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THREE-DIMENSIONAL MOTION OF THE RADIAL ARTERY AND THE SPATIALITY, RHYTHMICITY, FORMABILITY AND INTENSITY OF TCM PULSE DIAGNOSIS

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Abstract

Traditional Chinese medicine (TCM) pulse diagnosis can reflect the condition of human bodies. 44 young healthy human beings were involved in the investigation of the relationship between the three dimensional motion of the radial artery and the spatiality, rhythmicity, formability and intensity of TCM pulse diagnosis in TCM pulse diagnostics. The color Doppler vascular imaging, the self-designed cardioelectric phasic marking and non-pressure arm bath-tube were used in the study. **B**oth the radial artery and other arm superficial arteries had three forms of motion, namely diametrical motion, axial motion and the displacement of the axial center. The three forms of motion changed periodically, which was identical with that found in pulsation. The displacement of the vascular axial center was a three-dimensional message of the overall vascular revolving motion observed on a two-e level. Systematically studying the rules of vascular motion and the relationship between the rules of vascular motion and the spatiality, rhythmicity, formability and intensity of TCM pulse patterns has great significance in revealing the specificity of the vascular motion and explaining the mechanisms in the formation of TCM pulse diagnosis. This research could make TCM pulse diagnosis more understandable.

Key words: Displacement of the Vascular Axial Center; Color Doppler Ultrasonic Imaging; Spatiality, Rhythmicity, Formability and Intensity of TCM Pulse Diagnosis.

Introduction

Pulse diagnosis, as one of the foundations of Chinese medicine, the practice of taking the pulse at the wrist on the radial artery, has a long history. In Chinese medicine the pulse is felt on both the right and the left, with three different positions. The spatiality, rhythmicity, formability and intensity are essential forms of pulse diagnosis.

Each pulse position reveals the condition of different organs. The first position, closest to the crease of the wrist, offers information about the heart and lung. The second one, just behind this, offers information about the liver, gallbladder, stomach, spleen, pancreas and diseases in the area between the diaphragm and belly button. The third one offers information about kidneys, bladder, reproductive organs and intestines.

Even the tension in the vessel and the thickness of the blood in it can reveal essential information about a person's health. The practice of taking the pulse and using it as a tool to glean information about the body as a whole is based on a concept referred to as "the part representing the whole." This concept is mirrored in Chinese medicine with facial diagnosis, eye diagnosis, and tongue diagnosis, three similarly useful tools (Buell, PD., 2011).

Affected by the blood flow of pulsative arteries, the motion of the radial artery and other superficial arteries of the arm can shape different forms, such as radial motion, axial motion and displacement of the axial center (Jeon, et. al., 2011; Xiaotian Feng, 2009). Due to the limitation of detecting techniques, most of the conclusions from researches concerning this aspect are only inferences made from experimental simulative data and lack of evidences from the investigation of healthy human beings. In this study, we systematically investigated, from the angles of the changes in local vascular function and

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general cardiovascular function, the physiological basis and pathological changes in human TCM pulse diagnostic models and clinical cases with some typical diseased pulses, from which we had already achieved some initial results (Tang, et al., 2012; Xin Niu, 2012; Tibballs, and Weeranatna, 2010). The color Doppler imaging, a self-designed vascular motion detecting method (for detecting the motion of radial artery at *cunkou* and other superficial arteries), and some techniques of topographical autopsy were used in our study. In order to illustrate the mechanisms of the formation of TCM pulse patterns, we briefly report, in this paper, the methods for detecting the vascular motion of arm superficial arteries and the relationship between the vascular three-dimensional motion and the properties of spatiality, rhythmicity, formability and intensity of TCM pulse diagnosis.

Materials and Methods

Human Experimental Subjects and Experimental Equipments

Human Experimental Subjects

44 healthy young human experimental subjects (24 males and 20 females; man age, 22.8±6.0 years) were chosen according to the routine procedure of physiological tests for establishing the TCM pulse diagnostic models characterized by prominent changes in one of the four properties of spatiality, rhythmicity, formability and intensity of TCM pulse diagnosis. The 44 healthy young human experimental subjects were selected from the physical examination center in Dongzhimen Hospital of Beijing University of Chinese Medicine.

Inclusion criteria: The ratio of male and female about 1:1, 17-29 years old, body mass index (BMI) from 19 to 24, no smoking, no drinking, in healthy condition, no chronic or acute diseases and with no abnormal clinical findings in blood chemistry, electrocardiogram and B ultrasonic of abdomen. The informed consents were signed.

Exclusion criteria: Pregnancy or lactating female, menstrual period female and spiritual or disabled individuals.

The final number were 44 people, including 18 college students, 13 unemployed people, 6 company staff and 7 security personnel. The mean body mass index (BMI) was 21.5 ±2.1.

All the related detections were made 10 minutes after the participants came to the center.

The Detailed Data about the 44 Healthy Young Subjects are shown in Table 1 and Table 2.

Table 1 Detailed Data about the 44 Healthy Young Subjects

	Male	Female
Amount	24	20
Average Age	23.08	22.40
Average BMI	21.67	21.30

Equipments Used in the Experiment

An American HP company-made equipment, SONOS-1000 Color Ultrasonic Doppler Blood Flow Imaging Device (along with its multi-channel linear array scanning detector) was used in the experiment. The emission frequency of the equipment is 7.5 mHz with a detecting range of 3.5 cm x 1.5 cm, which is especially suitable for detecting superficial arteries. The gain, range and precision of frame holding of the equipment all can be adjusted to different levels. The equipment possesses high axial resolution and lateral resolution (at the level of millimeter) and also produces a rather high frame frequency.

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No.	Gender	Age	BMI	Smoking	Drinking	Chronic Disease	Acute Disease
1	Male	22	21.3	No	No	No	No
2	Male	24	19.8	No	No	No	No
3	Male	25	20.1	No	No	No	No
4	Male	21	21.3	No	No	No	No
5	Male	19	22.1	No	No	No	No
6	Male	26	20.3	No	No	No	No
7	Male	22	19.9	No	No	No	No
8	Male	25	22.1	No	No	No	No
9	Male	27	20.6	No	No	No	No
10	Male	18	21.5	No	No	No	No
11	Male	22	22.6	No	No	No	No
12	Male	23	22.4	No	No	No	No
13	Male	25	23.5	No	No	No	No
14	Male	20	22.8	No	No	No	No
15	Male	29	23.6	No	No	No	No
16	Male	24	23.1	No	No	No	No
17	Male	22	20.5	No	No	No	No
18	Male	26	22.9	No	No	No	No
19	Male	25	21.8	No	No	No	No
20	Male	19	22.5	No	No	No	No
21	Male	21	20.7	No	No	No	No
22	Male	23	20.1	No	No	No	No
23	Male	24	21.5	No	No	No	No
24	Male	22	23.0	No	No	No	No
25	Female	24	20.2	No	No	No	No
26	Female	23	22.3	No	No	No	No
27	Female	17	20.5	No	No	No	No
28	Female	22	21.6	No	No	No	No
29	Female	24	22.5	No	No	No	No
30	Female	26	19.4	No	No	No	No
31	Female	24	20.9	No	No	No	No
32	Female	28	20.5	No	No	No	No
33	Female	20	21.6	No	No	No	No
34	Female	22	20.6	No	No	No	No
35	Female	19	21.4	No	No	No	No
36	Female	18	20.1	No	No	No	No
37	Female	22	22.5	No	No	No	No
38	Female	21	23.6	No	No	No	No
39	Female	23	22.5	No	No	No	No
40	Female	24	20.6	No	No	No	No
41	Female	20	21.8	No	No	No	No
42	Female	26	20.9	No	No	No	No
43	Female	24	20.1	No	No	No	No
44	Female	21	22.4	No	No	No	No
Amount	44	22.8±6.0	21.5±2.1	0	0	0	0

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Table 2 Detailed Data about the 44 Healthy Young Subjects

Self-designed Device Used in the Experiment

A self-designed device for detecting arm superficial arteries, namely non-pressure arm bath-tube(Figure1),was used in the experiment. The wall of the tube is made of hard acryl glass. During the experiment, the tube was filled with an appropriate amount of water in order to avoid the influence of the direct pressure of the ultrasonic detector on the vascular motion (Congyuan Fu et al., 2011)

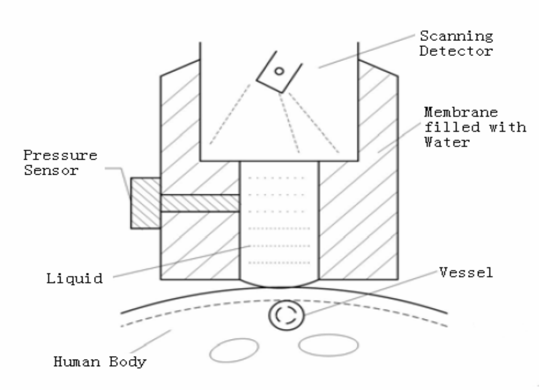

Figure 1: Non-pressure Arm Bath-tube

Detecting Methods

The human experimental subjects were told to take a sitting position or a lying position; their arms were placed in the non-pressure arm bath-tube after the equipment was on; and then, it was adjusted to the best state of motion.

Detection of the Longitudinal Section of Blood Vessels

The frame freezing function of the equipment was used to fix the images and the different phases of ECG were taken as the time marks; and then, the inner diameter of the blood vessels and the diameter of the blood flow column were measured by moving the orbital globe (the two values would be equal when a suitable mode of display was taken). The net value of the vascular longitudinal extension was calculated according to the formula, $\Delta L=2 [(1/2)^2 + \Delta\Phi^2]^{1/2} - L$ (Figure 2)

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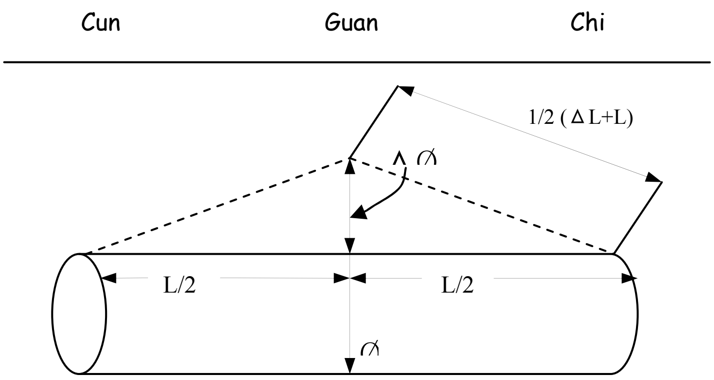

Figure 2: Measurement of the Longitudinal Extension

Detection of the Transection of Blood Vessels.

The cross-section perpendicular to the long axis of the blood vessels was taken by moving the vascular detector; after the cross-section for observing was decided, the angle formed by the sound beam and the blood flow was adjusted in order to obtain satisfied images; and then, the area, the long axis(a) and the short axis(b) of the cross-section of the blood vessels, and the thickness(h) of the peripheral tissues of the blood vessels were measured; and the extension rate and ellipticity of the blood vessels were calculated.

Detection of the Displacement of the Vascular Axial Center

Firstly, the section for observation, axial center and the direction of the displacement of the axial center were decided, and then, the images which were saved in the memory when the frame was frozen were reexamined in order to find the minimum transection of the blood vessels; the cross point of the long and minor axes of a blood vessel at the center of the blood vessel was taken as the axial center (0,0), and the horizontal line crossing the axial center was taken as x-axis and the perpendicular line, as y-axis. The peripheral transection was observed from the inner to outside, and the axial center could be shifted to the left (ulnar side), right (radial side), upper (epidermis), or lower (radius); a reverse direction was taken when it was necessary to observe the ulnar-radial axial center displacement in the other wrist of a subject. The direction was determined according to the usual practice of anatomy in the observation of the peripheral transection of other superficial arteries.

The corresponding time behind the R wave on ECG was t_0 when the area of a blood vessel was smallest according to the corresponding relationship between cardiac cycle, ECG and Doppler frequency spectrum of the blood flow; then, (0,0) was taken as the position of the axial center of a blood vessel corresponding to t_0 (Figure 3).

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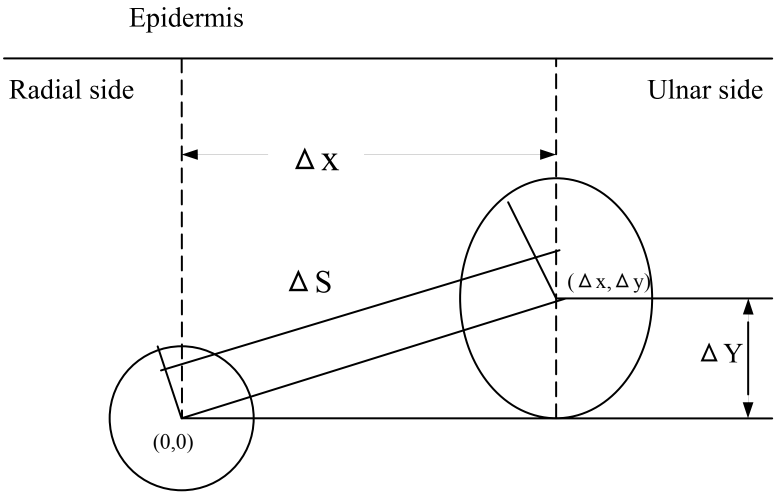

Figure 3: Measurement of the Displacement of the Vascular Axial Center

The magnitude of the displacement of the axial center was calculated by $\Delta s = (\Delta x^2 + \Delta y^2)^{1/2}$ at time t_i when the axial center shifted to the position ($\Delta x + \Delta y$)

In each cardiac cycle, 3 – 5 points of time were chosen randomly and the positions of different axial centers were detected according to the different values of t_i. When the number of images was limited, the positions of the axial center at different points of time could be rearranged according to the sequence of time behind the R wave after the maximum and the minimum values of positions of the axial center were detected in 3 – 5 cardiac cycles, and the locus of the motion of the axial center was the curve linking the values of different positions of the axial center. Thus, it could be seen that the displacement of the axial center was a three-dimensional criterion shown on a two-dimensional level, including some information such as time, spatial position and the changes in the diameter of a blood vessels (Figure 4 , Figure 5 and Figure 6).

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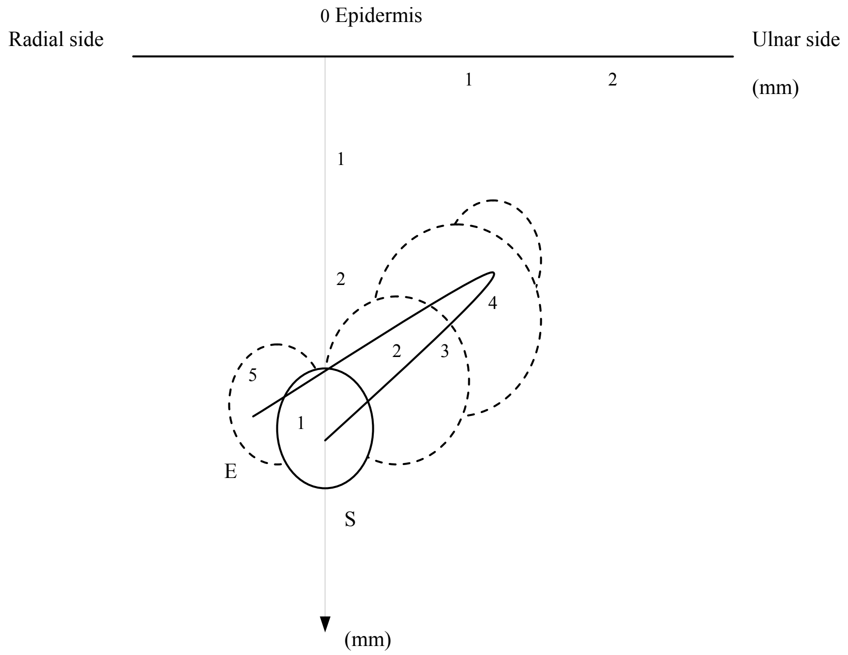

Figure 4: The Vascular Transection of the Short Axis and the Positions of The Vascular Axial Center

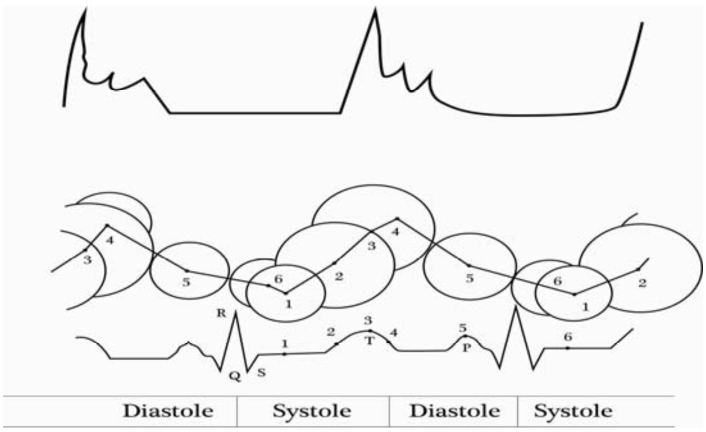

Figure 5: Correspondence between the Cardiac Cycle, Cardioelectric, Time Phase,Changes in Vascular Diameter, Displacement of Vascular Axial Center and Doppler Frequency Spectrum

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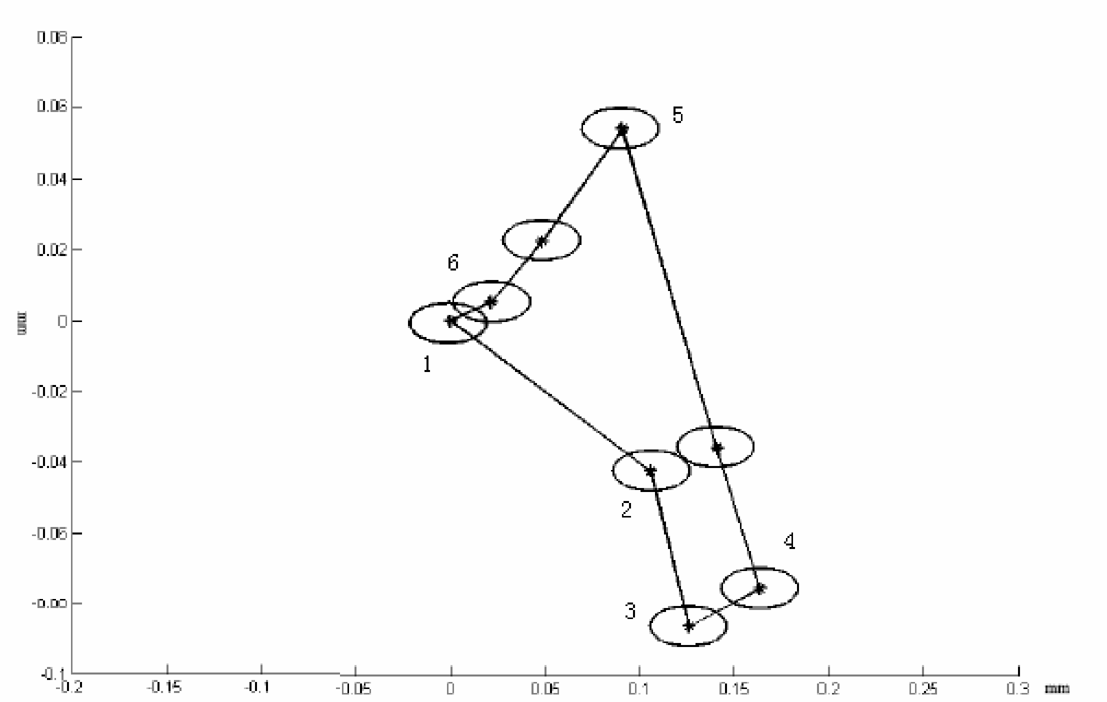

Figure 6: Correspondence between the Cardiac Cycle, Cardioelectric, Time Phase,Changes in Vascular Diameter, Displacement of Vascular Axial Center and Doppler Frequency Spectrum

Results and Discussion

About the Three-dimensional Motion of Blood vessels

We found that about the 44 healthy young human beings subjects, when in the state of expansion and contraction, the increment of the inner diameter of the radial artery was 1.34±0.27 mm and the area of the transaction of the radial artery, 5.90±2.16 mm. The value of a/b was approximately equal to 1 in the state of expansion and it would increase in the state of contraction, which suggests that the degree of the engorgement of the radial artery was different in different state of motion. We also found, as far as the values of the inner diameter and the area of the transaction of the radial artery were concerned, that there was a significant difference between the male and the female ($P<0.01$).

Our observation of both longitudinal section and transaction of the radial artery revealed a periodical change in the thickness of the vascular peripheral tissues along with the expansion and contraction of the radial artery. Topographical autopsy showed that at the radial artery, the value of the thickness from the surface of the bone to the epidermis was three times as large as that of the vascular diameter. However, the values of the diameter of the radial artery measured in the subjects were larger than those of the thickness of the peripheral tissues of the radial artery. Furthermore, as far as the ratio of the value of the diameter and that of the thickness were concerned, there was a significant difference between the contraction and expansion of the radial artery, which implied that the changes in the tension of the radial artery were large in the subjects. This difference suggested that the changes in the thickness of the vascular peripheral tissues were not only caused by passive vascular expansion, but were also induced by another possible mechanism.

Our detection of some superficial arteries (such as the radial, brachial, axillary, and subclavian artery) showed that significant displacements of the vascular axial center occurred in all of these arteries. It was found that at the radial artery, the form of the displacement was a periodical revolving motion along with the pulsation of arteries, mainly counterclockwise revolving motion in our present study. At the brachial artery (on the elbow), the axial center shifted mainly upward. At the axillary artery, the axial center shifted mainly downward. We conjectured that the entire scope of the motion of an artery and the form of the displacement of the vascular axial center were related to the anatomical site of the artery. The existence of the three-dimensional revolving motion of the arteries manifested by their displacements of the vascular axial center was associated with cardiac ejection of blood and cardiac torsive motion, the agitated vibration of large arteries, transmission of pulse waves, restraint of the vascular peripheral tissues, and the changes in the active tension of vascular smooth muscles. All these points were the biophysical factors which caused the various changes in TCM pulse patterns.

Along with the detection of the form of motion of the above-mentioned arteries, we also detected the frequency spectra of the blood flow for these arteries. The results showed that the diametrical expansion and the axial extension of the vascular motion reached their maximum values when the velocity and acceleration of the blood flow were at their maximum values (or a little bit after that), which was in accordance with MacDonald's theory of the velocity of the blood flow expanding blood vessels, namely the value of the diametrical expansion of a blood vessel became very small when the value of the velocity of the blood flowed decreases or becomes negative.

It could be seen from the results and analyzes mentioned above that the form of the motion of the superficial arteries, for example the radial artery, was one kind of three-dimensional form, consisting of diametrical expansion and contraction, axial extension and contraction, and the displacement of the axial center. In our present study, two new points had been brought forth, using the criteria of the displacement of the vascular axial center to reflect the overall motion of blood vessels and using the self-designed electrocardial phasic marking method and non-pressure arm bath-tube together with the color Doppler vascular imaging to investigate the various forms of the motion of blood vessels. These two new points were of great significance in studying the mechanisms of the formation of TCM pulse diagnosis, the specificity of blood vessels, and the regularity of vascular motion.

Research on the Mechanisms of the Formation of the Spatiality, Rhythmicity, Formability, and Intensity of TCM Pulse Diagnosis.

Our previous study on the main changes in the basic properties of the TCM pulse diagnosis, namely the spatiality, rhythmicity, formability and intensity, revealed that there was a close relationship between the form of the three-dimensional motion of the radial artery at the cunkun and the formation of the basic properties of TCM pulse diagnosis and the changes in them(Xin Niu et al., 2010). We thought that the various complicated TCM pulse diagnosis were formed by the combination of the various forms of motion (diametrical motion, axial motion, displacement of the axial center and axial revolving motion) of the blood vessel and the changes in the combination, and the changes in the parameters of the pressure, volume, impedance and blood flow relating to the combination. We have discovered, in our present study, the regularity of changes in TCM pulse diagnosis based on the three-dimensional motion of the blood vessel.

(1) When shallow and deep pulse diagnosis appears, the diametrical expansion, displacement of the axial center and the thickness of the peripheral tissues of the radial artery change to some degrees (Xin Niu et al.,2011)(Table 3). (2) The size of the pulse body is related to the magnitude of the vascular diameter and the displacement of the vascular axial center. When the pulse body is long, the scope of pulsation and the degree of the axial extension of the radial artery at the cun, guan, and chi are larger. When the pulse body is short, the extent of pulsation and the degree of the axial extension, smaller. When the taut pulse appears, the scope of vascular pulsation and the degree of the axial extension are rather large (Table 4). (3)When the solid pulse appears, the rate of diametrical expansion, degree of the axial extension, scope of the pulsation of the vascular wall and the degree of the displacement of the vascular axial center of the radial artery at the cunkou are rather large. When the hollow pulse appears, the rate of diametrical expansion and the degree of the vascular ellipticity of the radial artery at cunkou are rather smaller, but the displacement of the vascular axial center may be smaller or larger (Table 5, Figures 7 and 8).

Table 3: Influence of Different Spatiality on the Max, Min and Changing Rate of Distance between Radial Section Axis and Skin （X±s）

Group	N(Person)	MAX(mm)	MIN(mm)	Rate of Change(mm/ms)
Shallow Pulse	12	2.985±0.519	2.952±0.523	8.124±1.058
General Pulse	20	3.939±0.684*	3.864±0.681*	7.476±0.991
Deep Pulse	12	4.731±0.376**	4.572±0.329**	1.957±0.376**▲▲

Note：

*， Comparison with the shallow group， $P<0.05$； **， Comparison with the shallow group， $P<0.01$；

▲， Comparison with the general group， $P<0.05$； ▲▲， Comparison with the general group， $P<0.01$；

Table 4: Influence of Different Sizes on the Pulse Wave Velocity(PWV), Radial Motion Cycle Power(CP) and Length Parameter(LP) （X±s）

Group	N(Person)	PWV （m/s）	CP （Hz×db）	LP （Hz·db·m/s）
Longer Pulse	14	7.730±0.417▲▲	1.870±0.087▲▲	14.456±1.064▲▲
General Pulse	26	6.265±0.391**	1.689±0.132**	10.587±1.097**
Short Pulse	14	6.433±0.489**	1.333±0.080**▲▲	8.581±0.926**▲▲

Note：Comparison with the longer group， * $P<0.05$； ** $P<0.01$；

Comparison with the general group， ▲ $P<0.05$； ▲▲ $P<0.01$；

Table 5: Influence of Different Intensity on the Area of Radial Section Axis Motion（X±s）

Group	N(Person)	Area （mm2）
Solid Pulse	12	0.318±0.216▲▲
General Pulse	18	0.213±0.187**
Hollow Pulse	14	0.104±0.055**▲▲

Note：Comparison with the solid group， * $P<0.05$； ** $P<0.01$；

Comparison with the general group， ▲ $P<0.05$； ▲▲ $P<0.01$；

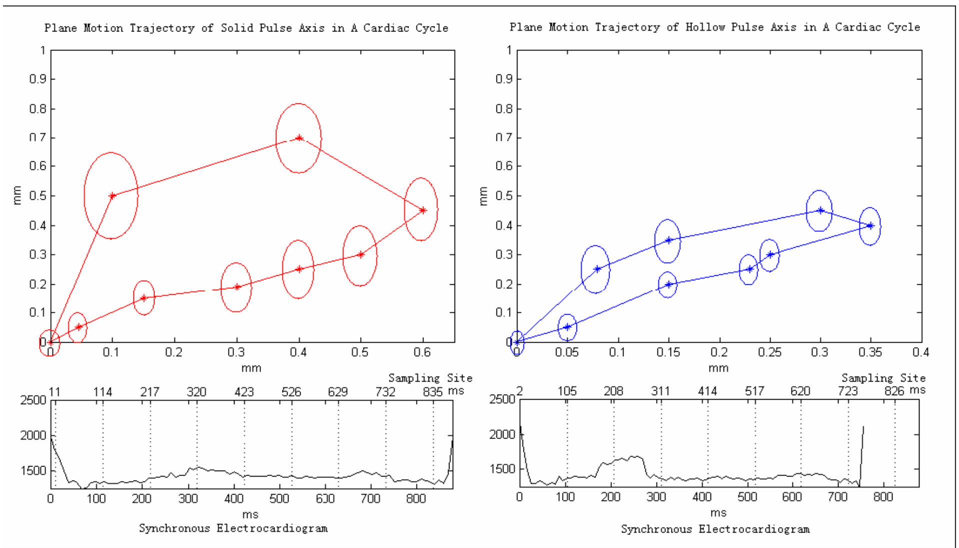

Figure 7: Plane Motion Trajectory of Solid Pulse and Hollow Pulse Axis in A Cardiac Cycle

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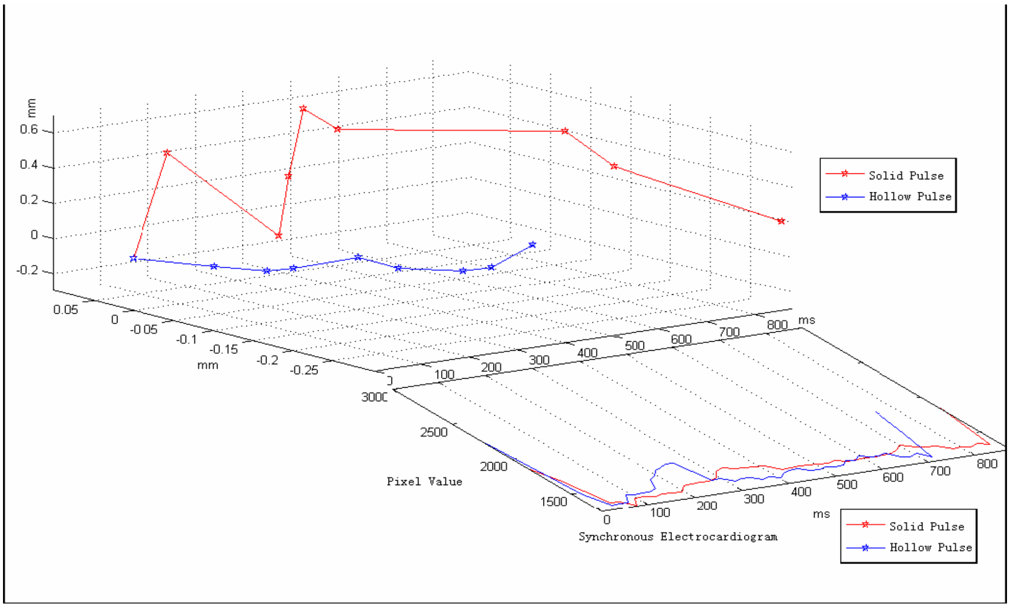

Figure 8: Three-dimensional Trace of Solid Pulse and Hollow Pulse Axis in A Cardiac Cycle

At the same time, three chief doctors of traditional Chinese medicine were invited to diagnose these 44 people respectively. Measuring results and the judgments of three chief doctors were compared and the coincidence rate was above 90%, and meanwhile the combination of spatiality, rhythmicity, formability and intensity could reflect the characteristics of concurrent pulses.

Table 6: Corresponding Degree of Pulse Condition between Measuring Results the Three Chief Doctors Judgments

	Corresponding People	Rate（%）
Chief Doctor A	40	90.9
Chief Doctor B	41	93.2
Chief Doctor C	40	90.9

Conclusion

Apparently, it is not enough to only investigate the messages of pressure from blood vessels in the studies of the observation of TCM pulse diagnostics. The studies deep into the vascular motion will provide numerous three-dimensional messages for the study of TCM pulse diagnostics, which will help to realize a breakthrough in the research on the mechanisms of the formation of TCM pulse diagnosis in order to improve the level of TCM pulse diagnostics.

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