Research paper

Diagnosis of traditional Chinese medicine constitution by integrating indices of tongue, acoustic sound, and pulse

Chun-Jen Huang[a], Hung-Jen Lin[a,b], Wen-Ling Liao[c,d], Will Ceurvels[e], Shan-Yu Su[a,b,*]

[a] *School of Post-baccalaureate Chinese Medicine, College of Chinese Medicine, China Medical University, Taichung 40402, Taiwan*
[b] *Department of Chinese Medicine, China Medical University Hospital, Taichung 40447, Taiwan*
[c] *Graduate Institute of Integrated Medicine, College of Chinese Medicine, China Medical University, Taichung 40402, Taiwan*
[d] *Center for Personalized Medicine, China Medical University Hospital, Taichung 404, Taiwan*
[e] *Graduate Institute of Chinese Medicine, Department of Classics, China Medical University, Taichung 40402, Taiwan*

ARTICLE INFO

Keywords:
Traditional Chinese medicine
Constitution identification
Tongue image
Acoustic sound
Pulse waveform

ABSTRACT

Introduction: Inspection, auscultation, and pulse-taking are the three physical examinations used by traditional Chinese medicine (TCM) practitioners to diagnose constitution. The aim of this study was to integrate biological signals extracted from these three examinations, including tongue image, waves of acoustic sound, and pulse waveforms, into the same model in order to identify TCM constitutions.
Methods: Tongue images, acoustic sound, and pulse waveforms were abstracted from 274 subjects, and indices of biological signals were extracted. Constitution scores were measured using the Nine-Constitution Scale questionnaire. Association between indices and constitution scores were analyzed by Pearson correlation analysis. For each of the eight abnormal constitutions, indices significantly correlated to the abnormal constitution were further used as arguments in a linear regression model to build an equation for predicting the constitution score.
Results: Tongue indices that were identified to be associated with abnormal constitutions included the G, B, S and b color values, maximum width of tongue body, number of red spots on the tongue surface, and proportion of scalloped tongue margin. Acoustic sound indices included intensity, average number of zero-crossing, high spectral energy ratio, and pitch of the acoustic sound. Pulse waveform indices included the height of the main wave, unsmooth wave, single systolic area, and rapid ejection time.
Conclusions: This study identified indices that are associated with scores of abnormal constitutions. Indices having a larger correlation coefficient can be considered to have larger relative weight in determination of the corresponding constitution. The equations make it possible to predict constitution scores based on biological signals of the tongue, acoustic sound, and pulse.

1. Introduction

Identifying constitution is a crucial process in the practice of traditional Chinese medicine (TCM), because accurate diagnosis of constitution helps practitioners to choose the most effective treatment method [1]. Constitution identification can be applied not only to patients with diseases [2–7], but also to general populations, helping people to be more aware of their health status and thereby preventing

the occurrence of disease [8–10]. Traditionally, constitutions are diagnosed based on the "four diagnosis methods"; among them are three physical examinations, including inspection, auscultation, and pulse palpation. These physical examinations are performed by TCM practitioners [11,12].

For several decades, instruments that abstract and analyze biological signals of tongue images [13–16], pulse waves [17–20], and acoustic waves [21–25], representing the three physical examinations,

have been developed in order to avoid diagnosis biases caused by subjective feelings of practitioners [26–29]. However, almost all of the studies regarding biological signals of the three physical examinations focused on the relationship either between only one particular signal and constitutions [14,17,25] or between one signal and one particular disease [13,15,16,19–24]. Literature that includes biological signals of the three physical examinations at the same time is limited. Since a single biological signal cannot provide comprehensive information regarding constitution, it will be more consistent with the traditional diagnostic modality if all three biological signals can be considered simultaneously for the diagnosis of TCM constitution. The first aim of the present study was to establish a model that includes all the influential indices abstracted from tongue images, pulse waves, and acoustic waves for each constitution.

Once all the indices of the three biological signals are considered together, there is a question: among those indices, which is the most important for a certain constitution. In the textbooks of TCM diagnosis, qualitative criteria for the diagnosis of constitutions are taught [30], while quantitative criteria and the weight for each criterion are unclear. Previous studies which only related one biological signal to constitutions did not solve the problem. For instance, both weak pulse and weak voice are diagnostic criteria for Qi-deficiency (QDf) constitution in TCM textbook [12]. A previous study regarding acoustic features reported that subjects with QDf constitution had lower acoustic intensities than subjects without QDf constitution [31], and one of the other studies on pulse waveforms found that high augmentation index exists in subjects with QDf [17]. Both studies identified biological signals for the diagnosis of the QDf constitution, however, because the two studies were conducted on different subjects, it is difficult for practitioners to differentiate which of the indices, the low acoustic intensity or the high augmentation index, plays a more important role for the diagnosis of QDf constitution than another.

In this study, indices of three biological signals, including tongue image, acoustic sound, and pulse waveform, were extracted at the same time from the same subjects. The correlation between each index of those biological signals and constitutions was analyzed. Important biological indices for each of the eight abnormal constitutions were identified, and then a prediction model and an equation for each of the eight abnormal constitutions were built. Our study provides an important reference material for TCM practitioners performing constitution diagnosis.

2. Methods

2.1. Study subjects

Subjects were recruited through an advertisement at China Medical University Hospital (CMUH), with written informed consent. The inclusion criterion was that the subject be more than 20 years of age. Exclusion criteria included being pregnant, suffering from acute diseases or acute pain, and taking any medications in the past three months. The entire protocol was approved by the Institutional Review Board at CMUH (DMR99-IRB-271).

2.2. Measurement of constitutions

Constitutions were measured by the Nine-Constitution Scale, which was published by the China Association for TCM in 2009. The nine constitutions include one normal constitution and eight abnormal constitutions, which include constitutions of Yang-deficiency (YaD), Yin-deficiency (YiD), QDf, Phlegm-wet (PW), Wet-heat (WH), Blood-stasis (BS), Special-diathesis (SDa), and Qi-depression (QDp) [30]. The Nine-Constitution Scale questionnaire has a test-retest reliability ranging from 0.77 to 0.90, and internal consistency (Cronbach's α) ranging from 0.72 to 0.82 [32]. This self-reported questionnaire comprises six to eight items for each constitution, and for each item the answer is

rated on a five-point Likert scale ("never" = 0, "occasionally" = 1, "sometimes" = 2, "often" = 3, and "always" = 4) (see *Supplemental material*). Then, the raw sum score was converted to a score on a 0-to-100 scale, and subjects with certain abnormal constitutional scores of more than 40 were identified as having the given constitution.

Each of the eight abnormal constitutions represents a certain type of health deviation. YaD and QDf are two constitutional states characterized by weak physical function, usually with weak voice and weak muscles. Besides, people with YaD tend to feel chilly, and have a cold sensation in part of the body or the whole body. YiD is characterized by dryness, including dry eyes, dry mouth, and dry skin, usually with feverish sensation in the cheeks, soles, and palms. PW is a constitutional state that has excessive fluid and lipid retention. People with PW are usually obese, with sputum in the throat and heavy sensation in the body. WH is a complex constitution that is composed of Wetness and Heat. People with WH manifest symptoms of oily skin, acne, foul breath, and viscous feces. BS is a constitution state characterized by poor blood circulation. People with BS constitution often feel pain and numbness in different parts of the body, and have a dark or purplish color in the local areas where BS happens. SDa is characterized by allergic symptoms, including skin allergy or nasal allergy. QDp is a constitutional state that is characterized by unstable emotion. People who have QDp tend to be depressive, nervous, anxious, sensitive, and irritable [8].

2.3. Measurement of indices of tongue, pulse, and acoustic sound

All examinations were performed after a 20-min rest, in an examination room with temperature 21 ± 1 °C.

2.3.1. Tongue indices measurement

Images of the surface and the back of the tongue were taken by Nikon E2 (Nikon, Tokyo, Japan) with a lens of Micro-Nikkor 10.5 mm/ 2.8D (Nikon, Tokyo, Japan) and a shutter speed of 1/125 s in a standardized studio surrounded by focusing cloth. The light was a cold light supplied by a source of Raiser Repro-Beleuchtungseinrichtung RB 5000.

Tongue indices were divided into tongue body indices, tongue coating indices, and indices of the sublingual vein. Indices of tongue body included the color values of the tongue body, maximum width (MW) of tongue body, number of red dots on the tongue surface, number of stasis dots on the tongue surface, and proportion of scalloped tongue margin (STM). A color value of a tongue body was the average value of six measurements. The color values of R, G, and, B in the RGB model, and that of H, S, and b in the HSB model were measured using Photoshop software (Adobe Systems Incorporated, San Jose, America).

The thickness of tongue coating was visually estimated by the modified Winkel tongue coating indices (MWTCI), which is highly correlated with the wet weight of the tongue coating and has a good reproducibility among different examiners. [33] Indices of the sublingual vein included the length and width of the sublingual vein.

2.3.2. Measurement of pulse indices

Radial pulse pressure waveforms were recorded from the left radial artery using sphygmography (WS 901, Skylark Device and Systems Co., Ltd.). The sensor was placed onto the middle position (the Guan position), which is parallel to the styloid process of the radius. For each measurement, arterial pressure waveforms were recorded for seven seconds. Pulse indices included pulse rates (PR), height of main wave (h_1), height of dicrotic wave (h_3), rapid ejection time (RET), single systolic area (sSA), one minute systolic area (tSA), and smoothness. The smoothness was measured by visual inspection of the pulse waveform. Pulse indices were measured and calculated by averaging the measurements of three stable consecutive waves [34].

2.3.3. Measurement of acoustic indices

The speech signals were recorded using a 90-degree angle uni-

direction stereo condenser microphone (SONY ECM-MS907, Japan). Subjects were asked to pronounce a sustained /a/ vowel sound for one second using their usual speech volume five centimeters from the microphone. The speech signals were digitized using a sound blaster (Model no. SB1090, Creative Labs, Singapore) at a 44.1 KHz sampling rate and then analyzed using a data acquisition system developed under the LabVIEW environment. The acoustic indices included traditional acoustic indices and modern ones. Traditional acoustic indices were intensity, maximum pitch (MaxP), average pitch (AvgP) and minimum pitch (MiniP). Modern acoustic indices were average number of zero-crossings (ANZC), variation in peaks and valleys (VPV), variation in formant frequencies (VFF), low spectral energy ratio (LSER), and high spectral energy ratio (HSER) [31].

2.4. Statistical analysis

Data were expressed as mean ± standard deviation (SD) or percentage (%) as appropriate. Associations between each constitution score and gender, surgery history, and chronic disease were examined using biserial correlation analysis. Association between each constitution score and age, basal body index, indices of tongue, acoustic sound, and pulse were examined using Pearson's correlation analysis. For each abnormal constitution, variables that were correlated with the constitutional score were added into a multivariate linear regression model. An equation was built for each constitution containing indices that were significantly correlated with the abnormal constitution and their standardized regression coefficients. All data were analyzed using SPSS software, version 24 (IBM Corporation, Chicago, IL). All P values are two-tailed and statistical significance level was set at less than 0.05. The statistical power would be higher than 80% with a Pearson's correlation coefficient r of more than 0.169 in this study.

3. Results

3.1. Characteristics of subjects

A total of 274 volunteers have been recruited in this study, with a mean age of 38.2 ± 12.8. Table 1 shows characteristics of the study subjects, and the mean scores of the eight abnormal constitutions.

Table 1
Characteristics of the 274 study subjects.

Characteristics	Value
Gender	
Male	78 (28.5%)
Female	196 (71.5%)
Age (year)	38.2 ± 12.8 (20–70)
Height (m)	162.4 ± 7.5 (145–183)
Weight (kg)	59.5 ± 11.1 (39–102)
BMI (kg/m^2)	22.5 ± 3.5 (15.8–38.4)
Surgery history	40 (14.6%)
Chronic disease	13 (4.7%)
Constitutional score	
YaD	25.1 ± 18.5 (0–89)
YiD	33.6 ± 17.1 (0–88)
QDf	35.3 ± 17.4 (0–97)
PW	33.3 ± 18.8 (0–91)
WH	29.9 ± 17.0 (0–83)
BS	29.2 ± 16.7 (0–82)
SDa	25.6 ± 19.3 (0–93)
QDp	29.5 ± 18.8 (0–100)

Abbreviations: YaD, Yang-deficiency; YiD, Yin-deficiency; QDf, Qi-deficiency; PW, Phlegm-wet; WH, Wet-heat; BS, blood-stasis; SDa, special-diathesis; QDp, Qi-depression; BMI, body mass index. Data are shown as Mean ± SD (minimum - maximum) for continuous variables and count (percentage) for categorical variables.

Table 2
Association between body characteristics and constitutional scores.

	Gender (male)	Age	BMI	Surgery history	Chronic disease
YaD	−0.167**	−0.089	−0.182**	−0.028	0.058
YiD	−0.175**	−0.305***	−0.115	−0.053	0.091
QDf	−0.083	−0.085	−0.080	−0.064	0.103
PW	−0.120*	−0.128*	0.150*	0.027	0.111
WH	−0.007	−0.184**	−0.017	−0.015	0.056
BS	−0.290***	−0.069	−0.110	0.061	0.067
SDa	0.009	−0.163	0.010	−0.078	0.063
QDp	−0.100	−0.187**	−0.137*	−0.070	0.111

Data are shown as correlation coefficient from Pearson correlation analysis and biserial correlation analysis. *p < 0.05, ** p < 0.01, and *** p < 0.001. Abbreviations: YaD, Yang-deficiency; YiD, Yin-deficiency; QDf, Qi-deficiency; PW, Phlegm-wet; WH, Wet-heat; BS, blood-stasis; SDa, special-diathesis; QDp, Qi-depression; BMI, body mass index.

3.2. Association between body characteristics and constitutional scores

In Table 2, the correlation coefficients between body characteristics and constitutions were listed. Male gender negatively correlated with scores of YaD, YiD, PW, and BS. Age negatively correlated with scores of YiD, PW, WH, and QDp. Basal mass index (BMI) had a positive correlation with the score of PW, but it had negative correlations with scores of YaD and QDp. Surgery history and chronic disease were not significantly correlated to any of the abnormal constitutions.

3.3. Association between indices of tongue inspection and constitutional scores

In Table 3, the MW of tongue body had a negative correlation with the score of QDp. The number of red dots on the tongue surface had positive correlations with scores of YiD and WH. The proportion of STM had positive correlations with scores of PW, BS, and QDp. Number of stasis dots, length of sublingual vein, width of sublingual vein, and the thickness of tongue coating were not significantly correlated to any of the abnormal constitutions.

Table 4 shows the correlation coefficients between tongue color values and body constitutions. Under the RGB model, the G color value had positive correlations with scores of YaD and BS, and the B color value had a positive correlation with the score of BS. Under the HSb model, the S value, had a negative correlation with the score of YiD, and the b value had a positive correlation with the score of YaD.

3.4. Association between acoustic indices and constitutional scores

In Table 5, acoustic intensity had negative correlations with scores of YaD, YiD, QDf, BS, and QDp. All the pitch related indices, MaxP, AvgP, and MiniP, had positive correlations with scores of YaD, YiD, QDf, and BS, with the exception that MiniP did not have significant correlation with the score of QDf. ANZC had negative correlations with scores of YaD, QDf, and BS, and HSER had a negative correlation with the score of QDp.

3.5. Association between indices of pulse waveforms and constitutional scores

In Table 6, the h$_1$ had negative correlations with scores of YaD, QDf, and QDp. The RET had negative correlations with scores of YiD, WH, and SDa. Both the systolic area indices, sSA and tSA, had negative correlations with scores of YaD and QDp. The unsmooth wave had a negative correlation with the score of SDa.

Table 3

Correlation between scores of the eight abnormal constitutions and indices of tongue inspection.

	Maximum width of tongue body	Number of red dots	Number of stasis dots	Length of sublingual vein	Width of sublingual vein	Coating index (MWTCI)	Proportion of scalloped tongue margin (%)
YaD	−0.086	0.045	0.086	0.017	0.059	0.087	0.114
YiD	−0.020	0.145*	−0.022	−0.119	−0.032	0.036	0.093
QDf	−0.114	−0.037	−0.002	−0.036	0.025	−0.053	0.068
PW	0.003	0.007	−0.022	−0.050	−0.008	0.074	0.138*
WH	0.082	0.135*	−0.057	−0.039	−0.045	0.128	0.120
BS	−0.054	0.071	0.055	−0.021	0.023	0.082	0.165*
SDa	−0.002	0.114	0.018	−0.024	−0.021	−0.048	0.102
QDp	−0.123*	0.043	−0.005	−0.102	−0.010	0.010	0.127*

Data are shown as Pearson correlation coefficient. *$p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$. Abbreviations: YaD, Yang-deficiency; YiD, Yin-deficiency; QDf, Qi-deficiency; PW, Phlegm-wet; WH, Wet-heat; BS, blood-stasis; SDa, special-diathesis; QDp, Qi-depression.

Table 4

Correlation between scores of the eight abnormal constitutions and tongue color values.

	R	G	B	H	S	b
YaD	0.112	0.142*	0.110	0.058	0.063	0.176**
YiD	0.039	0.094	0.117	0.070	−0.139*	0.084
QDf	−0.019	0.037	0.055	0.028	−0.055	0.060
PW	0.015	0.039	0.079	−0.038	−0.096	0.026
WH	−0.047	−0.013	0.046	−0.069	−0.110	0.032
BS	0.085	0.176**	0.161**	0.075	−0.062	0.099
SDa	0.103	0.096	0.118	−0.029	−0.075	0.083
QDp	0.056	0.092	0.114	0.027	−0.077	0.101

Data are shown as Pearson correlation coefficient. *$p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$. Abbreviations: YaD, Yang-deficiency; YiD, Yin-deficiency; QDf, Qi-deficiency; PW, Phlegm-wet; WH, Wet-heat; BS, blood-stasis; SDa, special-diathesis; QDp, Qi-depression.

3.6. Prediction of the eight abnormal constitutions by indices of the tongue, acoustic sound, and pulse

For each of the eight normal constitutions, indices that correlated with the constitution were entered into the linear regression model, and a linear equation for predicting the score of each abnormal constitution was built. Table 7 shows the linear equations and their sensitivities and specificities for predicting scores of the eight abnormal constitutions.

4. Discussion

This study was designed according to the TCM belief that constitution should be diagnosed using a combination of multiple TCM diagnosis methods. Therefore, the correlations between abnormal constitutions and the indices of the tongue, acoustic sound, and pulse were investigated simultaneously. Indices that were crucial for the diagnosis of the eight abnormal constitutions were identified by correlation analysis, and the degree of correlation revealed the relative weight of the indices for the diagnosis of a certain constitution. Furthermore, a constitution prediction equation for each of the eight abnormal constitutions was built by entering significant indices into a linear regression model. The equation can be used to predict constitutional scores using significant indices of the tongue, acoustic sound, and pulse.

Based on the results of correlation analysis, the present study not only revealed important indices for the diagnosis of constitutions, but identified the order of relative importance for these indices, which has not been emphasized in the TCM diagnosis textbook. For example, the TCM diagnosis textbook states that red color of the tongue body, the presence of red dots on the surface of the tongue, and rapid pulse are all considered signs of 'heat' [12], however, there is no relevant literature regarding which is more important for the diagnosis of heat. The present study found that the number of red dots significantly correlated with constitutions related to heat, including YiD and WH, while the red color of the tongue body and the rapid pulse did not correlate with either of the two heat constitutions, implying that red dots have greater significance in the diagnosis of heat constitution. Therefore, the relative weights described herein not only validate traditional TCM diagnosis methods but also helps prioritize indices for TCM practitioners in the diagnosis of constitution.

In addition to biological signals, relationship between body characteristics and constitutions were investigated. First, females were found to be more likely to have abnormal constitutions of YaD, YiD, PW, and BS than males. This result was partially consistent with the epidemiological survey that was done in nine provinces with 21,948 people in China, which shows that females were more likely to have abnormal constitutions of YaD, YiD, and BS than males [35]. Second, our study found that age negatively correlated with abnormal constitution of YiD, PW, WH, and QDp, which was partially consistent with the above-mentioned survey [35]. As for BMI, a previous study conducted in Hong Kong found that BMI higher than 25 was associated

Table 5

Correlation between scores of the eight abnormal constitutions and acoustic indices.

	Intensity (Db)	MaxP (Hz)	AvgP (Hz)	MiniP (Hz)	ANZC	VPV	VFF	LSER	HSER
YaD	−0.138*	0.190**	0.175**	0.129*	−0.129*	0.050	0.008	0.000	0.016
YiD	−0.153*	0.211**	0.216**	0.162**	−0.114	0.097	−0.030	−0.040	−0.102
QDf	−0.127*	0.125*	0.119*	0.105	−0.176**	0.047	0.038	0.075	−0.093
PW	−0.077	0.095	0.111	0.095	−0.115	0.069	−0.019	0.028	−0.111
WH	−0.089	−0.024	−0.026	−0.043	−0.029	0.026	−0.013	0.046	−0.072
BS	−0.207**	0.264**	0.273**	0.252**	−0.176**	0.003	−0.055	−0.074	−0.114
SDa	−0.094	0.056	0.042	−0.002	−0.083	0.045	0.002	0.097	−0.028
QDp	−0.173**	0.061	0.070	0.073	−0.082	−0.070	0.024	0.077	−0.126*

Data are shown as Pearson correlation coefficient. *$p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$. Abbreviations: YaD, Yang-deficiency; YiD, Yin-deficiency; QDf, Qi-deficiency; PW, Phlegm-wet; WH, Wet-heat; BS, blood-stasis; SDa, special-diathesis; QDp, Qi-depression; MaxP, maximum pitch; AvgP, average pitch; MiniP, minimum pitch; ANZC, average number of zero-crossings; VPV, Variation in peaks and valleys; VFF, variation in formant frequencies; LSER, low spectral energy ratio; HSER, high spectral energy ratio.

Table 6

Correlation between scores of the eight abnormal constitutions and pulse waveforms.

	h1 (mmHg)	h3 (mmHg)	RET (msec)	sSA (mmHg*sec)	tSA (mmHg*sec)	Pulse rate (beats/min)	Unsmooth wave
YaD	−0.198**	−0.029	−0.091	−0.169**	−0.177**	0.004	−0.020
YiD	−0.079	0.064	−0.142*	−0.065	−0.074	−0.039	−0.079
QDf	−0.120*	−0.011	−0.070	−0.114	−0.104	0.023	−0.027
PW	−0.060	0.033	−0.070	−0.039	−0.044	−0.035	−0.056
WH	−0.098	0.060	−0.179**	−0.061	−0.063	−0.021	−0.042
BS	−0.077	−0.028	−0.019	−0.084	−0.063	0.033	0.042
SDa	0.010	0.076	−0.208**	−0.019	0.038	0.035	−0.129*
QDp	−0.120*	0.040	−0.113	−0.131*	−0.129*	0.028	0.015

Data are shown as Pearson correlation coefficient. $*p < 0.05$, $** p < 0.01$, and $*** p < 0.001$. Abbreviations: YaD, Yang-deficiency; YiD, Yin-deficiency; QDf, Qi-deficiency; PW, Phlegm-wet; WH, Wet-heat; BS, blood-stasis; SDa, special-diathesis; QDp, Qi-depression; h_1, height of main wave; h_3, height of dicrotic wave, RET, rapid ejection time; sSA, single systolic area; tSA, one minute systolic area.

with almost all types of abnormal body constitution [36], but the present study found that BMI only positively correlated to abnormal constitution of PW, and negatively correlated to YaD and QDp.

Important indices for the diagnosis of each of the eight constitutions were identified in the present study. For YaD, b and G color values of the tongue body, and MaxP of the acoustic sound were positively correlated with the score of YaD, while the intensity and ANZC of the acoustic sound and h_1 of the pulse waveforms were negatively associated with it. This implied that people with YaD have a pale or greenish tongue, low-intensity but high-pitch voice, and weak pulses. Among these indices, the pulse pressure index h_1, which is an incident wave generated by the contraction of the left ventricle, representing cardiac stroke volume, was identified [37]. A previous study revealed that YaD patients have a low pulse pressure [17]. This finding coincides with the findings of the present study. The negative correlation between the score of YaD and h_1 implied that people with YaD may have relatively weak heart ejection function. For YiD constitution, the number of red dots on the tongue and the AvgP of acoustic sound were positively correlated with the score of YiD, while the S color value of the tongue, the intensity of acoustic sound, and the RET of the pulse waveforms were negatively correlated with YiD score. This implied that people with YiD are more likely to have tongues with red dots and low color saturation, and voices with low intensity but high pitch. Their pulse waveforms showed a decreased RET, representing a shorter duration of the rapid ejection phase of the left ventricle, which is consistent with the previous study [17]. For QDf, the MaxP of the acoustic sound had a positive correlation with the score of QDf, while the intensity and ANZC of the acoustic waves, and h_1 of the pulse waveforms had negative correlations with QDf score. This implied that people with QDf constitution may speak in a low-intensity but high-pitch voice, and may

have a relatively weak heart ejection function due to the low h_1 value, which is consistent with several studies showing that QDf syndrome commonly existed in patients with heart failure [38,39]. For PW and WH constitution, literature regarding their association with biological signal data is very limited, and our findings were the first to disclose the indices associated with PW and WH. For PW, the associated index was the proportion of the STM, which was positively correlated with the score of PW. For WH, the score of WH was positively correlated with the number of red dots on the tongue, while it was negatively correlated with RET, implying that red dots and a shorter duration of the rapid ejection phase of the heart could be found in people with WH. For BS constitution, the score of BS constitution was positively correlated with the proportion of STM, G and B values of the tongue, and AvgP of the acoustic sound, while the intensity and ANZC of the acoustic sound were negatively correlated with the score of BS. This implied that people with BS constitution are more likely to have a green-blue tongue color with a large proportion of STM, and speak in a low-intensity but high-pitch voice. A previous study reported that BS constitution is correlated with petechiae in type 2 diabetes patients [40], while subjects participating in this study seldom had tongue petechiae. For the SDa constitution, the indices RET and unsmooth wave were negatively correlated with the score of SDa. As SDa constitution is often associated with a susceptibility to allergic reactions, the result indicated short RET and unsmooth pulse waves could be found in people with allergies. This finding is consistent with previous studies reporting that respiratory allergy is correlated with arterial stiffness [41,42]. Finally, for QDp, the present study found that the proportion of STM was positively correlated with the score of QDp, while the MW of the tongue, intensity and HSER of the acoustic sound, and sSA of the pulse waveforms were negatively correlated. The data indicated that people with a QDp

Table 7

Constitution equations and their performance measures built by multivariate linear regression models.

	Equation	R^2	Sn	Sp	p value
YaD	$YaD = 20.027 − 0.021 \times Gender − 0.134 \times BMI − 0.002 \times G + 0.123 \times b$ $− 0.017 \times Intensity + 0.078 \times MaxP − 0.047 \times ANZC − 0.151 \times h1$	0.103	44.0%	82.6%	0.016
YiD	$YiD = 58.463 − 0.036 \times Gender − 0.246 \times Age + 0.050 \times Red\ dots − 0.097 \times S$ $− 0.025 \times Intensity + 0.163 \times AvgP − 0.021 \times RET$	0.146	67.6%	61.3%	0.009
QDf	$QDf = 63.156 − 0.068 \times Intensity + 0.016 \times MaxP − 0.146 \times ANZC − 0.094 \times h1$	0.050	43.5%	65.0%	0.684
PW	$PW = 15.878 − 0.155 \times Gender − 0.181 \times Age + 0.215 \times BMI + 0.136 \times STM$	0.093	76.6%	38.3%	0.947
WH	$WH = 41.852 − 0.108 \times Age + 0.066 \times Red\ dots − 0.106 \times RET$	0.048	37.9%	77.4%	0.738
BS	$BS = 40.948 − 0.172 \times Gender + 0.165 \times STM − 0.069 \times G + 0.126 \times B$ $− 0.128 \times Intensity + 0.083 \times AvgP − 0.010 \times ANZC$	0.136	46.2%	78.1%	0.265
SDa	$SDa = 41.027 − 0.187 \times RET − 0.073 \times Unsmooth\ wave$	0.048	62.1%	58.4%	0.187
QDp	$QDp = 100.166 − 0.128 \times Age − 0.082 \times BMI − 0.086 \times MW + 0.127 \times STM$ $− 0.089 \times Intensity − 0.162 \times HSER − 0.087 \times sSA$	0.115	47.6%	72.9%	0.202

Abbreviations: ANZC, average number of zero-crossing; AvgP, average pitch; b, b color value in the HSb color model; B, B color value in the RGB color model; BMI: body mass index; BS, blood-stasis; G, G color value in the RGB color model; h1, height of main wave; HSER, high spectral energy ratio; MaxP, maximum pitch; MW, maximum width of the tongue body; PW, Phlegm-wet; QDf, Qi-deficiency; QDp, Qi-depression; RET, rapid ejection time; S, S color value in the HSb color model; SDa, special-diathesis; Sn, sensitivity; Sp, specificity; sSA, single systolic area; STM, proportion of the scalloped tongue margin; WH, Wet-heat; YaD, Yang-deficiency; YiD, Yin-deficiency.

constitution may speak in a low-intensity voice, and have a small tongue with large proportion of STM. STM has been reported as one of the signs of bruxism [43], which is usually caused by psychosocial factors [44]. The above report coincides with the present study, since psychological symptoms such as depression, anxiety, and panic are commonly observed in subjects with QDp constitution [30].

The first limitation of this study was that the tool for diagnosing constitutions, i.e. the Nine-Constitution Scale, does not contain all the abnormal constitutions. For example, Blood-deficiency, a commonly seen constitution clinically, is not included in this questionnaire. We used this questionnaire due to its high reliability, internal consistency, and the fact that it has been utilized in several large-scale studies [30,35,45]. A further modification on the questionnaire is necessary. The second limitation was that the subject collection process in this study lasted for one year, throughout the four seasons. We cannot exclude the influence of weather, although the indoor room environment was controlled. The third limitation was that the three basic diagnosis instruments might not be enough to diagnose constitution, and therefore other instruments need to be adopted. The fourth limitation was that there might be mutual effects of different abnormal constitutions on a certain index, which needs to be clarified in future works. The last limitation was that there might be sampling bias in this study. Since we recruited subjects through an advertisement at a medical center and the study was performed during the daytime, subjects recruited in this study might not able to represent general population.

5. Conclusions

In this study, the constitution identification process was done by integrating indices of the tongue, acoustic sound, and pulse. The correlation between each index and a certain constitution identified the relative importance of each index, providing vital information for TCM practitioners with regard to constitution diagnosis. Finally, equations for scores of each constitution were built using the significant indices. This study suggested priorities of indices for each of the abnormal constitutions, and provided evidence-based literature for practitioners in the field of TCM diagnosis.

Conflicts of interest

The authors declared that there were no conflicts of interest.

Funding

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.eujim.2019.04.001.

References

[1] Y. Deng, H. Yang, M. Tang, P. Wang, L. Zhang, Y. Shi, Clinical therapeutic effect on bronchial asthma in children of different body constitutions treated with sanfu pingchuan plaster and sanjiu zhichuan plaster, Chin. Acupuncture Moxibustion 37 (4) (2017) 386–390.

[2] Y. Li, X.H. Li, X. Huang, L. Yin, C.X. Guo, C. Liu, Y.M. He, X. Liu, H. Yuan, Individualized prevention against hypertension based on traditional Chinese medicine constitution theory: a large community-based retrospective, STROBE-compliant study among Chinese population, Medicine 96 (46) (2017) e8513.

[3] M. Li, S. Mo, Y. Lv, Z. Tang, J. Dong, A study of traditional Chinese medicine body constitution associated with overweight, obesity, and underweight, Evid. Complement. Alternat. Med. 2017 (2017) 8.

[4] T. Yu, Z. Zhang, L. Xie, X. Ke, Y. Liu, The influence of traditional Chinese medicine constitutions on the potential repair capacity after osteonecrosis of the femoral head, Complement. Ther. Med. 29 (2016) 89–93.

[5] J. Liu, F. Xu, N. Mohammadtursun, Y. Lv, Z. Tang, J. Dong, The analysis of constitutions of traditional Chinese medicine in relation to cerebral infarction in a Chinese sample, J. Altern. Complement. Med. 24 (5) (2018) 458–462.

[6] Y.L. Ma, H. Yao, W.J. Yang, X.X. Ren, L. Teng, M.C. Yang, Correlation between traditional Chinese medicine constitution and dyslipidemia: a systematic review and meta-analysis, Evid. Complement. Alternat. Med. 2017 (2017) 7.

[7] C.I. Tsai, Y.C. Su, S.Y. Lin, I.T. Lee, C.H. Lee, T.C. Li, Reduced health-related quality of life in body constitutions of yin-xu, and yang-xu, stasis in patients with type 2 diabetes: Taichung diabetic body constitution study, Evid. Complement. Alternat. Med. 2014 (2014) 10.

[8] Q.Y. Jiang, J. Li, L. Zheng, G.H. Wang, J. Wang, Constitution of traditional chinese medicine and related factors in women of childbearing age, J. Chin. Med. Assoc. 81 (4) (2018) 358–365.

[9] Q. Jiang, J. Li, G. Wang, J. Wang, The relationship between constitution of traditional Chinese medicine in the first trimester and pregnancy symptoms: a longitudinal observational study, Evid. Complement. Alternat. Med. 2016 (2016) 8.

[10] H. Lv, L. Zhu, Z. Chen, H. Jin, L. Jin, Physical and mental health conditions of young college students with different Traditional Chinese Medicine constitutions in Zhejiang Province of China, J. Tradit. Chin. Med. 35 (6) (2015) 703–708.

[11] Y.C. Su, Establishment of traditional Chinese medical constitutional scale and classificatory index (2-1), Yearb Chin. Med. Pharm. 25 (5) (2007) 45–144.

[12] Q. Yi, A. Stone, Traditional Chinese Medicine Diagnosis Study Guide, Eastland Press, Seattle, 2008.

[13] H.H. Wang, C.H. Pan, P.P. Wu, S.F. Luo, H.J. Lin, C.H. Wu, Alteration of the tongue manifestation reflects clinical outcomes of peptic ulcer disease, J. Altern. Complement. Med. 18 (11) (2012) 1038–1044.

[14] R. Kanawong, T. Obafemi-Ajayi, T. Ma, D. Xu, S. Li, Y. Duan, Automated tongue feature extraction for ZHENG classification in traditional Chinese medicine, Evid. Complement. Alternat. Med. 2012 (2012) 912852-912852.

[15] J. Zhang, J. Xu, X. Hu, Q. Chen, L. Tu, J. Huang, J. Cui, Diagnostic method of diabetes based on support vector machine and tongue images, Biomed. Res. Int. 2017 (2017) 7961494-7961494.

[16] J. Ye, X. Cai, J. Yang, X. Sun, C. Hu, J. Xia, J. Shen, K. Su, H. Yan, Y. Xu, Y. Zhang, S. Zhang, L. Yang, H. Zhi, S. Gao, Q. Yu, J. Hu, P. Cao, Bacillus as a potential diagnostic marker for yellow tongue coating, Sci. Rep. 6 (2016) 32496-32496.

[17] H.K. Wu, Y.S. Ko, Y.S. Lin, H.T. Wu, T.H. Tsai, H.H. Chang, The correlation between pulse diagnosis and constitution identification in traditional Chinese medicine, Complement. Ther. Med. 30 (2017) 107–112.

[18] C.M. Huang, H.C. Chang, S.T. Kao, T.C. Li, C.C. Wei, C. Chen, Fj. Chen, S.S. Tsou, Radial pressure pulse and heart rate variability in normotensive and hypertensive subjects, J. Altern. Complement. Med. 17 (10) (2011) 945–952.

[19] C.M. Huang, H.C. Chang, S.T. Kao, T.C. Li, Y.T. Liao, C.C. Wei, C. Chen, Application of sphygmography to detection of dyspepsia and the rhinitis, Am. J. Chin. Med. 39 (2) (2011) 271–285.

[20] F.J. Chen, H.S. Wang, C.Y. Huang, Y.S. Chen, Pulse analysis in bipolar disordered and nonpsychotic human subjects, Am. J. Chin. Med. 40 (3) (2012) 455–465.

[21] K. Tjaden, V. Martel Sauvageau, Consonant acoustics in Parkinson's disease and multiple sclerosis: comparison of clear and loud speaking conditions, Am. J. Speech. Pathol. 26 (2S) (2017) 569–582.

[22] E. Vaiciukynas, A. Verikas, A. Gelzinis, M. Bacauskiene, Detecting Parkinson's disease from sustained phonation and speech signals, PLoS One 12 (10) (2017) e0185613-e0185613.

[23] H. Jin, L.A. Lee, L. Song, Y. Li, J. Peng, N. Zhong, H.Y. Li, X. Zhang, Acoustic analysis of snoring in the diagnosis of obstructive seep apnea syndrome: a call for more rigorous studies, J. Clin. Sleep Med. 11 (7) (2015) 765–771.

[24] L.D. Ruiz Allec, X. Hernández López, J.B. Arreguín Porras, R. Velasco Ramos, J.C. Pacheco del Valle, A.I. Pérez García, Alterations in voice, speech and swallowing in patients with with Sjögren's syndrome, Acta Otorrinolaringol. Esp. 62 (4) (2011) 255–264.

[25] C.C. Chiu, H.H. Chang, C.H. Yang, Objective aauscultation for traditional chinese medical diagnosis using novel acoustic parameters, Comput. Methods Programs Biomed. 62 (2) (2000) 99–107.

[26] L.C. Lo, Y.F. Chen, W.J. Chen, T.L. Cheng, J. Chiang, The study on the agreement between automatic tongue diagnosis system and traditional Chinese medicine practitioners, Evid. Complement. Alternat. Med. 2012 (2012) 505063-505063.

[27] P.Y. Huang, W.C. Lin, B. Chiu, H.H. Chang, K.P. Lin, Regression analysis of radial artery pulse palpation as a potential tool for traditional Chinese medicine training education, Complement. Ther. Med. 21 (6) (2013) 649–659.

[28] J.J. Shu, Y. Sun, Developing classification indices for Chinese pulse diagnosis, Complement. Ther. Med. 15 (3) (2007) 190–198.

[29] J.J. Yan, R. Guo, Y.Q. Wang, G.P. Liu, H.X. Yan, C.M. Xia, X. Shen, Objective auscultation of TCM based on wavelet packet fractal dimension and support vector machine, Evid. Complement. Alternat. Med. 2014 (2014) 502348-502348.

[30] Q. Wang, Classification and diagnosis basis of nine basic constitutions in Chinese medicine, J. Beijing Univ. Tradit. Chin. Med. 28 (4) (2005) 1–8.

[31] S.Y. Su, C.H. Yang, C.C. Chiu, Q. Wang, Acoustic features for identifying constitutions in traditional Chinese medicine, J. Altern. Complement. Med. 19 (6) (2013) 569–576.

[32] Y.B. Zhu, Q. Wang, H.S. Xue, Q. Orikasa, Preliminary assessment on performance of constitution in Chinese medicine questionnaire, Chin. J. Clin. Rehabil. 10 (3) (2006) 15–17.

[33] L. T, M. A, H. H, E. J, Evaluation of tongue coating indices, Oral Dis. 13 (2) (2007) 177–180.

[34] S.Y. Su, C.C. Wei, C.L. Hsieh, J.Y. Tsao, T.C. Li, T.H. Lin, H.H. Chang, L.C. Lo, Influence of menstrual cycle on pulse pressure waveforms measured from the radial artery in biphasic healthy women, J. Altern. Complement. Med. 15 (6) (2009)

645–652.

[35] Q. Wang, Y.B. Zhu, Epidemiological investigation of constitutional types of Chinese medicine in general population: base on 21,948 epidemiological investigation data of nine provinces in China, China J. Tradit. Chin. Med. Pharm. 24 (1) (2009) 7–12.

[36] C. Low, P. Lai, H. Li, W. Ho, P. Wong, S. Chen, W. Wong, Neighbourhood effects on body constitution-a case study of Hong Kong, Soc. Sci. Med. 158 (2016) 61–74.

[37] J.R. Levick, An Introduction to Cardiovascular Physiology, A Hodder Arnold Publication, London, 2003.

[38] X.Q. Li, J.C. He, P.X. Huang, X.B. Cao, Chinese medicine syndromes in congestive heart failure: a literature study and retrospective analysis of clinical cases, Chin. J. Integr. Med. 22 (10) (2016) 738–744.

[39] J.W. Luo, X.R. Meng, F.M. Huang, D. Hu, X. Yang, X.Y. Zheng, S.C. Wei, M.M. Guo, S.M. Wu, H.Y. Chen, Methylation in promoter region of SLC6A2 gene in heart failure patients and its correlation with qi deficiency/blood stasis syndrome, Chin. J. Integr. Tradit. West Med. 35 (12) (2015) 1448–1454.

[40] P.C. Hsu, Y.C. Huang, J. Chiang, H.H. Chang, P.Y. Liao, L.C. Lo, The association between arterial stiffness and tongue manifestations of blood stasis in patients with type 2 diabetes, BMC Complement. Altern. Med. 16 (1) (2016) 324-324.

[41] I. Tuleta, D. Skowasch, F. Aurich, N. Eckstein, R. Schueler, C. Pizarro, N. Schahab, G. Nickenig, C. Schaefer, S. Pingel, Asthma is associated with atherosclerotic artery changes, PLoS One 12 (10) (2017) e0186820-e0186820.

[42] M. Steinmann, C. Abbas, F. Singer, C. Casaulta, N. Regamey, D. Haffner, D.C. Fischer, G.D. Simonetti, Arterial stiffness is increased in asthmatic children, Eur. J. Pediatr. 174 (4) (2015) 519–523.

[43] P. Heasman, Master Dentistry: Restorative Dentistry, Paediatric Dentistry and Orthodontics, 2 ed., Churchill Livingstone, Edinburgh, 2008.

[44] S. Shetty, G.P.S. Kumar, V. Pitti, C.L.S. Babu, B.C. Deepthi, Bruxism: a literature review, J. Indian Prosthodont. Soc. 10 (2010) 141–148.

[45] Q. Wang, Y.-B. Zhu, H.-S. Xue, S. Li, Primary compiling of constitution in Chinese medicine questionnaire, Chin. J. Clin. Rehabil. 10 (3) (2006) 12–14.