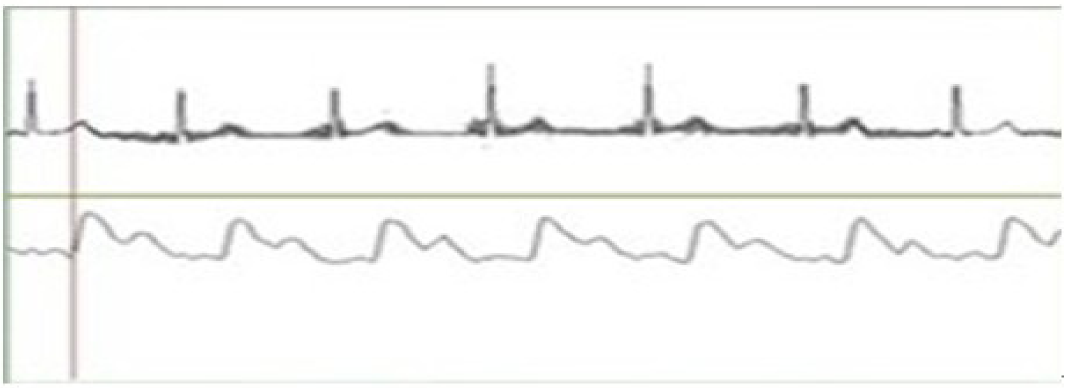


**Figure 5: B mode ultrasound images in a cardiac cycle**

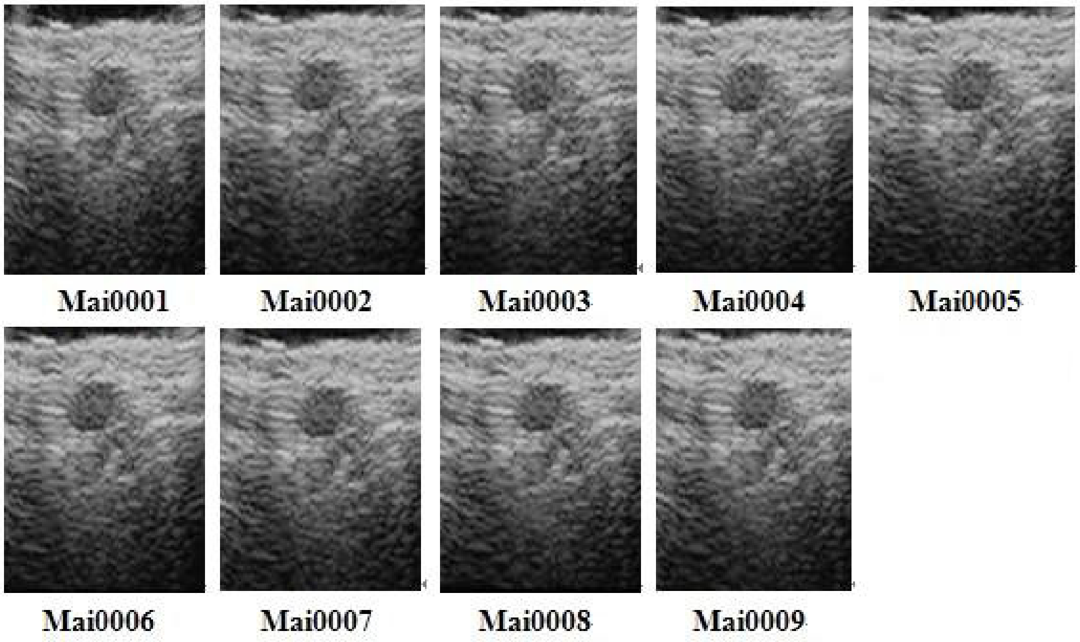
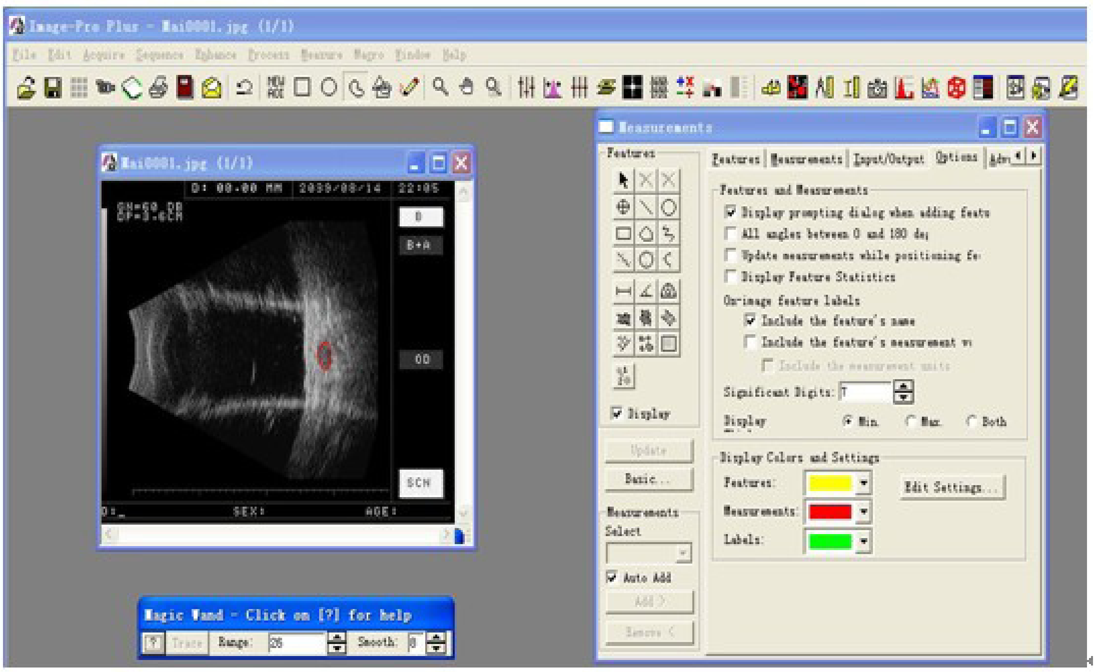



**Figure 6: Dynamic identification pulse information analysis process**




## Statistical Analysis

SPSS17.0 statistical software was used for statistical analysis. The measurement data which was taken by T test was shown by $\overline{c} \pm s$. The difference has statistical significance when P< 0.05, while it has significant statistical significance when P< 0.01.

## Results

1) Compared with the smooth venation, the radial artery of floating pulse expanded obviously, which the cross section diameter and area was significantly increased; axial displacement increases. The vascular diameter, area and the axial displacement decrease when it was deep pulse. All of the above changes were statistically significant (P<0.05 or P<0.01)

2) The radial artery vascular expanded when it was slippery pulse and the diameter, vascular axis displacement were all increased, All of the above changes were statistically significant (P <0.05 or P <0.01).

3). The radial artery of hollow pulse expanded with the cross-sectional diameter, area ,axial displacement, pulse rate and fluency were all increased while the strength decreased All of the above changes were statistically significant (P <0.05 or P <0.01).(Table1、2，Figure 7)

Table1： The radial artery diameter changes before and after modeling ($\bar{c} \pm s$； n=10)

| pulse | amax（mm） | bmax（mm） | Amax（mm²） | Amin（mm²） | (Amax-Amin)/T | Axial-displacement(mm) |
|---|---|---|---|---|---|---|
| flat | 2.95±0.24 | 2.25±0.36 | 6.88±1.42 | 4.35±1.28 | 0.02±0.01 | 1.81±0.44 |
| float | 4.0±0.23* | 3.2±0.13* | 8.9±0.83* | 5.48±0.78 | 0.03±0.01 | 2.31±0.23** |
| flat | 2.91±0.26 | 2.27±0.27 | 6.74±1.40 | 4.43±1.31 | 0.02±0.01 | 1.80±0.28 |
| deep | 2.38±0.19* | 1.85±0.27* | 5.06±0.99** | 3.96±1.01* | 0.02±0.01 | 1.27±0.25* |
| flat | 2.93±0.22 | 2.24±0.30 | 6.73±1.22 | 4.36±1.29 | 0.02±0.01 | 1.81±0.32 |
| slip | 3.26±0.15** | 1.96±0.13* | 6.60±0.62 | 4.68±0.31 | 0.02±0.01 | 2.29±0.25* |
| flat | 2.93±0.27 | 2.35±0.31 | 7.05±1.32 | 5.04±1.21 | 0.03±0.01 | 1.80±0.29 |
| vein | 3.89±0.11** | 3.78±0.24** | 14.71±0.15** | 5.45±0.28* | 0.11±0.01* | 2.39±0.31** |

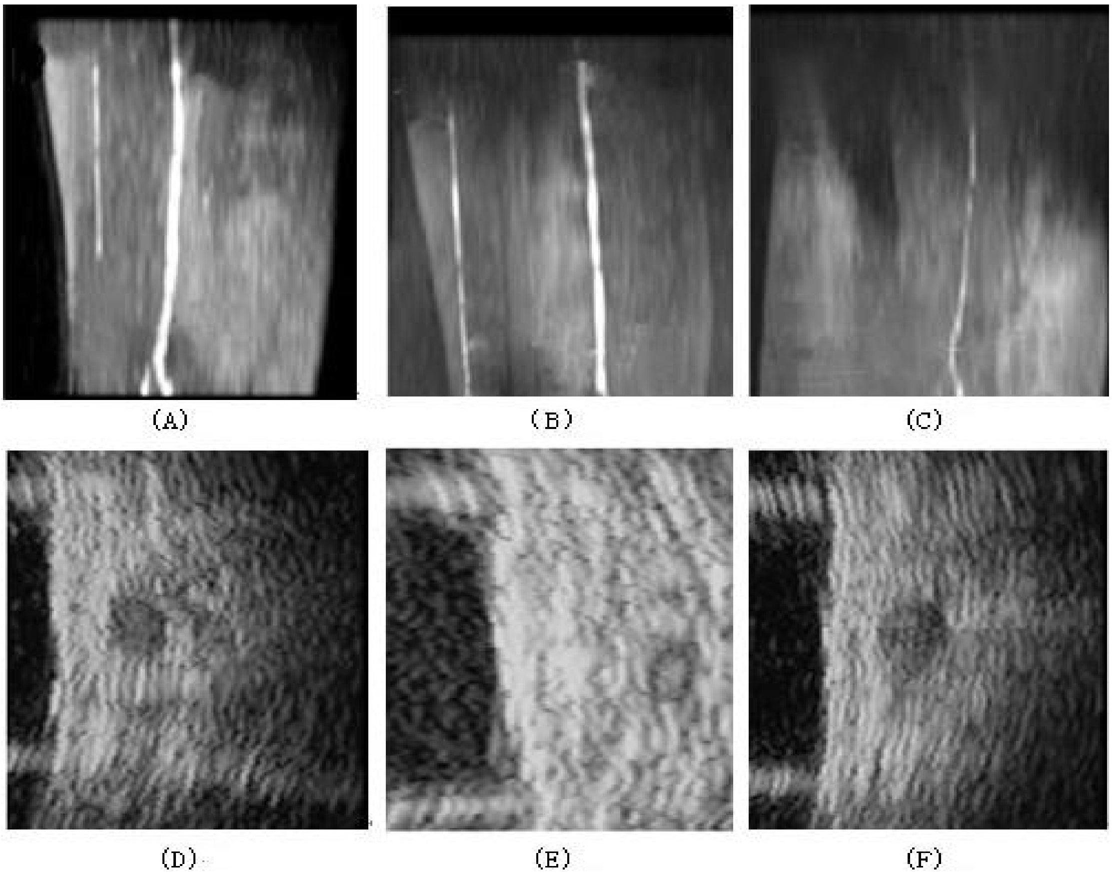
Compared with the flat pulse * P <0.05, ** P <0.01

Table2：Time index analysis of the radial artery ($\bar{c} \pm s$； n=10)

| pulse | T(beat/min) | R-Amax(ms) |
|---|---|---|
| flat | 75.36±4.83 | 370.35±39.43 |
| float | 77.08±4.12 | 372.32±22.21 |
| flat | 75.65±4.87 | 372.20±39.03 |
| deep | 76.32±3.02 | 368.13±35.12 |
| flat | 76.95±7.80 | 371.27±39.30 |
| slip | 87.27±3.02** | 320.00±30.48* |
| flat | 72.99±5.87 | 370.39±37.40 |
| vein | 85.36±2.72* | 353.00±32.45 |

Compared with the flat pulse * P <0.05, ** P <0.01

**Figure 7: Radial artery motion state of ultrasonic imaging**




A: Radial artery slit image of floating pulse model
B: Radial artery slit image of flat pulse
C: Radial artery slit image of deep pulse model
D: Radial artery transverse image of flat pulse
E: Radial artery transverse image of slippery pulse
F: Radial artery transverse image of vein pulse

## Discussion

Based on the current research achievement and conclusion, it was impossible to completely present the characteristics of 'position, number, shape, and the potential'in pulse diagnosis of TCM by only one kind of sensor and one-dimensional physical quantity. It is very necessary to gather the pulse information by applying multi-sensors which can present diverse information from different points, such diverse information can be processed by computer technology and the most valuable information can be extracted for further analysis. The acquisition and analysis system gives an optimized pulse diagnosis of TCM solution which can comprehensively present the characteristics of 'position, number, shape, and the potential',The property of position： To describe the superficial and deep of the pulse; The property of number： Mainly refers to the frequency of the pulse and rhythm; The property of shape and potential： Mainly refers to the pulse wave form and trend of the state.[15]。Based on the research results of detecting radial artery by Doppler ultrasound， we used B-mode ultrasound probe and multi-channel pressure sensors to gather the information of the radial artery. This method could convert the pulsation information into images by using the dynamic imaging analysis technology. It overtook the one-dimensional information gather method which was common used in current pulse diagnosis. As well, this method can recover the dynamic images which include three-dimensional information of the changes in the caliber of the radial artery, displacement and axial movement. Also, the system can record the real-time imaging information and obtain the simplified characteristics of "'position, number, shape, and the potential' with the software processing.

Doppler ultrasonic technique can detect the size and variation of pipe diameter of vascular lumen. At the same time, we can see the center movement of vessel and pulsation of the blood flow by ultrasound images because the movement of vascular corresponds to the change of the blood flow [16]. As a result, Doppler blood flow imaging that used for radial motion measurement was the preferred method. This study used ultrasound may special for probe of superficial vessel, gain margin, multi-stage adjustable freeze frame precision and measurement of radial artery. It had high lateral and on-axial resolution and provides high frame rate.

We coupled the bionic flexible pressure probe sensor with B type ultrasonic scanning probe, which could achieve a flexible contact between the probe and the measured object and provide the necessary acoustic coupling conditions. The ultrasound probe, bladders and pressure sensors were fixed on the bladders jacket; the ultrasound probe was preceded and the bladders sensor was located inside the pressure bladders side. The device was placed above the radial artery when we took the pulse; the ultrasonic probe could mediate through the water capsule and scan the vascular motion and the fluctuations of blood vessels. The changes of echo intensity in the blood vessels were observed during the observation of the vascular movement [17-19], which could assist in the innovative technology of the integration of the pressure ultrasonic and the pulse signal.

This system could track the state of vascular pulsing, by continually getting the B mode ultrasound images with a sample rate of twelve frames per second. It could get a series of consecutive images within one cardiac cycle, and then visually observed the specific law of vascular pulsing [20]. After process and measure the gathered images [21], the system could get the movement of cross section of a specific vascular within one cardiac cycle, and recovered the specific pulse condition.

It is shown from the research results that: (1) Under the normal pressure, the radial artery was nearly circular cross-section echo, the edge was regular, clear, and the transparent sound was good, cavity wall low echo area presents periodic cyclical systolic and diastolic activities. Longitudinal section was long echo, the edge was neat and clear, and the sound transmission was good, the cavity wall low echo area presented pulsatile changes in systolic and diastolic.;(2) After the pressure was applied, transverse vascular was oval, spindle, and the pressure was bigger, the length diameter ratio was bigger, and could occur linear change even in the presence of contracts.

The developed system pulse information acquisition and analysis system had the feature of dynamic recognition, and could continually track the artery activities within one cardiac cycle. It could obtain the vertical sector two-dimensional ultrasonic images by sector scan, it could used to observe the cross section and the axial movement of the detected pulse by the axial and transverse scanning. This system has many advanced characteristics, such as clear imaging, no radiation hazards, fast imaging rate, real-time scan, direct and dynamic track on vascular pulsation, accurate measurement by digitalization technology, flexibility, and low cost. This system can obtain the source images which can be used for imaging simulation and three-dimension reconstruction [22], it can greatly improve the reconstruction quality of the vascular mechanism of pulse forming, and is meaningful to be applied to the fields of the pulse diagnosis research and teaching. In conclusion, the developed system has many advanced characteristics which can meet the visualization and digitalization requirements of pulse information, it is very necessary and significant to be popularized to pulse research and other clinical areas。

By the way, although we have made great progress, but also need to have great progress, we still need some improvement. At first, It is necessary to use different sensors to collect different quantities of parts of pulse (such as pressure, impedance blood flow, volume pulse wave and ECG), when taking the pulse. Secondly, It is important to make a comprehensive study on common pulse of Chinese medicine combined with modern information analysis technology. At last, It is urgent to form a new device, and to promote modernization of traditional Chinese medicine.

List of abbreviations

ECG: Electrocardiogram; TCM: Traditional of Chinese medicine

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**Authors' contributions**

YXZ, ZQW, LHY conceived, designed and implemented the device, ZZG, NSD acquired the data. NX supervised the project and research group, and contributed to valuable discussions and suggestions. ZJ drafted the manuscript All authors read and approved the final manuscript.

**Competing interests**

The authors declare that they have no competing interests.

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