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Research

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Close Correlations between the Carotid and Radial Relative Artery Blood Flow Velocity Ratio and BMI and Temperature in Normal Individuals

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Abstract

Background: Measuring carotid and radial pulses as a diagnostic method plays a vital role in sphygmology applied via traditional Chinese medicine (TCM). In particular, many TCM theories and doctors have indicated that the pulse force ratio is closely correlated with human physiological conditions, such as weight and body temperature. However, few studies have explored these potential correlations. Thus, the purpose of this study was to investigate the relationships between the pulse strength ratio and human metabolism indicators.

Methods: The carotid and radial relative artery blood flow velocity (RABFV) and pulse force from 122 normal adults were examined by ultrasound and manual palpation by a doctor, and the same group was tested via a thermal texture map (TTM).

Results: Obvious differences in the body side and sex were not observed in the ratio of carotid and radial RABFV among normal individuals ($p>0.05$). However, the ratio of young people was greater than that of old people ($p<0.001$), and strong support was obtained for traditional Chinese medicine (TCM) assumptions of seasonal differences in the ratio ($p<0.001$). Furthermore, we discovered that the ratio had a negative correlation with BMI and torso temperature but a positive correlation with hand temperature.

Conclusion: Our results demonstrated that the ratio of carotid and radial RABFV could serve as an indicator of human physical conditions, such as BMI and human temperature, and represents a valuable tool for evaluating yin-yang properties in TCM clinical practice. The close correlations reported above verified some theories of TCM and provided strong support for sphygmology in TCM.

Keywords: Relationship, Ratio, RABFV, BMI, Human Temperature

Background

Manual palpation of carotid and radial arteries is a traditional pulse-taking method that is widely used for the diagnosis of meridian disease according to the context of traditional Chinese medicine (1-3).

The carotid artery, also called the Renying pulse, belongs to the stomach yang meridian and is used to evaluate the yang element in healthy conditions based on TCM theory and reflects the comprehensive function of the heart and arterial systems in Western medicine. The radial artery, named the Cunkou pulse, belongs to the lung yin meridian and is critical for determining the prognosis and modality of yin elements in humans. According to *Huang Di Nei Jing,* a classical TCM text, the ratio of Renying and Cunkou pulse forces reflects the functional and physical states of human beings (4-6). For instance, if the Cunkou pulse is larger than the Renying pulse, then the yin element will achieve a dominant position in the body, resulting in a lower temperature compared to normal conditions (3, 5, 6). In contrast, a thin individual usually produces more heat than a heavier individual due to yin deficiency (3, 5, 6). However, these important TCM physiology theories have not been verified by modern scientific experiments. Moreover, although many studies have investigated the characteristics of carotid and radial arteries separately, few reports have made a direct connection between the two arteries (7-12). Thus, we investigated potential relationships between pulse ratios and human physical activities in an attempt to prove and correct some assumptions of TCM.

Methods

Subjects

This study included a total of 122 adults (57 males, age: 40.05±2.68 years, height: 175.06±2.08 cm, weight: 70.23±8.29 kg; 65 females, age: 40.29±1.73 years, height: 160.38±5.45 cm, weight: 60.56±6.57 kg) who were 19 to 66 years of age, had no underlying diseases and were not prescribed any medicines.

The criteria for exclusion were as follows: mental and psychological disorders arrhythmia, atherosclerosis, arterial thrombosis, systolic blood pressure>140, diastolic blood pressure<60, wounds or scars in the region of pulse measurement, BMI<17 or >30, pregnancy, and menstruation.

All participants provided written informed consent. This study was approved by the Institutional Review Board of Oriental Hospital of Ruijing Hospital, Shanghai, China (approval no. KY2020-360).

Experimental equipment

During our study, a Sonoscape S15 (SN3026759) Colour Doppler Ultrasonic Diagnostic Apparatus (Sonoscape Medical, Ltd. Guangdong, China) equipped with a 1-5-MHz heart broadband probe and a 5-13-MHz vascular probe were adopted (Sonoscape Medical, Ltd. Guangdong, China). The apparatus used for the body temperature study was a TSI-2000 TTM manufactured by the Bioyear Group company (Beijing, China). A thermograph camera (Bioyear Group, Ltd, Beijing, China), with a measurement range from -20 to 60°C and a resolution of 640 × 480 pixels, was used to obtain thermographic images.

Manual pulse measurements

Pulse measurements were conducted in a quiet room by only one TCM doctor. The room temperature was kept constant at 24 and 26°C, and humidity was maintained between 40 and 60%. All participants rested for 30 minutes on a comfortable bed prior to the pulse measurement. The radial and carotid arteries were manually measured with the participants lying in a supine position. The Cunkou pulse was measured at the radial artery along the radius styloid, while the Renying pulse was also measured at the carotid artery along the anterior border of the sternocleidomastoid muscle. All measurements were repeated three times. The pulse force was tested, compared and recorded via manual palpation by one TCM doctor.

Relative arterial blood flow velocity measurement and analysis

Before testing, all participants were allowed to rest for 30 minutes on a comfortable bed. Both the radial and carotid arteries were measured with the participant in a supine position. The pulse sites were consistent with those for the manual pulse measurements. The blood flow velocity measurement was performed using a duplex ultrasound equipped with two-dimensional Doppler probes (1-5 and 5-13 MHz). The direction of the ultrasound beam was adjusted to produce an angle between 30° and 45°, and the angle was minimized as much as the anatomy allowed. The mean velocity was recorded continuously for 16 seconds, digitized, and stored as time-series data for further analysis. The arterial blood flow velocity waveforms were ensemble-averaged for 10 consecutive pulses. From the averaged waveform, we determined the following parameters in terms of flow velocity: peak systolic velocity (PSV) and end diastolic velocity (EDV). We calculated the following parameter as the relative arterial blood flow velocity: diastolic-to-systolic flow velocity = $|PSV| - |EDV|$. The ratio of relative arterial blood flow velocity was determined by comparing results from the same side of the body.

TTM measurement

The room temperature was controlled between 20 and 24°C, and the participants were asked to remove all clothing after resting for ten minutes in a conditioned room (humidity, 40-50%). The participants were asked to place their hands so that they did not touch the body. The TTM examinations were performed in several positions: anterior, dorsal, left lateral and right lateral to the body. Images were acquired with the subjects standing at these positions and the camera fixed approximately 70 cm away from the body.

BMI measurement

Self-reported weight and height from participants were deemed acceptably accurate if within ±2.0 kg or ±2.0 cm of the measured weight or height. The World Health Organization (WHO) classification of BMI was adopted for this study (13).

Statistical analysis

Data were expressed as the as mean ± standard deviation (*SD*). The data were analysed by SPSS version 15.0 (SPSS Inc., Chicago, IL, USA). An independent *t*-test was used to examine the potential differences in both intrinsic and extrinsic variables between the two groups. Serial changes between three groups were analysed based on two-way analysis of variance (ANOVA). Differences with P−values <0.05 were considered statistically significant, with significance levels marked as *P<0.05, **P<0.01, and ***P<0.001. The consistency between the two methods was determined based on the intraclass correlation coefficient (ICC) and the respective 95% confidence interval.

Results

Correlation of RABFV between ultrasound and manual palpation

First, the ICC test was used to examine whether the relative arterial blood flow velocity from ultrasound could represent the manual palpation results from TCM doctors. As seen in Fig. 1a-b, the ICC values between the machine and manual methods were 0.618 and 0.546 on the left and right sides, respectively, proving that the ratio of relative blood flow from ultrasound was positively correlated with manual palpations.

Ratio of RABFV based on body side and gender

As shown in Fig. 2a, significant differences were not observed in the results for the left and right sides regarding the ratio of blood flow velocity. A closer examination of the same figure shows that the average ratio of the carotid pulse was 1.5 times over that of radius, thus providing us with the overall percentage of pulses in normal individuals. Fig. 2b shows that the artery velocity rate was similar in terms of gender.

Ratio of RABFV for different ages and weather conditions

Fig. 2c compares the proportion of artery blood velocity based on the age distribution. The ratio was clearly higher in the young group ($\leq$40 years) than the aged group (>41 years), with noticeably larger values shown in the graph. Fig. 2d illustrates the relationship between the surrounding climate and the velocity ratio. As displayed in the picture, the ratios in cool and warm climates differed to a large extent. A closer examination of the figure shows that the rate of velocity was 1.76 in warm weather but dropped to 1.2 in the cold season (Fig. 2d).

RABFV ratio is inversely related to BMI

Fig. 3a shows that a lower blood velocity ratio corresponded to a higher BMI. Large differences in the ratio values were observed between the groups based on various weight/height indices. Specifically, the ratio of blood velocity in the light weight group was approximately 1.75 while that of the overweight group was less than 1.

RABFV ratio was positively correlated with human temperature

After determining the relationship between the blood velocity ratio and BMI, we sought to investigate the potential correlation between the ratio and body temperature. Fig. 3b illustrates that the torso temperature level dropped as the artery velocity ratio decreased. Fig. 4 further shows that the torso temperature differed considerably between the overweight and low-weight individuals under different blood velocity ratios. Interestingly, we found that hand temperature was negatively correlated with the ratio. As shown in Fig. 3c, a higher blood velocity ratio corresponded to lower hand temperatures in our testing group. Fig. 4 demonstrates that hand temperature was higher in people with a lower blood velocity ratio than in people with a higher ratio.

Discussion

In terms of pulse testing, many studies have focused on radial and carotid arteries. For instance, King examined 148 healthy humans to identify the characteristic radial pulse profiles based on gender differences (7). Yim investigated the physiological differences in radial pulse according to gender and measurement position in an objective manner (8). Although Luo performed research on both Renying and Cunkou pulses, the investigated hypertension group did not include normal individuals (11). Although many methods have been reported for the standardization of TCM pulse diagnosis, conflicts still exist (10, 12, 14-16). For instance, pulse wave velocity (PWV), a marker of arterial stiffness, is only able to measure the speed of travel of the pressure pulse between 2 given points within a limited time span (16, 17). In addition, Hodis doubted whether PWV is reliable when the arterial wall is thick (18). The augmentation index (AI), another measurement of pulse amplification, is not suitable for comparing pulses because the method of calculation between the two arteries lacks coherence (19). Moreover, manually checking pulse is a subjectivity activity; thus, certifying the relationship between manual operations and machine measurements is vital. Our experiment proved that the relative arterial blood flow velocity, which combines PSV and EDV, was suitable for representing the pulsating force and fluidity of pulsations checked by hand. Both PSV and EDV are vital haemodynamic parameters: PSV is a marker of blood vessel filling and blood supply strength, while EDV displays the blood perfusion situation (20). The blood velocity of the carotid artery is larger than that of the radius due to different artery diameters and blood supply forces in normal individuals (21-25). However, manually pulse measurements in practice do not always follow the rules. Our results showed that the relative arterial blood flow velocity of the radius could be 2 or 3 times larger than that of the carotid artery. Thus, the exceptional cases inspired us to identify the possible mechanism.

Renying and Cunkou pulses are mentioned 47 times in *Huang Di Nei Jing*, indicating their importance in TCM theory (4, 5). The book indicated that the pulse ratio was closely correlated with the yin-yang balance (2, 5, 6). Specifically, when the Renying pulse is larger than the Cunkou pulse, yang is larger than yin in humans, thus leading to greater heat in individuals and vice versa. Based on TCM yin-yang theory, young people are considered to have more yang than old people while yang is thought to be more common in summer than in winter (2, 4, 6). In addition, Western medicine has shown that changes in blood pressure and the cardiovascular system based on age differences also led to the response of radial and carotid arteries (10). Although we failed to find any gender-based differences in the ratio, some TCM physicians believe that the ratio differs based on sex (2, 3, 7, 8).

Regarding *Huang Di Nei Jing*, the ideal ratio of Renying and Cunkou in normal individuals is 1, which indicates equilibrium between yin and yang (4-6). However, we marked a question in the figure because the pulse force and width of the carotid artery appeared to be larger than those of the radial artery. Our experiment identified that the overall ratio in normal people was 1.5, which is consistent with human physiology findings.

TCM theories indicate that physiologically overweight individuals have weak heat and present yang deficiency and that thinner people have more heat and present yin weakness (4, 6). Ancient TCM books have explained this phenomenon as the insufficiency or hyperactivity of yin and yang, which leads to an imbalance in Qi or blood (2, 6, 26, 27). We believe that Qi and blood reflect the energy moving through the body, which can be demonstrated and evaluated by modern metabolic indices, such as human temperature and BMI. Here, our TTM results showed a significant difference in body temperature between the overweight and low-weight groups. Our TTM pictures clearly showed that adipose tissue with low temperature surrounded the torso of overweight individuals, and they showed that the low-weight individuals had less subcutaneous fat, resulting in a higher temperature on the surface. The ultrasound results demonstrated that overweight people had lower ratios of carotid and radial RABFV than low-weight people. The ratio of the artery blood velocities represented the activity of yang and yin; thus, a logical relationship was observed between the artery blood velocity ratio and human temperature. Interestingly, we also found that hand temperature was negatively correlated with the ratio. However, we failed to explain this finding due to limitations in knowledge. Further studies with a larger number of participants are needed in the future.

Conclusions

In conclusion, measuring radial and carotid relative blood arterial flow velocities and calculating their ratio provide information about human BMI and body temperature in clinical practice. In this study, the actual pulse rates and yin-yang properties conform with human temperature in the normal population and are compatible with TCM theoretical concepts, thus indicating that further demographic investigations should be performed to establish and explain TCM assumptions.

Abbreviations

TCM: traditional Chinese medicine (TCM); RABFV: relative arterial blood flow velocity; BMI: body mass index; TTM: thermal texture map; PSV: peak systolic velocity; EDV: end diastolic velocity; WHO: World Health Organization; SD: standard deviation; ICC: intraclass correlation coefficient; MSE: mean square error; PWV: pulse wave velocity; AI: augmentation index.

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Not applicable.

Authors' contributions

SJJ designed the study. ZX participated in the study design. ZX, RW and CY performed the research and wrote the manuscript. CY and WZY analysed the data. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used during this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

The human experiments were approved by the Institutional Review Board of Oriental Hospital of Ruijing Hospital, Shanghai, China.

Consent for publication

All authors have read and agreed to the published version of the manuscript.

Competing interests

The authors declare no conflict of interest.

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Figures

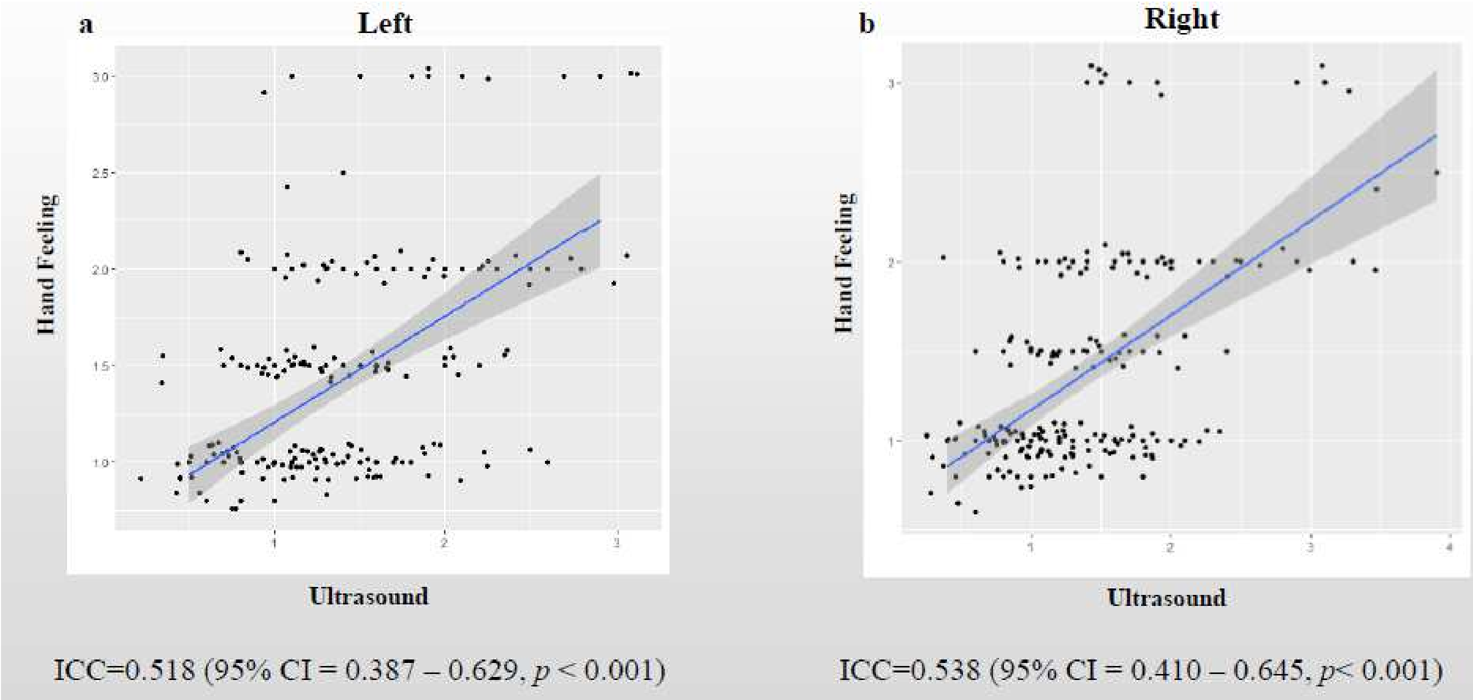

Figure 1

Relationship of pulse measurement between ultrasound and hand feeling on left (a) and right (b) sides. Carotid and radial relative arterial blood flow velocity were tested by an ultrasound while the pulse force from hand feeling was examined ,quantified and recorded by a doctor. The ratio of velocity was calculated and compared with the hand feeling results. The test of intraclass correlation coefficient (ICC) was used to assess the consistency between ultrasound and hand feeling. For left side (a) 95% CI= 0.387 - 0.629, p<0.001). For right side (b), 95% CI=0.410 - 0.645, p<0.001).

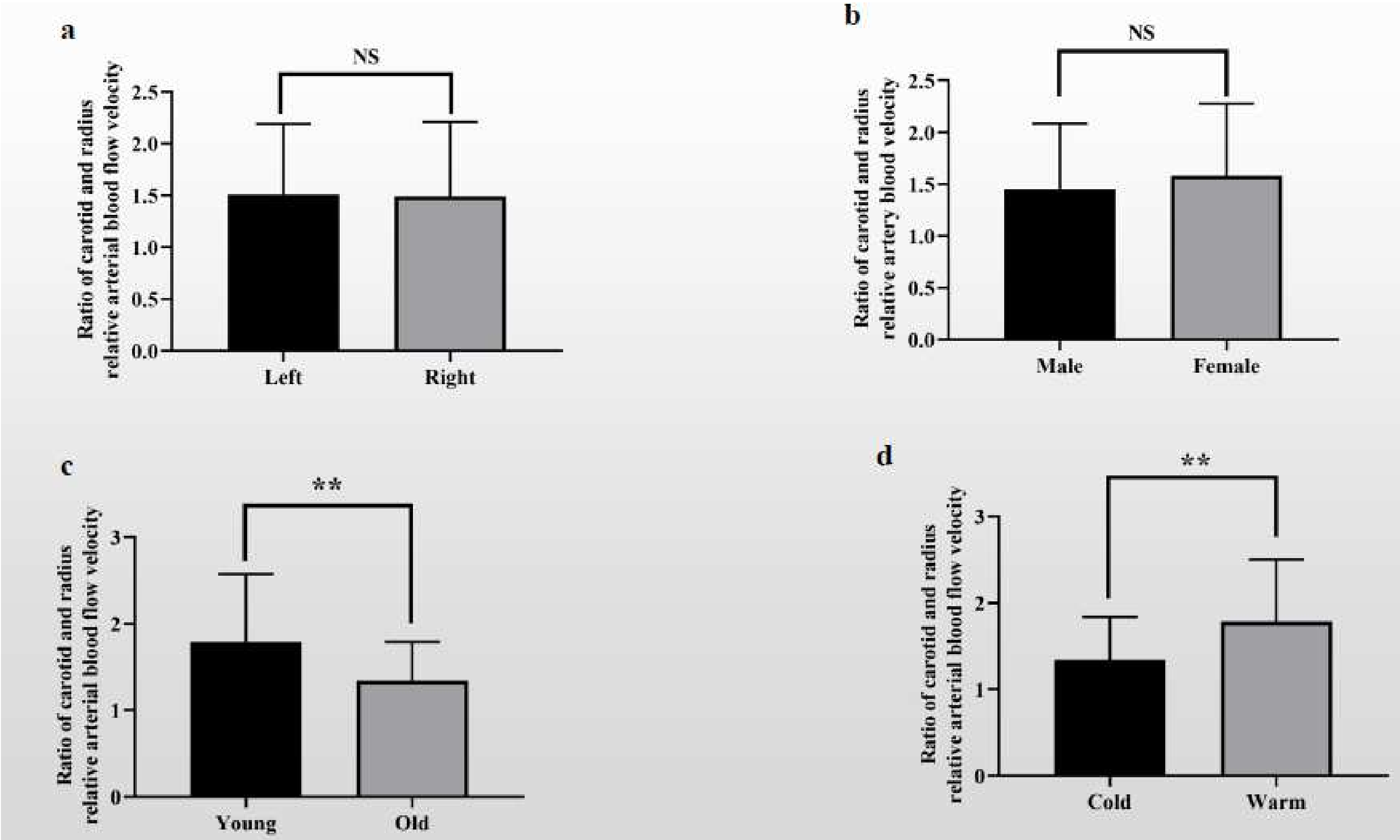

Figure 2

Relationship between the ratio of carotid and radial relative arterial blood flow velocity and influence factors. Carotid and radial arterial blood flow velocity from normal individuals were examined via an ultrasound. Correlation of ratio concerning both intrinsic and extrinsic parameters, such as side(a), gender(b), age(c) and surrounding climate(d) was shown in the graph. Data were expressed as means ± standard deviation (SD). The ratios were analyzed by independent t test. NS=not significant p>0.05, *p<0.05, **p<0.01, ***p<0.001.

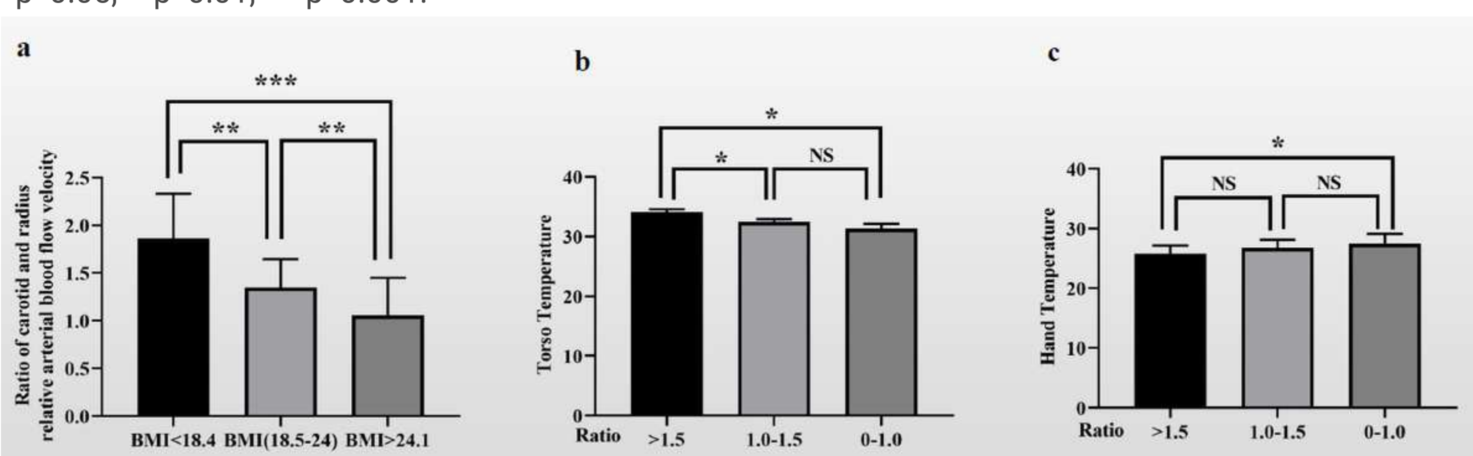

Figure 3

Relationships between ratio of carotid and radial relative arterial blood flow velocity, BMI and body temperature. BMI and ratio of blood velocity in were collected by self-reported documents and an ultrasound while the same group were scanned by TTM. Relation of ratios of blood velocity and BMI (a) was shown in the graph. Correlation between the temperature of torso (b) and hands (c) regarding to ratio of carotid and radial relative arterial blood velocity was demonstrated in the graph Data were analyzed using a two way ANOVA followed by Tukey's post hoc test. Values were expressed as means ± standard deviation(SD). NS=not significant p>0.05, *p<0.05, **p<0.01, ***p<0.001.

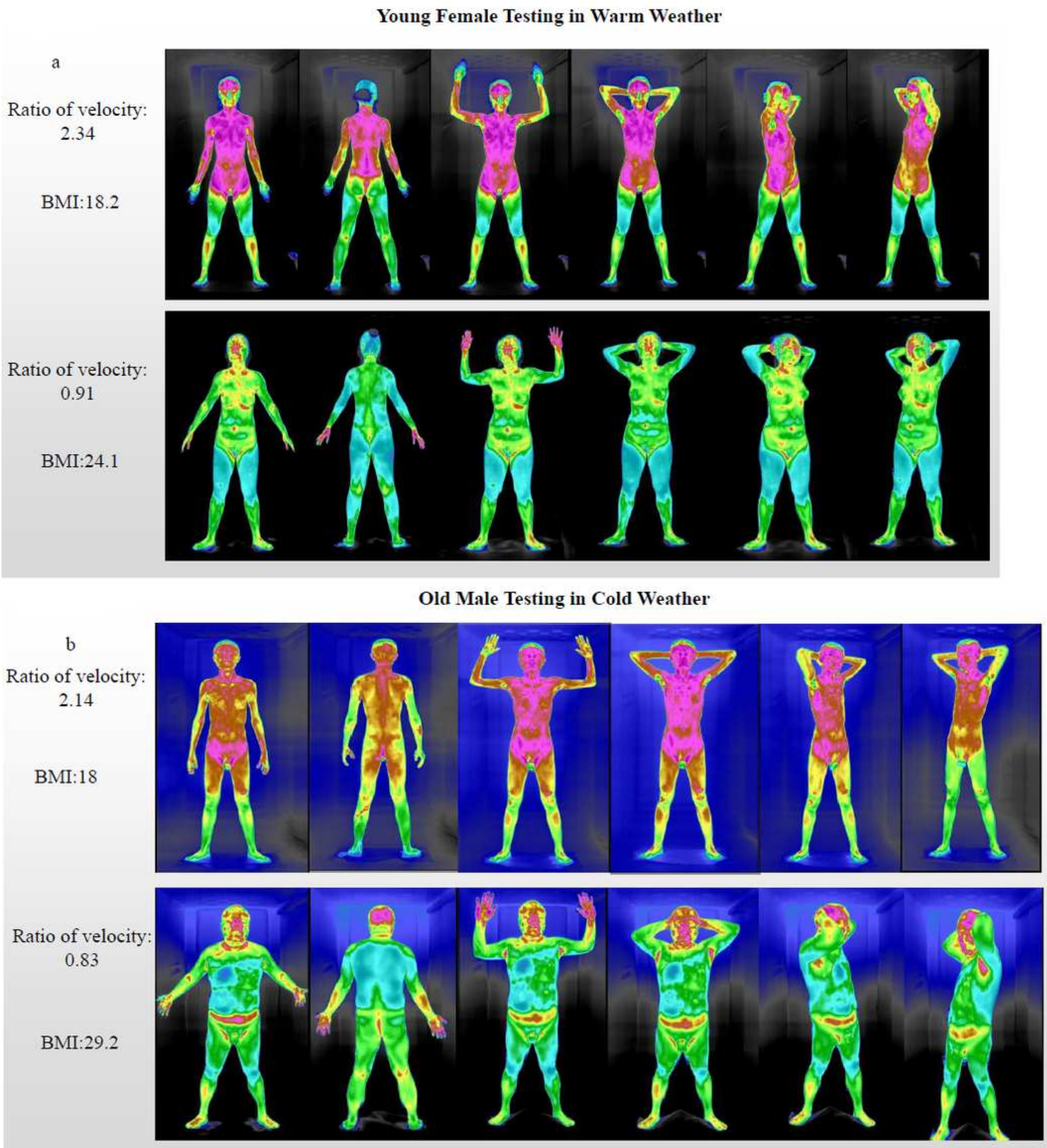

Figure 4

Images of TTM results on the relationship between ratio of carotid and radial relative arterial blood flow velocity, BMI and body temperature, Two young ladies with different ratio of carotid and radial relative arterial blood flow velocity and BMI were scanned by TTM in Summer (a). Two old men regarding to different ratio of carotid and radial relative arterial blood flow velocity and BMI were scanned by TTM in Winter (b). The TTM examinations were performed in several positions and images were recorded.