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Research paper

Gender differences in arterial pulse wave and anatomical properties in healthy Korean adults

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ABSTRACT

Introduction: Gender differences are important intrinsic factors in wrist arterial pulse assessment in traditional Chinese and Korean medicine. The current study aimed to examine gender differences in wrist pulse waves at the Cun, Guan, and Chi positions of the wrist and to identify associations between physical indices and anatomical properties at all three positions.

Methods: One hundred thirty-nine middle-aged Korean men and women participated in this cross-sectional study. A blood analysis was performed, and blood pressure and medical history were recorded. Artery diameter and depth, blood flow velocity, and pulse wave were measured.

Results: The pulse power index (PPI), pulse depth index (PDI), and power spectrum density at the third harmonic frequency/first harmonic frequency (PSD_w3_w1) showed highly significant differences according to gender. Men exhibited larger PPI values than women at all three positions. The PDI and PSD_w3_w1 in men were higher at the Cun position than those in women, whereas the PDI at the Chi position was higher in women than in men. Gender differences in the spectral harmonic energy ratio were greater at the Guan and Chi positions than those at the Cun position. The subendocardial viability ratio differed significantly between genders. In women, the PDI was highly positively correlated with radial artery depth at all positions; however, in men, the PDI was only marginally correlated with artery depth at the Guan and Chi positions.

Conclusion: We suggest that gender differences should be considered in wrist artery pulse diagnosis, including those related to pulse diagnostic positions and anatomical properties.

1. Introduction

The wrist arterial pulse wave is one of the most studied topics in traditional Chinese medicine (TCM) and traditional Korean medicine (TKM). Frequently performed in several fields, studies of the wrist arterial pulse have included pulse measurement or protocols [1–4], sensing equipment [5,6], physical factors or indices based on time and frequency domains [3,7–10], and the association between pulse waves and diseases/organs [9–12].

TCM and TKM physicians use their fingertips to palpate pulse differences in both wrists. The pulse wave and pulse diagnosis reflect health information about the body because intrinsic and extrinsic factors such as age, gender, and disease may affect the wrist pulse wave [2,13]. In pulse diagnosis, gender differences are one of most important intrinsic factors, and gender differences in physical factors or indices from both wrists have been examined in several studies [2,14–18]. For example, indices such as the augmentation index (AIx) and augmented pressure (AP) extracted from the pulse wave of the wrist or proximal right carotid artery differed between genders [14–16]. In contrast, several studies have demonstrated that physical wrist pulse indices are associated with disease [12,14,19]. For example, the AIx and AP were powerful and independent risk indices of early coronary artery disease [14]. A low frequency (LF) ranging from 0.04 to 0.15 Hz is mediated according to cardiac vagal and sympathetic nervous activity, and the ratio of the low frequency to the high frequency (LFHF) was been considered a predictor of cardiac sympathovagal balance [12,18]. Maximum pulse amplitudes in the wrist Guan position were the factors most strongly related to hypertension in Korean adults [11]. Additionally, obesity has been associated with the pulse depth index (PDI), spectral energy ratio (SER) at a frequency of 10 Hz, and high-frequency

Abbreviations: PPI, pulse power index; PDI, pulse depth index; PSD, power spectrum density; SEVR, subendocardial viability ratio; SHER, spectral harmonic energy ratio; LF, low frequency; HF, high frequency; TCM, traditional Chinese medicine; TKM, traditional Korean medicine

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spectral energy proportion of the total pulse energy [20]. Although many studies on physical indices of the wrist have been performed in various TCM and TKM fields, whether any differences in physical indices of the wrist pulse wave and anatomical properties, such as arterial diameter, arterial blood flow velocity, and radial artery depth, exist at the Cun, Guan, and Chi positions between men and women remains unknown.

The purposes of this study were to assess gender differences in the wrist pulse wave at the Cun, Guan, and Chi positions of healthy Korean adults, to identify correlations between the physical indices and anatomical properties at the Cun, Guan, and Chi positions of the wrist, and to examine differences in the physical indices at the Cun, Guan, and Chi positions. No studies comparing associations between physical indices and anatomical properties between genders and the physical indices at the Cun, Guan, and Chi positions have been reported. New findings regarding gender differences and associations between physical indices and anatomical properties may advance guidelines for improved pulse diagnosis.

2. Materials and methods

2.1. Subjects

Demographic and clinical data such as blood analysis results, blood pressure (BP), body mass index (BMI), pulse waves, artery diameter, artery depth, and blood flow velocity were recorded for all subjects. All measurements, tests, and assessments were performed at the Oriental Hospital of Daejeon University (Cheonan City, Republic of Korea) from August 2014 to November 2014. The Institutional Review Board of the Oriental Hospital of Daejeon University approved the study (I0906-01-02). All men and women received a detailed explanation of the study, and all subjects provided written informed consent.

The inclusion criteria required that the study participants 1) submit written informed consent after receiving a detailed study description, 2) were men or women aged 30–50 years, 3) were Koreans residing in the Republic of Korea, 4) were healthy individuals without chronic diseases, such as hypertension, diabetes, or hyperlipidaemia, as assessed by a medical history survey and physical examination, and 5) were not pregnant or menstruating. The exclusion criteria were as follows: 1) a history of surgery or medical treatment within one month of the first visit to the hospital, 2) intake of medicines that can affect the autonomic nervous system and pulse waves, 3) excessive diet control for the purposes of weight management or disease treatment within one week of the first visit to the hospital, and 4) pulse waves that could not be easily measured due to vascular anomalies of the wrist or bone fracture of the wrist. In total, 139 middle-aged (30–50 years) Korean men and women (63 men, 76 women) participated in this cross-sectional study. Fig. 1 shows the sample selection procedure used in this study. The rationale for including adults aged 30–50 years was that diseases related to high blood pressure are more likely to occur in adults over 50 years, and we surmise that the characteristics of pulse waves of adults aged 20–29 years are likely to show characteristics similar to those of pulse waves in adults aged 30–39 years. We did not consider any basic characteristic differences, matching of the subjects, or stratification by demographic data, such as age.

2.2. Measurements

Pulse waves were acquired using a pulse analysis system (KIOM-PAS) developed by the Korea Institute of Oriental Medicine [21]. The electro-mechanical stability of the KIOM-PAS was certified based on IEC 60601-1 by a certificate authority. The clinical good manufacturing practice (GMP) of the KIOM-PAS was also approved by the Ministry of Food and Drug Safety of Korea (MFDS), and the reliability and safety of the device were confirmed [22]. Several prior studies have investigated the reliability of the KIOM-PAS [21–24]. The KIOM-PAS has sensors for 7 piezo-resistive elements in a row, and the motor unit exerts continuous pressure on a palpation position. Measurements of heart rate variability and pulse waves are very sensitive to fatigue, emotional status, position, and posture. For our measurements, after the subjects had rested comfortably for 10 min, we measured pulse waves at the three positions of Cun, Guan, and Chi in the left wrist (Fig. 2). These positions were marked by an Oriental medical doctor. Specifically, when the subjects visited the hospital, each participant assumed a comfortable posture, and after sitting in a chair for more than 10 min and relaxing, a well-trained operator measured the pulse waves. The signal from the sensor was processed by a pre-amplifier, band-pass filter, and main amplifier. Signals passing through the main amplifier were converted into a digital signal with a sampling frequency of 1000 Hz.

In this study, we measured the pulse wave at the left radial artery. A previous study argued that the pulse wave on the left side is more indicative of cardiac function than that on the right side, and the pulse wave at the Cun position on the left side is less influenced by reflection waves than those at other positions and on the right side [4]. Another study mentioned that the pulse wave from the Cun position on the left side can reflect the conditions and function of the cardiac system [9]. To compare the results of this study with those of previous studies, we selected the left side for measurements since many previous studies have mainly measured the left wrist [3,4,7,10,11,21].

We extracted various parameters from the pulse waves. As a brief description of the physical indices, LF indicates the low-frequency spectral power in the 0.04-0.15-Hz band, whereas HF indicates the high-frequency spectral power in the 0.15-0.4-Hz band derived from the pulse signal (unit: ms^2) [12,19,25]. LFHF signifies the relative spectral power, specifically, the LF/HF ratio, and is regarded as an indicator of cardiac sympathovagal balance. HF100 signifies HF power in normalised units, specifically, HF/(HF + LF)*100 (unit: %); this value reflects the balanced activity of the two branches of the autonomic nervous system [12,19,25]. The pulse power index (PPI) is the voltage response of the sensor when the pulse amplitude reaches the maximum (unit: V), and the PDI indicates the pulse depth calculated by actual sensor displacement based on continuously evolving tonometric mechanisms (unit: mm) [21]. Additionally, we computed three variables for power spectrum density (PSD), PSD_w3_w1, PSD_w5_w1, and PSD_w7_w1, which were calculated using the following formulae: PSD_w3 (PSD at the third harmonic frequency)/PSD_w1 (PSD at the first harmonic frequency); PSD_w5 (PSD at the fifth harmonic frequency)/PSD_w1; and PSD_w7 (PSD at the seventh harmonic frequency)/PSD_w1. Indices related to PSD_w1 were described in a previous study [11]. The spectral harmonic energy ratio (SHER) indicates the energy ratio between the 1–3 harmonic energies and the 4–6 harmonic energies [4]. $SE_{10\text{-}30Hz}$ indicates the integrated spectral energy within 10–30 Hz (unit: $Vrms^2$) [9,10]. SER_10 is the SER at a frequency of 10 Hz, which is defined by $SE_{0\text{-}10Hz}/SE_{10\text{-}30Hz}$ [8]. HSEP_10 is the high-frequency spectral energy proportion of the total pulse energy, which is defined by $SE_{10\text{-}30Hz}/SE_{0\text{-}30Hz}$ [12]. The subendocardial viability ratio (SEVR) indicates the integral ratio of the systolic and diastolic pressures, which reflects the relation of myocardial oxygen supply and demand [26–28].

To determine anatomical properties such as artery diameter, radial artery depth, and blood flow velocity, a medical ultrasound scanner (Voluson 730 Pro, GE Medical, USA) with a 12 L probe was used at the Cun, Guan, and Chi palpation positions, which were marked by an Oriental medical doctor. To identify the positions on ultrasound images, three tiny metal wires were wrapped around each measurement location and covered with a gel pad (Parker Laboratories, Inc., USA). Table 1 lists the basic characteristics of the subjects and their anatomical properties.

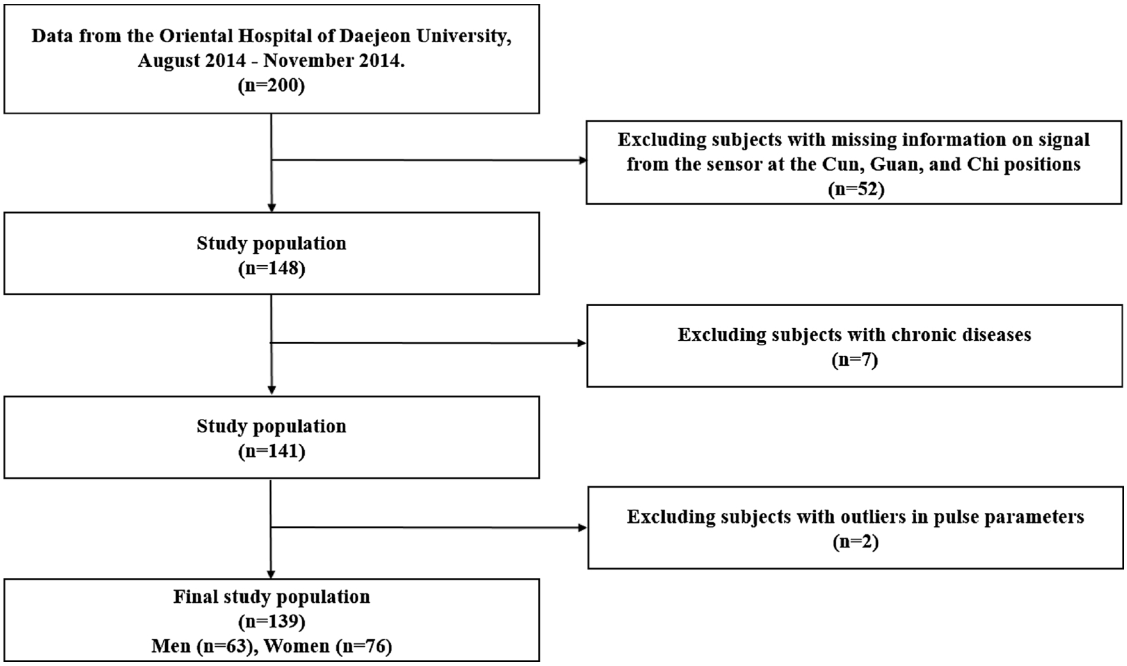

Fig. 1. Sample selection procedure.

Fig. 2. The positions of Cun, Guan, and Chi for palpation.

2.3. Statistical analysis

All statistical analyses of clinical data were performed using SPSS 19 for Windows (SPSS, Inc., Chicago, IL, USA) and R-3.3.3 (Another Canoe). The Shapiro-Wilk normality test was performed to test the normality assumption before statistical analysis. The statistical tests were performed after logarithmic transformation of the variables that did not satisfy the normality assumption and were skewed. Gender differences at the Cun, Guan, and Chi positions were analysed using independent two-sample t-tests and analysis of covariance (ANCOVA) with adjustments for age, BMI, and dominant side (right, left, and neither). Significant differences among the Cun, Guan, and Chi positions in men and women were assessed by repeated measures analysis of variance (Repeated Measures ANOVA) and Tukey (post hoc) tests. Correlations between physical indices and artery diameter, artery depth, and blood flow velocity at the Cun, Guan, and Chi positions in men and women were assessed using Pearson's correlation test. Differences with a p-value < 0.05 were considered statistically significant.

3. Results

3.1. Gender differences in physical indices at the Cun, Guan, and Chi positions

Table 2 lists the gender differences in the physical indices obtained

Table 1
Basic characteristics of the subjects and the anatomical properties examined in this study.

Variable	Men	Women	p	
	Mean (SD)	Mean (SD)		Description
Subjects (n)	63	76	–	Number of subjects
Age (year)	38.08 (5.410)	39.76 (6.037)	0.0886	Age
Height (cm)	174.5 (5.026)	160.9 (4.697)	< 0.0001	Height
Weight (kg)	74.90 (9.562)	58.57 (8.590)	< 0.0001	Weight
BMI (ratio)	24.57 (2.783)	22.69 (3.679)	0.0010	Body mass index
SBP (mmHg)	115.6 (10.20)	114.3 (11.38)	0.4699	Systolic blood pressure
DBP (mmHg)	77.73 (12.20)	73.25 (11.48)	0.0276	Diastolic blood pressure
PP (mmHg)	37.89 (9.762)	41.03 (9.791)	0.0618	Pulse pressure (SBP-DBP)
Pulse rate (min)	72.22 (6.724)	71.16 (8.045)	0.4049	Pulse
Cun diameter (mm)	2.540 (0.484)	2.089 (0.449)	< 0.0001	Arterial diameter at Cun
Cun velocity (cm/s)	39.77 (14.54)	34.24 (12.08)	0.0155	Arterial blood flow velocity at Cun
Cun depth (mm)	3.371 (0.955)	3.483 (0.922)	0.4863	Radial artery depth at Cun
Guan diameter (mm)	2.410 (0.366)	2.136 (0.375)	< 0.0001	Arterial diameter at Guan
Guan velocity (cm/s)	31.72 (8.820)	32.32 (11.81)	0.7374	Arterial blood flow velocity at Guan
Guan depth (mm)	2.921 (0.747)	3.459 (0.999)	0.0006	Radial artery depth at Guan
Chi diameter (mm)	2.441 (0.415)	2.187 (0.350)	0.0001	Arterial diameter at Chi
Chi velocity (cm/s)	31.39 (9.710)	29.69 (11.25)	0.3416	Arterial blood flow velocity at Chi
Chi depth (mm)	3.190 (0.909)	4.053 (1.339)	< 0.0001	Radial artery depth at Chi

The p-value indicates a significant difference between genders by an independent two-sample t-test.
Abbreviations: SD: standard deviation.

from the wrist pulse wave at the Cun position. At this position, the greatest gender differences were observed for PSD_w3_w1 (p = < 0.0001, adjusted p = 0.0001) and PSD_w7_w1 (p = 0.0002, adjusted p = 0.0002) in the crude analysis and the analysis adjusted for age, body mass index, and dominant side. The PPI (p = 0.0011, adjusted p = 0.0040) and SHER (p = 0.0023, adjusted p = 0.0010) were substantially different between genders. Significant gender differences were found in most of the indices in both the crude and adjusted analyses, except for the LF, PDI, PSD_w5_w1, and $SE_{10\text{-}30Hz}$.

At the Guan position (Table 3), the greatest gender differences were observed for the PPI (p = < 0.0001, adjusted p = < 0.0001), PSD_w3_w1 (p = < 0.0001, adjusted p = < 0.0001), and SHER (p = 0.0001, adjusted p = < 0.0001). Additionally, the PSD_w7_w1 (p = 0.0037, adjusted p = 0.0004) and SEVR (p = 0.0006, adjusted p = 0.0002) were considerably different between genders. LFHE (p = 0.0161, adjusted p = 0.0153) and $SE_{10\text{-}30Hz}$ (p = 0.0332, adjusted p = 0.0185) differed significantly between genders in both the crude and adjusted analyses.

At the Chi position (Table 4), the PSD_w3_w1 (p = < 0.0001, adjusted p = < 0.0001), PSD_w7_w1 (p = < 0.0001, adjusted p = < 0.0001), and SHER (p = < 0.0001, adjusted p = < 0.0001) showed the greatest gender differences. All indices except for the HSEP_10 and SER_10 differed significantly, and these differences were not substantially altered following adjustments for age, BMI, and dominant side.

3.2. Correlations between physical indices and anatomical properties according to gender

Overall, the anatomical properties at the pulse diagnostic positions of men differed from those observed in women. Men displayed greater diameters than women at the Cun, Guan, and Chi positions, whereas women had greater artery depths at the Guan and Chi positions than men.

Table 5 lists the correlations between physical factors and anatomical properties at the Cun, Guan, and Chi positions in men and women. At the Cun position in women, radial artery depth was highly positively correlated with the PDI (r = 0.548). Additionally, radial artery depth was negatively correlated with the SEVR (r = -0.298). At the Guan position in men, the PDI was positively correlated with arterial diameter (r = 0.276) and radial artery depth (r = 0.277), arterial blood flow velocity was positively correlated with the $SE_{10\text{-}30Hz}$ (r = 0.262),

Table 2
Gender differences in physical indices at the Cun position.

Index	Men	Women	T	p	Adjusted p
LF (ms^2)	3.205 (1.094)	2.838 (0.963)	2.079	0.0397	0.1507
LFHF (ratio)	−0.052 (0.987)	−0.529 (1.035)	2.777	0.0063	0.0119
HF100 (%)	43.21 (20.49)	51.13 (21.77)	−2.207	0.0290	0.0453
PPI (V)	1.226 (0.176)	1.131 (0.153)	3.345	0.0011	0.0040
PDI (mm)	1.530 (0.171)	1.473 (0.181)	1.889	0.0610	0.3259
PSD_w3_w1 (ratio)	−2.875 (0.615)	−3.288 (0.514)	4.246	< 0.0001	0.0001
PSD_w5_w1 (ratio)	−5.414 (0.924)	−5.531 (0.687)	0.830	0.4085	0.5431
PSD_w7_w1 (ratio)	−7.105 (1.379)	−7.993 (1.351)	3.812	0.0002	0.0002
SHER (ratio)	4.202 (0.803)	4.588 (0.620)	−3.120	0.0023	0.0010
HSEP_10 (ratio)	−7.234 (0.990)	−7.640 (0.923)	2.479	0.0145	0.0219
SER_10 (ratio)	7.233 (0.991)	7.639 (0.924)	−2.480	0.0144	0.0218
$SE_{10\text{-}30Hz}$ ($Vrms^2$)	−7.371 (1.053)	−7.754 (0.935)	2.249	0.0263	0.0662
SEVR (%)	−0.688 (0.271)	−0.824 (0.247)	3.067	0.0026	0.0024

The p-value was obtained by an independent two-sample t-test, and the adjusted p-value was calculated by ANCOVA after adjustments for age, BMI, and dominant side following logarithmic transformation, except for HF100 (the normality assumption was satisfied).
Abbreviations: LFlow-frequency spectral power; LFHF: relative spectral power; HF: high-frequency spectral power; PPI: pulse power index; PDI: pulse depth index; PSD: power spectrum density; SHER: spectral harmonic energy ratio; HSEP: high-frequency spectral energy proportion; SER: spectral energy ratio; SE: integrated spectral energy; SEVR: subendocardial viability ratio.

Table 3
Gender differences in physical indices at the Guan position.

Index	Men	Women	T	p	Adjusted p
LF (ms^2)	3.176 (1.153)	2.821 (0.868)	2.015	0.0463	0.0757
LFHF (ratio)	−0.347 (1.073)	−0.797 (1.097)	2.439	0.0161	0.0153
HF100 (%)	48.13 (22.35)	55.77 (23.87)	−1.944	0.0539	0.0826
PPI (V)	1.245 (0.188)	1.068 (0.201)	5.371	< 0.0001	< 0.0001
PDI (mm)	1.578 (0.201)	1.576 (0.239)	0.069	0.9449	0.4061
PSD_w3_w1 (ratio)	−2.804 (0.558)	−3.316 (0.596)	5.223	< 0.0001	< 0.0001
PSD_w5_w1 (ratio)	−4.964 (0.839)	−5.193 (0.667)	1.751	0.0826	0.0393
PSD_w7_w1 (ratio)	−6.565 (1.441)	−7.263 (1.317)	2.955	0.0037	0.0004
SHER (ratio)	3.887 (0.736)	4.352 (0.619)	−3.975	0.0001	< 0.0001
HSEP_10 (ratio)	−6.466 (0.931)	−6.526 (0.875)	0.385	0.7008	0.3941
SER_10 (ratio)	6.464 (0.932)	6.524 (0.876)	−0.387	0.6996	0.3933
$SE_{10\text{-}30Hz}$ (Vrms^2)	−6.421 (0.955)	−6.764 (0.911)	2.153	0.0332	0.0185
SEVR (%)	−0.696 (0.245)	−0.852 (0.281)	3.504	0.0006	0.0002

The p-value was obtained by independent two-sample t-test, and the adjusted p-value was calculated by ANCOVA after adjustments for age, BMI, and dominant side following logarithmic transformation, except for HF100 (the normality assumption was satisfied).
Abbreviations: LFlow-frequency spectral power; LFHF: relative spectral power; HF: high-frequency spectral power; PPI: pulse power index; PDI: pulse depth index; PSD: power spectrum density; SHER: spectral harmonic energy ratio; HSEP: high-frequency spectral energy proportion; SER: spectral energy ratio; SE: integrated spectral energy; SEVR: subendocardial viability ratio.

and arterial diameter was negatively correlated with the PSD_w7_w1 (r = -0.374) and positively correlated with the SHER (r = 0.350). In women, arterial diameter was positively correlated with the PPI (r = 0.275), and radial artery depth was highly positively correlated with the PDI (r = 0.515). Additionally, radial artery depth was negatively correlated with the PSD_w5_w1 (r = -0.293), PSD_w7_w1 (r = -0.368), and HSEP_10 (r = -0.280) and positively correlated with the SHER (r = 0.318) and SER_10 (r = 0.280). At the Chi position in men, radial artery depth was positively correlated with the PDI (r = 0.288) and SER_10 (r = 0.381) and negatively correlated with the HSEP_10 (r = -0.381) and $SE_{10\text{-}30Hz}$ (r = -0.356). In women, arterial blood flow velocity was positively correlated with the PSD_w5_w1 (r = 0.359), PSD_w7_w1 (r = 0.280), HSEP_10 (r = 0.283), and $SE_{10\text{-}30Hz}$ (r = 0.253) and negatively correlated with the SHER (r = -0.392) and SER_10 (r = -0.284). Moreover, radial artery depth was highly positively correlated with the PDI (r = 0.456) and SHER (r = 0.386) and marginally correlated with the SER_10 (r = 0.242). Additionally, artery depth was negatively correlated with the PSD_w3_w1 (r = −0.282), PSD_w5_w1 (r = −0.295), PSD_w7_w1 (r = −0.331), and HSEP_10 (r = −0.242).

3.3. Differences in physical indices among the three positions according to gender

Table 6 shows several physical factors that exhibited significant differences among the Cun, Guan, and Chi positions. Specifically, 8 physical factors were identified in men and 9 factors were identified in women. In men, the PPI and PDI exhibited highly significant differences between the Chi position and other positions (p = 0.0007 and p = < 0.0001, respectively), while highly significant differences between the Cun position and the other positions were found for the PSD_w5_w1 (p = 0.0001), PSD_w7_w1 (p = 0.0001), SHER (p = 0.0002), HSEP_10 (p = < 0.0001), SER_10 (p = < 0.0001), and $SE_{10\text{-}30Hz}$ (p = < 0.0001). In women, the PDI showed highly significant differences at the Cun, Guan, and Chi positions (p = < 0.0001). Highly significant differences between the Cun position and the other positions were found in the PPI (p = 0.0004), PSD_w7_w1 (p = < 0.0001), HSEP_10 < 0.0001, SER_10 (p = < 0.0001), and $SE_{10\text{-}30Hz}$ (p = < 0.0001). The PSD_w5_w1 and SHER differed significantly between the Guan position and the other positions (p = 0.0003 and p = 0.0062, respectively). The significance levels for the differences between the HSEP_10, SER_10, and $SE_{10\text{-}30Hz}$ were equivalent in men and women.

Table 4
Gender differences in physical indices at the Chi position.

Index	Men	Women	T	p	Adjusted p
LF (ms^2)	3.282 (0.961)	2.772 (0.986)	3.078	0.0025	0.0049
LFHF (ratio)	−0.056 (1.033)	−0.671 (1.054)	3.461	0.0007	0.0010
HF100 (%)	42.33 (20.51)	53.22 (22.29)	−2.996	0.0033	0.0025
PPI (V)	1.165 (0.182)	1.048 (0.198)	3.631	0.0004	0.0049
PDI (mm)	1.864 (0.166)	1.930 (0.228)	−1.979	0.0498	0.0006
PSD_w3_w1 (ratio)	−2.818 (0.658)	−3.330 (0.551)	4.912	< 0.0001	< 0.0001
PSD_w5_w1 (ratio)	−5.072 (0.810)	−5.469 (0.763)	2.953	0.0037	0.0032
PSD_w7_w1 (ratio)	−6.435 (1.286)	−7.529 (1.289)	4.986	< 0.0001	< 0.0001
SHER (ratio)	3.928 (0.723)	4.534 (0.695)	−5.014	< 0.0001	< 0.0001
HSEP_10 (ratio)	−6.464 (0.955)	−6.698 (1.018)	1.398	0.1645	0.1004
SER_10 (ratio)	6.461 (0.957)	6.696 (1.019)	−1.397	0.1647	0.1006
$SE_{10\text{-}30Hz}$ (Vrms^2)	−6.579 (0.878)	−6.971 (1.093)	2.348	0.0203	0.0337
SEVR (%)	−0.743 (0.266)	−0.891 (0.276)	3.205	0.0017	0.0004

The p-value was obtained by an independent two-sample t-test, and the adjusted p-value was calculated by ANCOVA after adjustments for age, BMI, and dominant side following logarithmic transformation, except for HF100 (the normality assumption was satisfied).
Abbreviations: LFlow-frequency spectral power; LFHF: relative spectral power; HF: high-frequency spectral power; PPI: pulse power index; PDI: pulse depth index; PSD: power spectrum density; SHER: spectral harmonic energy ratio; HSEP: high-frequency spectral energy proportion; SER: spectral energy ratio; SE: integrated spectral energy; SEVR: subendocardial viability ratio.

Table 5
Correlations between physical factors and anatomical properties at the Cun, Guan, and Chi positions.

Gender	Index	Cun			Guan			Chi		
		Diameter	Velocity	Depth	Diameter	Velocity	Depth	Diameter	Velocity	Depth
Men	PPI	−0.054	−0.011	−0.033	0.034	0.139	−0.055	0.131	0.057	0.034
	PDI	−0.086	0.186	0.242	0.276*	−0.043	0.277*	0.092	−0.077	0.288*
	PSD_w3_w1	−0.041	0.024	0.009	−0.082	−0.197	0.174	0.006	0.122	0.085
	PSD_w5_w1	−0.097	0.103	0.015	−0.206	−0.022	−0.096	−0.167	0.186	−0.196
	PSD_w7_w1	−0.235	0.005	0.184	−0.374**	0.094	−0.072	−0.221	0.020	−0.070
	SHER	0.145	−0.102	−0.063	0.350**	−0.050	0.041	0.212	−0.126	0.107
	HSEP_10	−0.144	−0.113	0.044	−0.196	0.146	−0.156	−0.021	0.038	−0.381**
	SER_10	0.144	0.113	−0.044	0.196	−0.146	0.156	0.021	−0.038	0.381**
	$SE_{10\text{-}30Hz}$	−0.194	−0.100	0.080	−0.161	0.164	−0.149	0.049	0.100	−0.356**
	SEVR	−0.071	0.083	0.101	−0.192	0.055	0.113	−0.027	0.152	−0.044
Women	PPI	−0.083	0.187	0.060	0.275*	0.163	−0.078	0.157	−0.055	0.189
	PDI	0.165	0.125	0.548**	0.186	0.132	0.515**	−0.084	0.035	0.456**
	PSD_w3_w1	0.199	−0.102	−0.067	0.182	0.141	−0.152	0.007	0.210	−0.282*
	PSD_w5_w1	0.157	0.061	−0.041	−0.067	0.055	−0.293*	−0.115	0.359**	−0.295**
	PSD_w7_w1	0.091	0.169	−0.155	−0.085	−0.036	−0.368**	−0.155	0.280*	−0.331**
	SHER	−0.171	−0.165	0.145	0.048	−0.099	0.318**	0.194	−0.392**	0.386**
	HSEP_10	−0.028	0.052	0.050	−0.185	0.011	−0.280*	−0.113	0.283*	−0.242*
	SER_10	0.028	−0.052	−0.050	0.185	−0.011	0.280*	0.113	−0.284*	0.242*
	$SE_{10\text{-}30Hz}$	−0.027	0.074	0.150	−0.141	0.047	−0.190	−0.078	0.253*	−0.085
	SEVR	0.016	0.116	−0.298**	0.150	−0.021	−0.151	0.018	−0.001	−0.044

The results were generated by Pearson correlation analysis after logarithmic transformation. * $p < 0.05$, ** $p < 0.01$.
Abbreviations: LFlow-frequency spectral power; LFHF: relative spectral power; HF: high-frequency spectral power; PPI: pulse power index; PDI: pulse depth index; PSD: power spectrum density; SHER: spectral harmonic energy ratio; HSEP: high-frequency spectral energy proportion; SER: spectral energy ratio; SE: integrated spectral energy; SEVR: subendocardial viability ratio.

Table 6
Significant differences among the Cun, Guan, and Chi positions in physical factors.

		Men			Women		
Index	Position	Mean (SD)	F	P	Mean (SD)	F	P
PPI	Cun	1.226 (0.176) [a]	7.699	0.0007	1.131 (0.153) [a]	8.602	0.0004[†]
	Guan	1.245 (0.188) [a]			1.068 (0.201) [b]		
	Chi	1.165 (0.182) [b]			1.048 (0.198) [b]		
PDI	Cun	1.530 (0.171) [a]	90.33	< 0.0001	1.473 (0.181) [a]	161.0	< 0.0001
	Guan	1.578 (0.201) [a]			1.576 (0.239) [b]		
	Chi	1.864 (0.166) [b]			1.930 (0.228) [c]		
PSD_w3_w1	Cun	−2.875 (0.615)	0.637	0.5307	−3.288 (0.514)	0.289	0.7495
	Guan	−2.804 (0.558)			−3.316 (0.596)		
	Chi	−2.818 (0.658)			−3.330 (0.551)		
PSD_w5_w1	Cun	−5.414 (0.924) [a]	10.37	0.0001	−5.531 (0.687) [a]	8.580	0.0003
	Guan	−4.964 (0.839) [b]			−5.193 (0.667) [b]		
	Chi	−5.072 (0.810) [b]			−5.469 (0.763) [a]		
PSD_w7_w1	Cun	−7.105 (1.379) [a]	10.58	0.0001	−7.993 (1.351) [a]	15.06	< 0.0001
	Guan	−6.565 (1.441) [b]			−7.263 (1.317) [b]		
	Chi	−6.435 (1.286) [b]			−7.529 (1.289) [b]		
SHER	Cun	4.202 (0.803) [a]	9.156	0.0002	4.588 (0.620) [a]	5.256	0.0062
	Guan	3.887 (0.736) [b]			4.352 (0.619) [b]		
	Chi	3.928 (0.723) [b]			4.534 (0.695) [a]		
HSEP_10	Cun	−7.234 (0.990) [a]	16.62	< 0.0001	−7.640 (0.923) [a]	36.37	< 0.0001
	Guan	−6.466 (0.931) [b]			−6.526 (0.875) [b]		
	Chi	−6.464 (0.955) [b]			−6.698 (1.018) [b]		
SER_10	Cun	7.233 (0.991) [a]	16.62	< 0.0001	7.639 (0.924) [a]	36.35	< 0.0001
	Guan	6.464 (0.932) [b]			6.524 (0.876) [b]		
	Chi	6.461 (0.957) [b]			6.696 (1.019) [b]		
$SE_{10\text{-}30Hz}$	Cun	−7.371 (1.053) [a]	21.65	< 0.0001	−7.754 (0.935) [a]	26.92	< 0.0001
	Guan	−6.421 (0.955) [b]			−6.764 (0.911) [b]		
	Chi	−6.579 (0.878) [b]			−6.971 (1.093) [b]		
SEVR	Cun	−0.688 (0.271)	2.651	0.0746	−0.824 (0.247) [a]	3.060	0.0498
	Guan	−0.696 (0.245)			−0.852 (0.281) [ab]		
	Chi	−0.743 (0.266)			−0.891 (0.276) [b]		

The results were generated by repeated measures analysis of variance (Repeated Measures ANOVA) after logarithmic transformation. Before the Repeated Measures ANOVA, Mauchly tests for the sphericity assumption were performed; [†] p-values obtained from Greenhouse-Geisser corrections for departure from sphericity; a, b, and c: significant differences among the Cun, Guan, and Chi positions using the Tukey (post hoc) test.
Abbreviations SDstandard deviation; LF: low-frequency spectral power; LFHF: relative spectral power; HF: high-frequency spectral power; PPI: pulse power index; PDI: pulse depth index; PSD: power spectrum density; SHER: spectral harmonic energy ratio; HSEP: high-frequency spectral energy proportion; SER: spectral energy ratio; SE: integrated spectral energy; SEVR: subendocardial viability ratio.

4. Discussion

In the present study, we assessed gender differences in physical indices at the Cun, Guan, and Chi positions, associations between physical indices and anatomical properties, and differences in physical factors at the three above-listed positions in healthy Korean men and women.

Men showed significantly larger PPI values than women at the Cun, Guan, and Chi positions, probably because men tend to have larger vascular diameters and higher blood velocities, which increase blood flow and blood pressure in the wrist artery. In particular, the greatest difference in the PPI between men and women was at the Guan position. At the Cun position, the PSD_w3_w1 was higher in men than in women. Women had larger PDI values at the Chi position than men, probably due to the deeper location of the artery. Men had a higher PSD_w3_w1 than women at all positions. Regarding physical indices at the Cun, Guan, and Chi positions, in both the crude and adjusted analyses, the PPI, PSD_w3_w1, PSD_w7_w1, and SHER showed highly significant differences between genders. LFHF and HF100 at the three positions were also significantly different between genders, except for HF100 at the Guan position. The LF was significantly different at the Chi position in both the crude and adjusted analyses, but not at the Cun and Guan positions.

Several physical indices were significantly different among the Cun, Guan, and Chi positions. For example, the PDI differed significantly at all three positions in women, whereas the PSD_w3_w1 was non-significant at all three positions. Additionally, the SEVR differed significantly only in women. The HSEP_10, SER_10, and $SE_{10\text{-}30Hz}$ at the Cun position differed significantly from those at the Guan and Chi positions in both men and women. The PSD_w3_w1 was not statistically different among all three positions in both men and women. We believe that some wrist physical indices may show different pulse waveforms according to these positions.

In previous studies on gender differences in pulse waves, Gatzka et al. [15]. examined gender differences in arterial wave reflection indices of untreated hypertensive subjects of the same body height. They documented that diastolic pressure was higher in men than in women, the time to systolic peak was longer in women than in men, and the argumentation index (AI) was higher in women than in men. They suggested that women have smaller and stiffer blood vessels than men. Hayward and Kelly [16] assessed the association of gender with several indices from carotid artery pressure waveforms based on data from 350 healthy subjects without hypertension. They considered that central arterial haemodynamics had gender-related differences in systolic pressure augmentation. Nam et al. [29] measured spatial pulse wave velocity from the radial artery at the Guan position of the wrist. They revealed that this velocity was faster in men than in women because men have greater terminal tissue vascularity. Additionally, Yim et al. [2] investigated associations between gender and wrist pulse indices in 372 healthy young adults and found that pulses in men were deeper and slower than those in women. Duprez et al. [17] studied small artery elasticity and large artery elasticity from the radial artery diastolic pulse in several ethnic groups and both genders and documented that men had greater small artery elasticity and large artery elasticity than women. King et al. [18] argued that pulse force in women is lower than that in men and that mean systolic and diastolic blood pressures in men are significantly higher than those in women, regardless of laterality. These previous studies reported gender differences in the radial arterial pulse. Similar to previous results, our findings showed gender differences in several physical indices as well as correlations between physical indices and anatomical properties.

Various TCM and TKM studies have suggested that several physical indices derived from wrist pulses are associated with disease [8–10,12,19,26–28]. In the present study, which examined gender differences in physical indices as suggested by previous studies [8–10,12,19,26–28], we found that LF differed significantly between genders at the Chi position. Gender differences in LFHF and HSEP_10 were found at all three positions, except for HF100 at the Guan position. The SHER was highly significantly different between genders at the Cun, Guan, and Chi positions. This index was highly correlated with arterial diameter at the Guan position in men and with radial artery depth at the Guan and Chi positions and arterial blood flow velocity at the Chi position in women. The PDI at the Cun and Guan positions and the HSEP_10 and SER_10 at the Guan and Chi positions did not differ significantly between genders. However, the PDI was correlated with radial artery depth at the Guan and Chi positions in both men and women. Additionally, the HSEP_10 and SER_10 were correlated with radial artery depth at the Guan and Chi positions in both men and women and with arterial blood flow velocity at the Chi position in women.

In the clinical practice of pulse diagnosis, we believe that practitioners experience difficulty in identifying harmonic indices such as the LF, HF, HF100, and SHER without the use of a pulse analysis system. Therefore, many previous studies have been conducted to examine associations between diseases and indices identified by scientific techniques. These efforts can help practitioners more easily understand differences in pulse waves. This study examined gender differences in pulse waves, which constitute one of the most important intrinsic factors in wrist arterial pulse assessment. Additionally, various studies on the quantification, scientification, and standardization of the pulse qualities and indices related to pulse waves have been performed, but no breakthrough has been achieved. The main reason for this is that the physical and scientific definitions and standardization of these pulse qualities and indices are still immature. To advance the clinical use of pulse diagnosis devices and standardization of pulse parameters, this study was conducted to obtain standard distribution characteristics of variables from the pulses of healthy subjects. The standard distribution characteristics were obtained to enhance the clinical value of pulse wave assessment through the frequency domain and the waveform of the pulse as well as variables such as the PPI (pulse intensity) and PDI (pulse depth), which are directly related to pulse quality. Therefore, the clinical objectives of this study were to contribute to the detection of these standard distribution characteristics and to verify that gender differences should be considered in arterial pulse diagnosis and in the development of a pulse analysis system. However, future studies should be carried out to promote the definitions of the physical properties of pulse quality, to determine the clinical implications of each pulse parameter in clinical practice, and to reveal the relationships between these properties in TCM and TKM.

This study has several limitations. More reliable evidence will require a larger sample size to assess gender differences in the physical indices and anatomical properties of the wrist. Moreover, further studies are needed to define the association between the right and left pulse waves according to the dominant side of a subject.

5. Conclusion

In this study, we demonstrated that gender differences in many physical indices obtained from wrist pulse waves are significant in healthy middle-aged adults, and correlations between physical indices and anatomical properties, such as artery diameter, artery depth, and blood flow velocity, also differed significantly according to gender. We suggest that gender differences should be considered in wrist artery pulse diagnosis, including those related to pulse diagnostic positions and anatomical properties. New findings concerning gender differences in physical indices and associations among physical indices and anatomical properties may advance guidelines towards improved pulse diagnosis and facilitate the development of a pulse analysis system.

Conflict of interest

The pulse instrument was developed by this institution.

Author contributions

BJL designed and developed the study and was responsible for the data analysis. He conducted all the experiments, interpreted the results, and wrote the manuscript. YJJ, JHB, and MHY analysed the data and interpreted the results. JYK interpreted and reviewed the results. All authors approved the final article.

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References

[1] Y.F. Chung, C.S. Hu, C.C. Yeh, C.H. Luo, How to standardize the pulse-taking method of traditional Chinese medicine pulse diagnosis, Comput. Biol. Med. 43 (2013) 342–349.
[2] Y.K. Yim, C. Lee, H.J. Lee, K.S. Park, Gender and measuring-position differences in the radial pulse of healthy individuals, J. Acupunct. Meridian Stud. 7 (2014) 324–330.
[3] Y.J. Jeon, J.U. Kim, H.J. Lee, et al., A clinical study of the pulse wave characteristics at the three pulse diagnosis positions of Chon, Gwan and Cheok, Evid. Complement. Alternat. Med. 2011 (2011) 904056.
[4] C.M. Huang, C.C. Wei, Y.T. Liao, et al., Developing the effective method of spectral harmonic energy ratio to analyze the arterial pulse spectrum, Evid. Complement. Alternat. Med. 2011 (2011) 342462.
[5] Y.W. Chu, C.H. Luo, Y.F. Chung, et al., Using an array sensor to determine differences in pulse diagnosis—three positions and nine indicators, Eur. J. Integr. Med. 6 (2014) 516–523.
[6] H. Kim, J.Y. Kim, Y.J. Park, Y.B. Park, Development of pulse diagnostic devices in Korea, Integr. Med. Res. 2 (2013) 7–17.
[7] C.C. Wei, C.M. Huang, Y.T. Liao, The exponential decay characteristic of the spectral distribution of blood pressure wave in radial artery, Comput. Biol. Med. 39 (2009) 453–459.
[8] L.Y. Wei, C.T. Lee, P. Chow, A new scientific method of pulse diagnosis, Am. J. Acupunct. 12 (1984) 205–218.
[9] C.M. Huang, H.C. Chang, S.T. Kao, et al., Application of sphygmography to detection of dyspepsia and the rhinitis, Am. J. Chin. Med. 39 (2011) 271–285.
[10] C.M. Huang, H.C. Chang, T.C. Li, et al., Acupuncture effects on the pulse spectrum of radial pressure pulse in dyspepsia, Am. J. Chin. Med. 40 (2012) 443–454.
[11] B.J. Lee, Y.J. Jeon, B. Ku, et al., Association of hypertension with physical factors of wrist pulse waves using a computational approach: a pilot study, BMC Complement. Altern. Med. 15 (2015) 222.
[12] C.M. Huang, H.C. Chang, S.T. Kao, et al., Radial pressure pulse and heart rate variability in normotensive and hypertensive subjects, J. Altern. Complement. Med. 17 (2011) 945–952.
[13] D. Liangyue, G. Yijun, H. Shuhui, et al., Chinese Acupuncture and Moxibustion, Foreign Language Press, Beijing, 1987, pp. 267–271.
[14] T. Weber, J. Auer, M.F. O'Rourke, et al., Arterial stiffness, wave reflections, and the risk of coronary artery disease, Circulation 109 (2004) 184–189.
[15] C.D. Gatzka, B.A. Kingwell, J.D. Cameron, et al., Gender differences in the timing of arterial wave reflection beyond differences in body height, J. Hypertens. 19 (2001) 2197–2203.
[16] C.S. Hayward, R.P. Kelly, Gender-related differences in the central arterial pressure waveform, J. Am. Coll. Cardiol. 30 (1997) 1863–1871.
[17] D.A. Duprez, D.R. Jacobs Jr, P.L. Lutsey, et al., Race/ethnic and sex differences in large and small artery elasticity–results of the multi-ethnic study of atherosclerosis (MESA), Ethn. Dis. 19 (2009) 243–250.
[18] E. King, D. Cobbin, D. Ryan, The reliable measurement of radial pulse: gender differences in pulse profiles, Acupunct. Med. 20 (2002) 160–167.
[19] C.M. Huang, H.C. Chang, S.T. Kao, et al., Radial pressure pulse and heart rate variability in heat- and cold-stressed humans, Evid. Complement. Alternat. Med. 2011 (2011) 751317.
[20] B.J. Lee, Y.J. Jeon, J.Y. Kim, Association of obesity with anatomical and physical indices related to the radial artery in Korean adult, Eur. J. Integr. Med. 14 (2017) 22–27.
[21] J.H. Bae, Y.J. Jeon, J.Y. Kim, J.U. Kim, New assessment model of pulse depth based on sensor displacement in pulse diagnostic devices, Evid. Complement. Alternat. Med. 2013 (2013) 938641.
[22] J.H. Bae, J.U. Kim, J. Kim, Harmonic analysis of pulse morphology variability for pulse smoothness assessment, Biomed. Signal Process. Control 44 (2018) 1–11.
[23] M.H. Jun, Y.M. Kim, J.H. Bae, et al., Development of a tonometric sensor with a decoupled circular array for precisely measuring radial artery pulse, Sensors (Basel) 16 (2016) E768.
[24] S.K. Yoo, K.Y. Shin, T.B. Lee, et al., Development of a radial pulse tonometric (RPT) sensor with a temperature compensation mechanism, Sensors (Basel) 13 (2013) 611–625.
[25] Task force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, Heart rate variability: standards of measurement, physiological interpretation, and clinical use, Eur. Heart J. 17 (1996) 354–381.
[26] H. Hintsala, A. Kandelberg, K.H. Herzig, et al., Central aortic blood pressure of hypertensive men during short-term cold exposure, Am. J. Hypertens. 27 (2014) 656–664.
[27] D. Tsiachris, C. Tsioufis, D. Syrseloudis, et al., Subendocardial viability ratio as an index of impaired coronary flow reserve in hypertensives without significant coronary artery stenoses, J. Hum. Hypertens. 26 (2012) 64–70.
[28] Z.C. Ma, Y.L. Zhang, C.M. Ni, et al., A new method for determining subendocardial viability ratio from radial artery pressure waves, J. Mech. Med. Biol. 13 (2013) 1350060.
[29] D.H. Nam, W.B. Lee, Y.S. Hong, S.S. Lee, Measurement of spatial pulse wave velocity by using a clip-type pulsimeter equipped with a hall sensor and photoplethysmography, Sensors 13 (2013) 4714–4723.