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Original article

Using an array sensor to determine differences in pulse diagnosis—Three positions and nine indicators

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Abstract

Introduction: In pulse diagnosis, three positions (*Cun*, *Guan*, *Chi*) and three levels or depths (*Fu*, *Zhong*, *Chen*), called the Three Positions and Nine Indicators (TPNI) are generally used as a finger-reading method, to obtain a holistic view of the patient. However, single pulse signals at nine TPNI locations (three depths at three positions) look quite similar in a waveform. Hence, the aim of this study was to determine if there was a significant difference between pulse-taking depths (Fu, Zhong, and Chen) and pulse-taking positions (Cun, Guan, and Chi).
Method: To explore the significance of array pulses at the nine TPNI locations, a Bi-Sensing Pulse Diagnosis Instrument (BSPDI) with array sensors was used to measure wrist artery pulse signals. It was proposed that a three-dimensional pulse mapping (3DPM) could present array pulses mimicking the fingertips' sensations of a physician. Four parameters, namely peak value (P_V_{max}), power (P_P), ascending slope (P_AS), and descending slope (P_DS) were elucidated from 3DPM using a two-way analysis of variance. Eight volunteers with TPNI health rule of thumb from the R.O.C. Air Force Academy participated in this research.
Results: The variance of four parameters at nine TPNI locations all reached the level of significance ($p<0.05$). Paired comparison between positions or depths nearly reached significance.
Conclusions: The differences in wrist artery signals exist between TPNI locations. TPNI pulse diagnosis could be used to check the holistic health of a patient as determined by TCM.

Keywords: Three positions and nine indicators (TPNI); Traditional Chinese medicine (TCM); Pulse diagnosis

Introduction

In palpating a patient's body to substantiate a disease or illness, pulse or abdominal diagnosis is used. Palpation is an important and practical diagnostic method in Traditional Chinese Medicine (TCM). TCM clinicians are able to diagnose the nature of illness and identify effective treatments as a result of using palpation [1–7]. Pulse diagnosis is an examination skill through which a TCM clinician uses his index finger, middle finger, and ring finger to palpate the artery on the patient's wrist by pressing on it to feel the nuances of the pulse. They can determine change in frequency, shape, size, width, power, and strength of the pulse, which are then used to judge the circulation of Qi and blood as well as that of the viscera. Despite its importance, palpation is subjective and mysterious. Lots of researchers have attempted to quantify pulse diagnosis over the last decades.

The basic concepts of TCM in relation to pulse diagnosis have been investigated [8–11]. Pulse diagnosis instruments have been proposed to obtain pulse conditions [12–14]. Several analytical methods have been proposed for exploring the mechanism of pulse conditions [15–22]. In addition, a case study found a relationship between disease and pulse conditions [23–25]. The need to quantify pulse diagnosis is of key importance for both clinical practice and especially research. The integration between clinical practice and research will be successful if the research

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starts from a clinical base and the physicians share their experiences with researchers. Hence, this present study investigated the effectiveness of using the Three Positions and Nine Indicators (TPNI) using the finger-reading method to quantify pulse diagnosis. The physiology of patients is reflected in the condition of their pulse, which can be assessed using the different pulse taking positions and pulse taking depths. Using TPNI diagnostic methods not only obtains pulse signals at TPNI locations but also provides a holistic diagnosis. Unfortunately, pulse diagnosis has not been scientifically verified with valid data.

The single pulse signals at nine TPNI locations look quite similar in a waveform. Based on cardiovascular dynamics, blood velocity is about 40.0 ± 15.45 cm/s. The distances between pulse taking positions (such as Cun-Guan-Chi) are about 1.4 cm [26]. Maybe this is the reason why nearly all quantifiable results of pulse diagnosis have just obtained a single pulse signal at one position, Guan [26]. However, this is inconsistent with the descriptions in TCM literature. Taking the pulse at one position is different from the TPNI diagnostic methods used in clinical practice, when different health information is determined from the pulse at different positions and depths [25]. Hence, the goal of this study was to explore if there was a significant difference among the nine TPNI array pulses (which is needed for a holistic TCM health diagnosis), instead of using the conventional single pulse.

Materials and methods

TPNI pulse diagnosis method

In general, TCM physicians take the wrist artery pulse at three positions, namely Cun, Guan, and Chi. The Guan position is the central region over the radial artery, distal to it is Cun, and proximal to it is Chi. The tip of the physician's middle finger is placed on the Guan position. The Cun position (on the distal side) is where the tip of the physician's index finger rests, and the Chi position (on the proximal side) is where the tip of the physician's ring finger is placed. TCM doctors take the pulse by putting their index, middle, and ring fingers on Cun, Guan, and Chi, respectively, and then apply pressure to them. The pressure is applied at three levels of strength and depth at Cun, Guan, and Chi: pressing superficially and floatingly (Fu), pressing by sinking down deeply (Chen), and pressing at an intermediate level (Zhong). The three positions and three levels of depth together form nine indicators, namely Fu-Cun, Fu-Guan, Fu-Chi, Zhong-Cun, Zhong-Guan, Zhong-Chi, Chen-Cun, Chen-Guan, and Chen-Chi. Healthy people usually have a sunken Chi pulse (i.e., Chen-Chi), a floating Cun pulse (i.e., Fu-Cun), and an intermediate Guan pulse (i.e., Zhong-Guan) [3,25,27,28].

Modern society demands a different living style far from the principles of nature described in TCM classics. The circulation of Qi in people in modern society has deviated from the normal condition. Therefore, it is quite difficult to find subjects with a normal balanced pulse. The rule was called TPNI-HRT (health rule of thumb) [25]. This is the pulse diagnosis rule initially proposed by Neijing about body organs [34] Qi which

Fig. 1. Photograph of Bi-sensing pulse diagnosis instrument (BSPDI).

reflects the wrist pulses, "the sequential appearance of a pulse at CUN-GUAN-CHI positions in the wrist artery as the fingertip displacement moves from superficial (Fu) to deep (Chen)".

Participants

Eight volunteers with TPNI-HRT from the R.O.C. Air Force Academy participated in this research. The participants were asked to refrain from eating and drinking for two hours prior to pulse measurement. The participants' pulses were taken for both hands, resulting in 16 sets of TPNI data. Detailed information regarding the participants is given in Table 1.

Average systolic and diastolic blood pressures were 112.8 mmHg and 67.7 mmHg, respectively and the average heart rate was 65 beats/min. The participants had a mean height of 172.6 ± 4.9 cm and weight of 68.6 ± 10.3 kg. The mean BMI was 22.9 ± 2.5.

The Bi-sensing pulse diagnosis instrument

The Bi-Sensing pulse diagnosis instrument (BSPDI) shown in Fig. 1 comprises a set of strain gauges with? Three bands and a set of array pressure sensors for mimicking the pulse taking procedure of TCM physicians [12,13,23,25]. The pulse-taking depth can be adjusted by strain gauges and the pulse is detected by array pressure sensors. The wrist artery signals were sampled by BSPDI and converted into a three-dimensional pulse mapping (3DPM).

The participants' pulses were taken for both hands. The operation of the BSPDI consisted of locating the positions where pulses were taken by TCM doctors and pulse taking by the BSPDI. Firstly, physicians checked three positions (Cun, Guan, and Chi) at three depths (Fu, Zhong, and Chen) and recorded the corresponding pulse conditions. Then, the BSPDI was used to take pulses at the same three positions and depths to obtain 9 sets of TPNI signals per hand.

The pulse-taking depths were sensed by the strain gauge. The depths were sensed as the degrees of deformation of copper strips in the sensor, which were converted to changes in electrical resistance, and then further converted through an electric bridge

Table 1
Baseline demographic and clinical characteristics of participants.

Participant	Height (cm)	Weight (kg)	BMI	Gender (M/F)	Age	Systolic pressure (mmHg)	Diastolic pressure (mmHg)	Heartrate (per min)
1	176	78	25.2	M	19	132	91	62
2	180	92	28.4	M	20	116	74	71
3	170	62	21.5	M	19	112	62	55
4	174	60	19.8	M	18	110	59	73
5	174	66	21.8	M	19	102	56	57
6	174	68	22.5	M	19	121	71	73
7	171	62	21.2	M	19	109	66	65
8	162	61	23.2	M	18	101	63	61
Average	172.6 ± 4.9	68.6 ± 10.3	22.9 ± 2.5		18.9 ± 0.6	112.8 ± 9.5	67.7 ± 10.3	64.6 ± 6.6

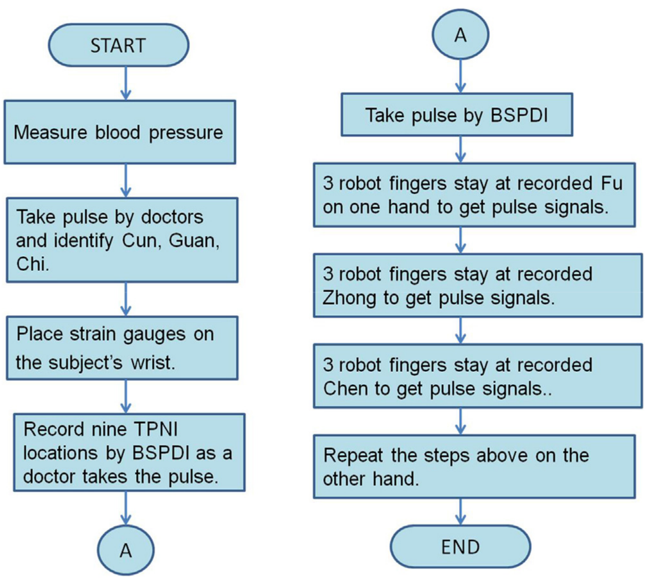

Fig. 2. Sampling process of BSPDI.

circuit and an amplifier to voltage change signals. The BSPDI was used to take pulses at the identified positions and depths. The signals of fingertip sensations were obtained through the array sensor. The details of the sampling procedure are shown in Fig. 2.

Signal processing

Fig. 3 shows the analysis of BSPDI signals, which is divided into five steps (acquiring data from 12 pressure sensors, 60-Hz filtering, wavelet analysis, average calculation of each channel, and calculation of parameters). Each robotic finger has an array of 12 pressure sensors that is used to produce a 3DPM. 60-Hz noise and baseline wander are removed from the signals by a filter and wavelet analysis, respectively. The filtered pulse signals are used to form a 3DPM, from which several parameters are derived.

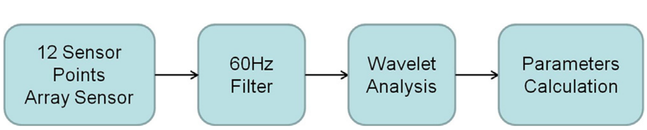

Fig. 3. Flowchart of signal analysis.

Definitions of parameters

Xuehai Zhou (周學海), a physician in the Qing dynasty, proposed a pulse classification method extended from those proposed by Mai Jian Bu Yi and Zhen Jia Zhi Jue [27]. Zhou differentiates a pulse condition based on its position and depth, frequency and rhythm, shape, and tendency. From a quantitative point of view, a pulse-taking position refers to Cun, Guan, or Chi, and Fu, Zhong, or Chen. Frequency and rhythm correspond to the frequency and rhythm of a pulse condition. Shape corresponds to the pulse length and width can be seen as a geometric property of pulse conditions. Tendency is related to the amplitude, energy, and tendency of pulse conditions.

Hence, four parameters of pulse conditions were derived to explore the TPNI's significance, namely position (Cun, Guan, Chi, and Fu, Zhong, Chen), frequency (rate and rhythm), shape (length and width), and tendency (increased slope and decreased slope) [27,28].

The 12 pulse signals were measured by the BSPDI at a given TPNI position. The 3DPM of a pulse condition can be constructed based on these signals, as shown in Fig. 4.

The parameters derived from a 3DPM are defined below.

Peak value (P_V_{max}) is the maximum of $P\_V(x, y)$:

$$P\_V_{max}(j, k) = \text{Max}(P_{V(j,k,x,y)}) \tag{1}$$

where $P\_V(j, k, x, y)$ is the pulse signal at a given TPNI position; x is the index of a pressure sensor perpendicular to the wrist artery ($x = 1, 2, 3$); y is the index of a pressure sensor parallel to the wrist artery ($y = 1, 2, 3, 4$); j is the TPNI position (Cun ($j = 1$), Guan ($j = 2$), Chi ($j = 3$)); k is the TPNI depth (Fu ($k = 1$), Zhong ($k = 2$), Chen ($k = 3$)).

Power (P_P) is defined as the volume of 12 pulse signals in a 3DPM:

$$P\_P(j, k) = \sum_{x=1}^{3}\sum_{y=1}^{4}((P_{V(j,k,x,y)} \times 6.25\,\text{mm}^2) \tag{2}$$

The area of a pressure sensor is 6.25 mm^2 [13,23,29].

The ascending slope (P_AS) is defined as the ascending slope between $0.7 \times P\_V_{max}$ and P_V_{max}. Seven slopes are shown in

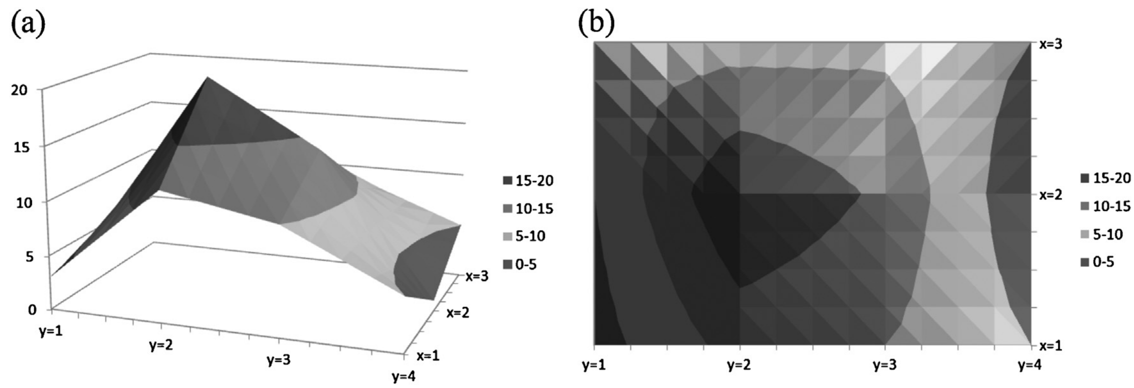

Fig. 4. Three-dimensional pulse mapping (3DPM) at a TPNI location. (a) 3D chart and (b) color contour plot. x (= 1, 2, 3), index of a pressure sensor perpendicular to the wrist artery; y (= 1, 2, 3, 4), index of a pressure sensor parallel to the wrist artery; amplitude in gray level (0–20). The sub-scale data are obtained by interpolation.

Fig. 5. The first slope was obtained by drawing a middle line from $P\_V_{\max}$ to $0.7 \times P\_V_{\max}$ and parallel to the y axis from the top view. The other six lines were obtained with a 15° span from the middle line with starting point $P\_V_{\max}$. P_AS is the average of the seven ascending slopes, P_AS(R) and P_AS(U) are the average of two ascending slopes in the radial and ulnar sides to reflect the geometry of 3DPM in the radial and ulnar sides respectively, P_AS(M) is the average of three ascending slopes in the middle:

$$P_{\mathrm{AS}} = \left(\left(\sum_{i=1}^{7} P_{AS(i)}\right)/7\right), \quad P_{\mathrm{AS}(R)} = \left(\left(\sum_{i=1}^{2} P_{\mathrm{AS}(i)}\right)/2\right)$$
$$P_{\mathrm{AS}(M)} = \left(\left(\sum_{i=3}^{5} P_{\mathrm{AS}(i)}\right)/3\right), \quad P_{\mathrm{AS}(U)} = \left(\left(\sum_{i=6}^{7} P_{\mathrm{AS}(i)}\right)/2\right) \tag{3}$$

Descending slopes (P_DS, P_DS(R), P_DS(M), P_DS(U)) are the same as P_ASs except that a descending slope is used:

$$P_{\mathrm{DS}} = \left(\left(\sum_{i=1}^{7} P_{\mathrm{DS}(i)}\right)/7\right), \quad P_{\mathrm{DS}(R)} = \left(\left(\sum_{i=1}^{2} P_{\mathrm{DS}(i)}\right)/2\right)$$
$$P_{\mathrm{DS}(M)} = \left(\left(\sum_{i=3}^{5} P_{\mathrm{DS}(i)}\right)/3\right), \quad P_{\mathrm{DS}(U)} = \left(\left(\sum_{i=6}^{7} P_{\mathrm{DS}(i)}\right)/2\right) \tag{4}$$

Nine TPNI locations measurement

Previous research has defined the depths of Fu, Zhong, and Chen by using the actual displacement of the sensor or by the pressure change. These depths could then be defined automatically [30–32]. The pulse taking depths in this research were defined by TCM physicians who were famous because of their pulse diagnosis. TCM physicians press the patient's wrist artery to Fu, Zhong, and Chen depths in order to take the pulse. Decisions on the depths of Fu, Zhong, or Chen at Cun, Guan, and Chi positions were made by TCM physicians and recorded by BSPDI, in which the strain gauge was used to sense the depths.

Fig. 6 shows where the set of strain gauges in BSPDI were placed [12]. The strain gauge senses deformation of a band touched by a physician's fingertip in order to obtain nine TPNI locations [12,13], so the BSPDI can repeat the pulse taking method of a physician to retrieve the pulse signals.

Three pieces of strain gauge on Cun, Guan, Chi positions were used to obtain data on the depth [12,25] calculate the depths of Skin to Fu (SF), Fu to Zhong (FZ), Zhong to Chen (ZC), Fu to Chen (FC), Skin to Zhong (SZ), the ratio of Fu-Zhong to Zhong-Chen (FZCR), and the ratio of Skin-Zhong to Zhong-Chen (SZCR). It is showed in Fig. 7.

$$\mathrm{FZCR} = \frac{\mathrm{FZ}}{\mathrm{ZC}} \tag{5}$$

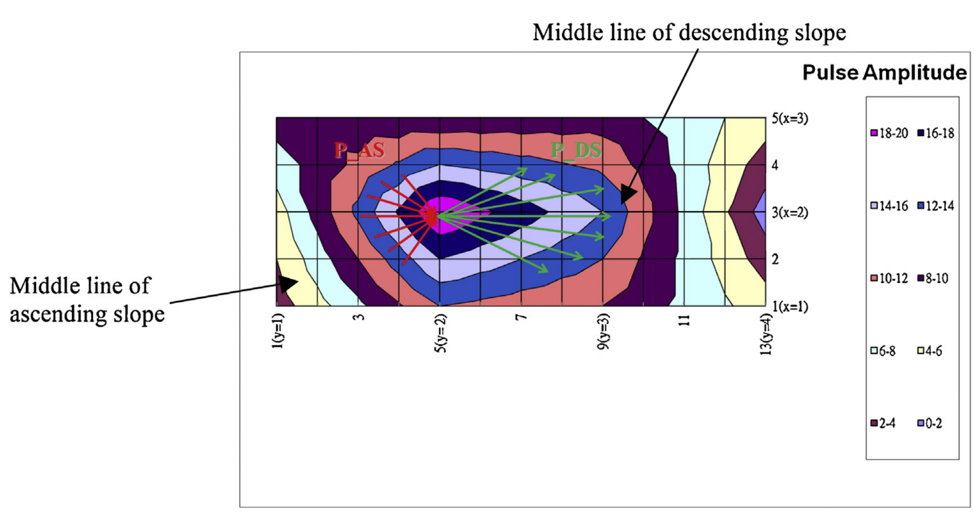

Fig. 5. P_AS and P_DS used for geometry of 3DPM.

Table 2
Interaction comparison between position versus depth.

Position	Depth	Peak value (P_V_{max})	Power (P_P)	Ascending slope (P_AS)	Descending slope (P_DS)
	Fu	39.5 ± 14.1	200.6 ± 81.4	6.1 ± 4.1	6.6 ± 5.0
Cun	*Zhong*	62.9 ± 37.7	373.9 ± 274.7	9.3 ± 1.0	8.2 ± 5.1
	Chen	49.9 ± 19.5	276.7 ± 104.2	8.7 ± 6.2	10.2 ± 9.0
	Fu	62.8 ± 29.6	261.8 ± 113.1	9.5 ± 9.0	10.1 ± 5.8
Guan	*Zhong*	90.7 ± 37.3	451.3 ± 222.4	13.2 ± 8.3	12.1 ± 1.2
	Chen	91.5 ± 25.6	436.7 ± 160.3	16.2 ± 1.0	16.5 ± 1.3
	Fu	12.2 ± 7.8	83.5 ± 31.1	2.2 ± 2.1	1.4 ± 1.4
Chi	*Zhong*	20.3 ± 13.5	104.7 ± 38.1	4.0 ± 3.3	2.6 ± 2.0
	Chen	57.2 ± 3.4	262.7 ± 260.1	12.1 ± 1.0	7.6 ± 3.7

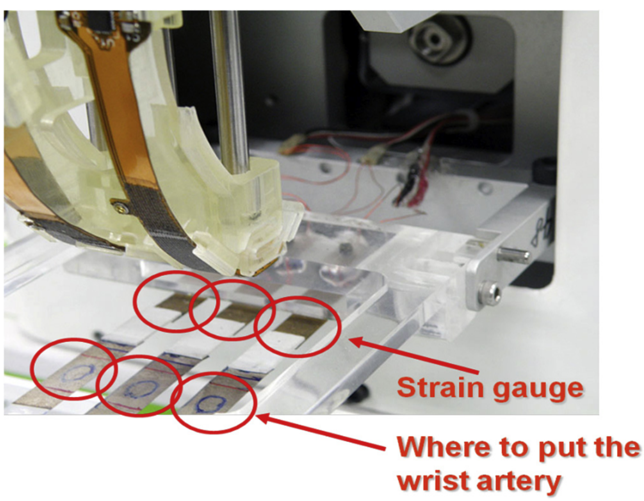

Fig. 6. Locations of strain gauges.

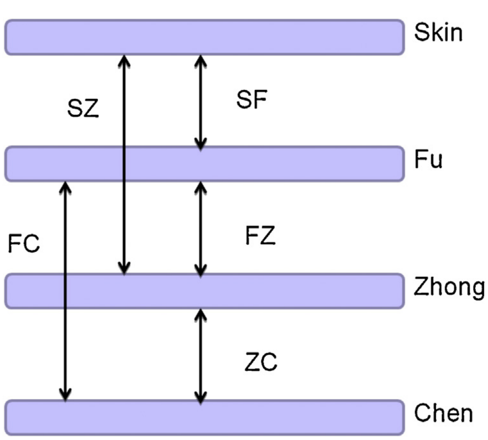

Fig. 7. The definition of a pulse taking depth.

$$\mathrm{SZCR} = \frac{\mathrm{SZ}}{\mathrm{ZC}} \tag{6}$$

Statistics

The two-way analysis of variance (ANOVA) of TPNI signals was conducted using SPSS Statistics Version 17.0.

The two independent variables were position and depth, the three positions were Cun, Guan, and Chi and the three depths were Fu, Zhong, and Chen. The four dependent variables are namely peak value (P_V_{max}), power (P_P), ascending slope (P_AS), and descending slope (P_DS). Four dependent variables were analyzed in relation to position and depth. The factors of the analysis were the three positions and the three depths. The level of significance was set at $p < 0.05$. The variance pair comparison was calculated between positions and depths, and its level of significance was also set at $p < 0.05$.

Results

Two-way ANOVA of four parameters

Analysis of variance

The differences among Peak Value (P_V_{max}), Power (P_P), Ascending Slope (P_AS), and Descending Slope (P_DS) at both Position and Depth were analyzed using two-way ANOVA. Table 2 gives the comparison of the interaction between Position versus Depth. The data are shown as average values with the standard error.

Significance was reached at each of four parameters in three depths and three positions, shown in Table 3. About the interaction between position and depth, significance was reached at Peak Value and Power. Figs. 8 and 9 show the statistical chart of positions and depths for Peak Value by SPSS.

Table 3
Two-Way ANOVA analysis of four parameters between left hand and right hand.

Parameter	Peak value (P_V_{max})	Power (P_P)	Ascending slope (P_AS)	Descending slope (P_DS)
Position	.000	.000	.000	.000
Depth	.000	.000	.000	.024
Position × depth	.004	.031	.217	.918

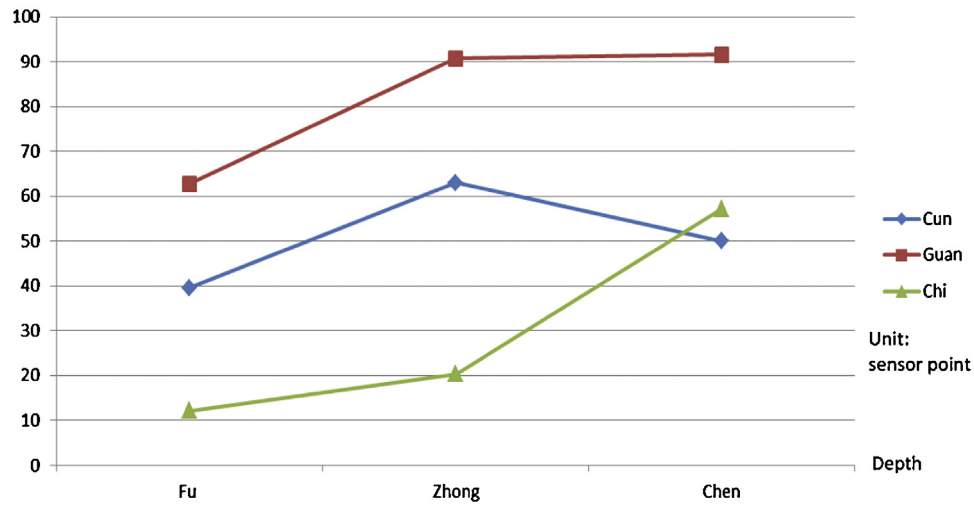

Fig. 8. The statistical chart of Cun, Guan, and Chi in Fu, Zhong, and Chen.

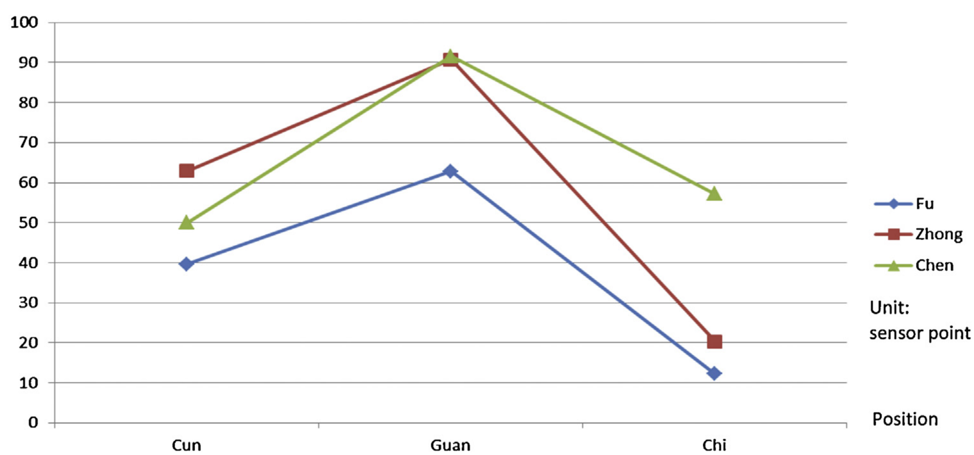

Fig. 9. The statistical chart of Fu, Zhong, and Chen on Cun, Guan, and Chi.

Comparing parameters between left and right hands were not significantly different because both hands satisfied the TPNI-HRT.

*Paired comparison between positions (*Cun, Guan, Chi)

Paired comparison between positions for four parameters mostly shows significance except partial insignificance at Cun-Chi for *P*_AS(R/M/U) and P_DS(R/M/U) in Table 4.

Paired comparison between depths (*Fu*, *Zhong* and *Chen*) As shown in Table 5, Peak Value and Power reach significance except at *Zhong-Chen*. For geometry significance study, *P*_AS(R/M/U) and *P*_DS(R/M/U) are insignificant at Fu-Zhong, partially significant at Zhong-Chen, and completely significant at Fu-Chen.

Tendency Analysis of Parameters One-way ANOVA was used for the tendency analysis of Peak Value. Fig. 10 shows the paired comparison diagram for Cun, Guan, and Chi. Significance for Fu was reached at Cun-Guan, Guan-Chi, and Cun-Chi. Significance for Zhong was reached at Guan-Chi and Cun-Chi. Significance for Chen was reached at Cun-Guan, and Guan-Chi. Fig. 11 shows the paired comparison diagram for Fu, Zhong, and Chen. Cun is not significant among Fu, Zhong, and Chen; Guan is significant between Fu and Chen; Chi is significant at both Fu-Chen and Zhong-Chen. Significance is shown by a dotted line, and no significance is shown by a thick line.

Table 4
Paired comparison between positions.

	Cun-Guan	Cun-Chi	Guan-Chi
P_V_{max}	.000	.001	.000
*P*_*P*	.013	.000	.000
*P*_AS(R/M/U)	.003/.000/.001	.001/.291/.998	.000/.000/.002
*P*_DS(R/M/U)	.096/.007/.001	.040/.183/.612	.000/.000/.000

Table 5
Paired comparison between depths.

	Fu-Zhong	Fu-Chen	Zhong-Chen
P_V_{max}	.001	.000	.345
*P*_*P*	.001	.000	.958
*P*_AS(R/M/U)	.562/.258/.172	.002/.000/.000	.042/.023/.067
*P*_DS(R/M/U)	.900/.758/.117	.039/.038/.003	.107/.181.375

Table 6
Ratio of Fu-Zhong to Zhong-Chen and Skin-Zhong to Zhong-Chen.

	Cun (FZCR)	Guan (FZCR)	Chen (FZCR)	Cun (SZCR)	Guan (SZCR)	Chen (SZCR)
Left and right hands	1.00	1.00	0.99	2.02	2.01	2.01
Left hand	1.00	1.00	1.00	2.02	2.01	2.02
Right hand	0.99	0.99	0.99	2.01	2.00	2.01

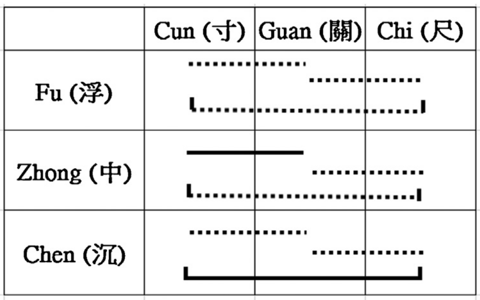

Fig. 10. Pair comparison diagram for *Cun*, *Guan*, and *Chi*. Dashed (solid) line indicates significance (insignificance).

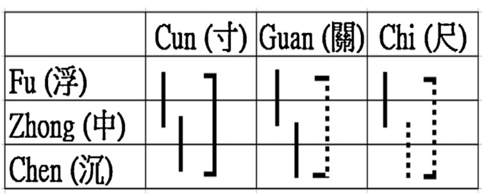

Fig. 11. Pair comparison diagram for *Fu*, *Zhong*, and *Chen*. Dashed (solid) line indicates significance (insignificance).

Pulse-taking – depth measurement

Table 6 shows the ratios of Fu-Zhong to Zhong-Chen (FZCR) and Skin-Zhong to Zhong-Chen (SZCR) at Cun, Guan, and Chi. FZCR values are close to 1 at Cun, Guan, and Chi, and SZCR values are close to 2 at these positions. This implies that the distance from Fu to Zhong is similar to that from Zhong to Chen and that the distance from Skin to Zhong is double that from Zhong to Chen.

Discussion and conclusions

BSPDI was used to measure pulse signals by array sensors at nine TPNI locations. The array pulses were analyzed quantitatively to create a 3DPM from the array of 12 pressure sensors in an array sensor. The theory of Position (位), Frequency (數), Shape (形), and Tendency (勢) proposed by Zhou (周學海) in the Qing dynasty was used as a theoretical underpinning for a significance study. Four quantifiable parameters (P_V_{max}, P_P, P_AS, and P_DS) were derived to discuss the significance for TPNI pulse diagnosis.

The results of two-way ANOVA reveal that both position and depth are significant for four parameters (Tables 2 and 3). This indicates that array pulses at different TPNI locations could give different physiology measures as suggested by TCM scriptures. The results are consistent with Luo, Hu, and Chung's reports [12,13,25].

In Fig. 8, three curves belong to the increased type from Fu to Zhong in Cun, Guan and Chi. There are two curves on the downside from Zhong to Chen in Cun and Guan; one rising curve from Zhong to Chen in Chen. Generally speaking, the pulse in a healthy person belongs to normal distribution curve. In other words, the maximum point of a wrist pulse should be appeared at Zhong depth [33].

In Fig. 9, there is an interaction between curve Zhong and curve Chen on Guan position. The pulse of Zhong and Chen were obviously higher than the pulse of Fu on Guan position. It means there is a clear and substantial pulse signal in Zhong and Chen depths in comparison to the one in Fu. On Chi position the pulse signal in Chen depth is clearer than the pulse in Fu and Zhong depths. All pulses on Cun position are apparent.

In Tables 4 and 5, Peak Value and Power still show significance in the paired comparison except at Zhong-Chen. Fig. 8 shows the paired comparison between Fu, Zhong, and Chen. In the part of Zhong-Chen, the insignificance is showed in Cun and Guan positions and the significance is showed in Chi position. According to TPNI-HRT, at the Fu displacement, the superficial pulse should normally appear only in Cun position. In Guan position, the pulse appears initially at the Zhong displacement. And in Chi position, the pulse appears initially at the Chen displacement [25]. It is the reason that the insignificance was showed in Cun and Guan positions, and the significance was shown in the Chi positions.

P_AS(R/M/U) and P_DS(R/M/U) mostly show significance except Fu-Zhong was completely insignificant. However, Fu-Chen is completely significant and Zhong-Chen is partially significant. It indicates that the geometry of 3DPM is gradually changed from Fu to Chen. Paired comparison may be useful in the unhealthy status such as string-like, weak, or other pulses. Physicians can identify the trend of pulse conditions by P_AS and P_DS and obtain the meaningful physiological information.

TPNI pulse diagnosis in TCM is used to check the holistic health status of a person. For instance, right Cun reflects the lungs and large intestine, right Guan reflects the spleen and stomach, right Chi reflects the kidneys and life gate; left Cun reflects the heart and small intestine, left Guan reflects the liver and gallbladder, and left Chi reflects the kidneys and bladder. The array pulses at each TPNI location should thus be independent to reflect the corresponding health status of the organs. This present study and Chung et al.'s study [25] support this idea by showing the significance among four parameters of 3DPM at nine TPNI locations.

Our results show the statistical significance of four parameters on TPNI positions and depths. It suggests that pulse signals at TPNI positions and depths may contain their own physiological information as suggested by Neijing and Nanjing (難經). However, our results cannot classify the pulse signal at certain TPNI positions and depths related with the internal organs as defined by Nanjing. This study gives a hint that a protocol should be designed to testify TPNI diagnosis in relation to internal organs.

3DPM can provide both the spatial and temporal properties of array pulses in the wrist artery. To check the holistic status of a patient, TCM doctors apply three fingers to measure array pulses at nine TPNI locations. 3DPM generated by an array sensor reasonably reflects the information obtained by TCM physicians. Luo et al. [23] derived a parameter named Plane Pulse Wave (PPW) from 3DPM to differentiate string-like pulses from others. Two kinds of string-like pulse were included, sick string-like pulse indicated by high blood pressure and spring string-like pulse that usually appears in the Spring for general healthy people as proposed in the Neijing (內經).

Conflict of interests

None. The authors declare that there is no conflict of interests regarding the publication of this article.

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References

[1] Hua S. Classic of difficult issues. Taipei: Publishing House of Wen Guang; 2002.
[2] Liu WL, Liu XR, Zhang BC. Vernacular of Binhu's sphygmology. Beijing, China: People's Medical Publishing House; 2000.
[3] Meng JC, Zhou ZY. Introduction to Chinese medicine. Taipei: Jyin Publishing Company; 2001.
[4] Unschuld PU. Medicine in China: Nan-Ching, classic of difficult issues. NY: University of California Press; 1986.
[5] Wang LF. Diagnostics of traditional Chinese medicine. Shanghai: Publishing House of Shanghai University of Traditional Chinese Medicine; 2000.
[6] Wang SH. The pulse classic: a translation of the Mai Jing. Boulder: Blue Poppy Press; 2002.
[7] WHO. WHO international standard terminologies on traditional medicine in the western pacific region. NY: Renouf Pub Co Ltd.; 2007.
[8] Kim JU, Jeon YJ, Kim YM, Lee HJ, Kim JY. Novel diagnostic model for the deficient and excess pulse qualities. Evidence Based Complement Altern Med 2012.
[9] Huang CM, Chang HC, Kao ST, Li TC, Wei CC, Chen CC, et al. Radial pressure pulse and heart rate variability in heat- and cold-stressed humans. Evidence Based Complement Altern Med 2011;2011:1–9.
[10] Kim JU, Jeon YJ, Lee YJ, Kim KH, Kim JY. Novel diagnostic algorithm for the floating and sunken pulse qualities and its clinical test. Evidence Based Complement Altern Med 2011:1–10.
[11] Jeon YJ, Kim JU, Lee HJ, Lee J, Ryu HH, Lee YJ, et al. A clinical study of the pulse wave characteristics at the three pulse diagnosis positions of Chon, Gwan and Cheok. Evidence Based Complement Altern Med 2011:1–9.
[12] Luo CH, Chung YF, Hu CS, Yeh CC, Si XC, Feng DH, et al. Possibility of quantifying TCM finger-reading sensations: I. Bi-sensing pulse diagnosis instrument. Eur J Integr Med 2012;4:e255–62.
[13] Hu CS, Chung YF, Yeh CC, Luo CH. Temporal and spatial properties of arterial pulsation measurement using pressure sensor array. Evidence Based Complement Alternat Med 2012;2012:9.
[14] Chen JX, Liu F. Research on characteristics of pulse delineation in TCM and omnidirectional. In: IEEE Ineterantional symposium on IT in medicine and education. IEEE; 2008. p. 536–8.
[15] Wei CC. An innovative method to measure the peripheral arterial elasticity: spring constant modeling based on the arterial pressure wave with radial vibration. Ann Biomed Eng 2011;39:2695–705.
[16] Wei CC, Huang CM, Liao YT. The exponential decay characteristic of the spectral distribution of blood pressure wave in radial artery. Comput Biol Med 2009;39:453–9.
[17] Wang XX, Guo PY. Time–frequency analysis of pulse signal based on system of wrist strap sensor. J Beijing Technol Bus Univer 2006;24:47–50.
[18] Wang YYL, Chang CC, Chen JC, Hsiu H, Wang WK. Pressure wave propagation in arteries. IEEE Eng Med Biol Mag 1997;16:51–6.
[19] Wang YYL, Chang SL, Wu YE, Hsu TL, Wang WK. Resonace – the missing phenomenon in hemodynamics. Circul Res 1991;69:246–9.
[20] Wang YYL, Chiu WB, Jan MY, Bau JG, Li SP, Wang WK. Analysis of transverse wave as a propagation mode for the pressure pulse in large arteries. J Appl Phys 2007;102:4.
[21] Wang YYL, Hsu TL, Jan MY, Wang WK. Theory and applications of the harmonic analysis of arterial pressure pulse waves. J Med Biol Eng 2010;30:125–31.
[22] Wang YYL, Sze WK, Bau JG, Wang SH, Jan MY, Hsu TL, et al. The ventricular-arterial coupling system can be analyzed by the eigenwave modes of the whole arterial system. Appl Phys Lett 2008;92:3.
[23] Luo CH, Chung YF, Yeh CC, Si XC, Chang CC, Hu CS, et al. Stringlike pulse quantification study by pulse wave in 3D pulse mapping. J Alternat Complement Med 2012;18:924–31.
[24] Liao YT, Chen HY, Huang CM, Ho M, Lin JG, Chiu CC, et al. The pulse spectrum analysis at three stages of pregnancy. J Alternat Complement Med 2012;18:382–6.
[25] Chung YF, Hu CS, Luo CH, Yeh CC, Si XC, Feng DH, et al. Possibility of quantifying TCM finger-reading sensations: II. An example of health standardization. Eur J Integrat Med 2012;4:e263–70.
[26] Bojakowski K, Gorczyca-Wiśniewska G, Szatkowski M, Walecki J, Andziak P. Preoperative ultrasonographic examination of the radial artery and the cephalic vein and risks of dialysis arterio-venous fistula dysfunction. Pol J Radiol 2010;75:7–12.
[27] Zheng HX, Li JL. Complete collection of Zhou Xue Hai medical works. Beijing, China: China Press of Traditional Medicine; 1999.
[28] Chung YF. Pulse diagnosis health rule of thumb and string-like pulse researches based on bi-sensing pulse diagnosis instrument. Taiwan: National Cheng Kung University; 2012.
[29] Chung YF, Hu CS, Yeh CC, Luo CH. How to standardize the pulse-taking method of traditional Chinese medicine pulse diagnosis. Comput Biol Med 2013;43:342–9.
[30] Bae JH, Jeon YJ, Kim JY, Kim JU. New assessment model of pulse depth based on sensor displacement in pulse diagnostic devices. Evidence Based Complement Alternat Med 2013.
[31] Kim JY, Kim KY, Ko KD. A study on the problems and the method for improvement of pulse analyzers. J Kor Inst Orient Med Diagnos 1999.
[32] Kim SH, Kim JU, Lee YJ, Kim KH, Kim JY. New algorithm of determining the floating and sunken pulse with a pulse diagnosis instrument. Kor J Orient Physiol Pathol 2009.
[33] Fei ZF. Contemporary sphygmology in traditional Chinese medicine. Beijing: People's Medical Publishing House; 2002.
[34] Qian CC. Nei-Jing. Beijing: Zhonghua Book Company; 2010.