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Article

An Observational Study on the Associations between Arterial Stiffness and Health-Related Physical Fitness in Young Adults

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Abstract: Objective: The aim of this study was to explore the relationship between health-related physical fitness (HPF) and arterial stiffness, which was evaluated using skin autofluorescence (AF) to measure advanced glycosylation end products (AGEs) and pulse wave velocity (PWV). **Methods:** The 132 young adults aged 20–30 were recruited for this study. According to the National Physical Fitness Standards Manual, HPF was measured by the indicators that reflect the body composition, cardiopulmonary fitness, muscular fitness and flexibility. AGEs were evaluated through AF, which performed using a non-invasive detection system. PWV was measured by Pulse wave velocity measurement system. Spearman correlation analysis and multiple linear regression analysis were used for data analysis. **Results:** AF in young adults, whether male or female, was positively correlated with BMI and body fat (BF) (male: $p = 0.013$, $p = 0.0004$, female: $p = 0.049$, $p = 0.015$ with BMI and BF, respectively). AF in male young adults was negatively correlated with the cardiorespiratory endurance index (CEI) ($p = 0.046$). Multiple linear regression adjusted for age showed that AF and BF were positively correlated for only male young adults ($p = 0.032$). There was no significant correlation between the carotid-femoral or carotid-radial pulse wave velocity (CFPWV or CRPWV) and AF or any of the HPF indicators in the undergraduate participants ($p > 0.05$). **Conclusion:** BMI and body fat are the main factors affecting the risk of arterial stiffness in young adults, whether male or female. In addition, cardiorespiratory fitness is also the main factor for the risk of chronic disease in young male adults. It is suggested that young male adults should pay more attention to the exercise of cardiorespiratory fitness.

Keywords: health-related physical fitness; autofluorescence; advanced glycosylation end products; pulse wave velocity

1. Background

Chronic diseases are a major public health problem worldwide. The prevalence of chronic diseases continues to increase annually, and the age at which individuals develop these conditions is gradually becoming younger 12, which is related to unhealthy lifestyles 34. At present, unhealthy lifestyle factors such as sedentary behaviour, inactivity, and staying up late are common habits among young people. Eighty-one percent of young people are insufficiently physically active 5, 29% of them suffer from obesity 6, and 55.9% of them have sub-healthy status worldwide 7. If the current unhealthy lifestyles of the young population are not substantially improved, the incidence of chronic diseases will further increase in the future 8. Therefore, to reduce the incidence of chronic diseases, the health of young people should receive increased attention. Health-related risk factors should be identified and addressed as early as possible, which is highly important for reducing the incidence of chronic diseases in the future.

Arterial stiffness is an age-related process that is a shared consequence of numerous diseases, including diabetes mellitus (DM). Pulse wave velocity (PWV) is considered to be an effective predictor of arterial stiffness [9]. The reason is that arterial stiffness could lead to an increase in PWV. Moreover, Advanced glycosylation end products (AGEs) are also associated with arterial stiffness [10]. AGEs are structurally diverse irreversible polymers formed by a series of complex nonenzymatic reactions between reducing sugars and free amino termini of proteins, amino acids and other substances [11]. With ageing, AGEs accumulate in the body and can change the protein structure or trigger inflammatory pathways by binding to receptors, causing chronic diseases [12]. Therefore, it is feasible for PWV and AGEs to jointly predict the risk of arterial stiffness for young adults.

However, daily monitoring using AGEs, PWVAGEs and PWV is not convenient because they require expensive and technical equipment. Health-related physical fitness (HPF) is associated with health or skill attributes that people are born with or can acquire, and it can be measured using objective indicators [13]. HPF mainly comprises body composition, cardiorespiratory fitness, muscular fitness, and flexibility. Currently, some studies have explored the relationships of AGEs and arterial stiffness with HPF indicators. Previous studies have indicated a negative correlation between AGEs and muscle strength in women over 65, with higher AGEs linked to reduced strength [14]. In a cross-sectional study on the relationships of cardiorespiratory fitness and muscular fitness with arterial stiffness, it was reported that higher levels of cardiorespiratory fitness and muscular fitness were associated with lower PWV in elderly individuals [15]. Another study examined the relationship between cardiorespiratory fitness and arterial stiffness in 1035 men aged 52 years with metabolic syndrome and reported that cardiorespiratory fitness was negatively correlated with PWV and that better cardiorespiratory fitness was associated with lower arterial stiffness [16]. Most of these studies have focused on people with diseases and middle-aged and elderly people. An increasing number of studies have demonstrated that arterial stiffness is becoming increasingly common among younger people [17]. Lu's research indicates that the degree of arterial stiffness increases continuously from the age of 20 to 80 [18]. Meani's study points out that the independent predictors of ΔPWV are age, baseline PWV, and so on. They pointed out that the accelerated arterial aging in treated hypertensive subjects was largely explained by age and BP values. Moreover, the PWV changes over time can provide important information which needs to be further investigated [19]. It follows that the degree of arterial stiffness in youth is closely related to that in old age, which in turn causes various chronic diseases. Therefore, if arterial stiffness changes can be detected earlier in young people, it could help prevent chronic diseases, mainly obesity, diabetes and cardiovascular disease, in middle-aged and elderly people. Indicators related to HPF can be easily measured and conveniently self-monitored at home by the public. However, the limited research in existing literature on the relationship between HPF and AF, PWV. Therefore, this study analyzed the relationship between health fitness indicators that are convenient for testing and AF, PWV tested by professional equipment, and discovered simple indicators that can be self-detected and evaluated. This enables the early detection of danger warnings before the clinical diagnostic criteria for chronic diseases are reached, improving the disease management.

As a result, chronic disease prevention could be implemented at an earlier age, effectively delaying and reducing the occurrence of chronic disease in middle-aged and elderly individuals. An improvement in the quality of life of middle-aged and elderly people and a reduction in the cost of chronic diseases would be of substantial importance.

2. Methods

2.1. Study Design

This was a cross-sectional observational study on the associations between arterial stiffness and HPF in young adults. The study was conducted between 1 April 2022 and 29 April 2022 at the College of Physical Education, Shaanxi Normal University. All the participants participated voluntarily and signed informed consent forms. The Ethics Committee of Shaanxi Normal University approved this study, and the ethical approval code is 202216015.

2.2. Participants

The 132 students aged 20–30 were recruited. The participants were recruited through the Science and Technology Month activity of Shaanxi Normal University in April 2022. Participants had to meet the inclusion criteria, including young adults between the ages of 20 and 30. The exclusion criteria included individuals with a long-term exercise habit (moderate-intensity exercise more than three times a week for more than six months) for more than half a year and those with a history of taking medication for cardiovascular diseases, as both exercise and medications can influence arterial stiffness [20]. A total of 21 young adults were excluded, including 9 who did not complete the tests and 12 with regular exercise habits. Finally, 111 young adults were included in the study (Figure 1).

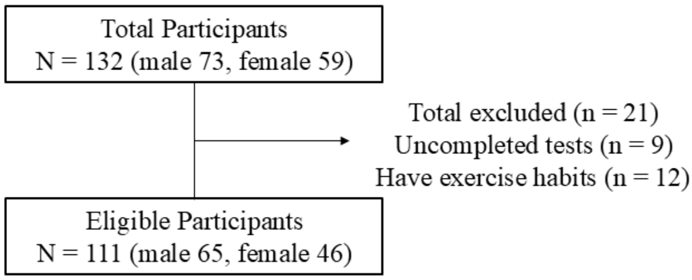

Figure 1. Participant selection flow diagram.

2.3. Outcome Measures

In this study, the risk of arterial stiffness was predicted with HPF indicators. AGEs and PWV are taken as outcome measures because both AGEs and PWV were related to arterial stiffness. Age was a classical parameter known to affect the primary outcome. It was selected as a predefined confounder and had been demonstrated in previous studies [21].

2.3.1. Measurement of AF

AGEs were assessed by skin autofluorescence (AF), which was measured with a non-invasive detection system (AGE Reader, Diagnoptics, the Netherlands). Figure 2 shows how the AGE reader works. UV light with a peak intensity of 370 nanometers was emitted by the AGEs Reader with an ultraviolet (UV) tube, which can excite AGEs fluorescence in the skin because AGEs had unique spontaneous fluorescence properties in the frequency range of 300–420 nm. Then, AGEs fluorescence in the skin was transmitted to the instrument through a fiber-optic probe. After analysis, the results are transmitted to a personal computer. During the measurement, the skin on the palmar side of the right forearm was exposed, and a skin area without blood vessels, scars, or deformities was selected for detection via the fibre optic probe. In this study, AGEs were assessed by skin autofluorescence (AF) using a non-invasive detection system, which offers the advantages of being non-invasive, quick, and specific for detecting AGEs in the skin due to their unique fluorescence properties. However, its accuracy may be influenced by skin conditions and environmental factors, and it requires proper calibration and trained operators. Despite these potential limitations, AGE Reader was only used for risk identification and not for disease diagnosis in this experiment.

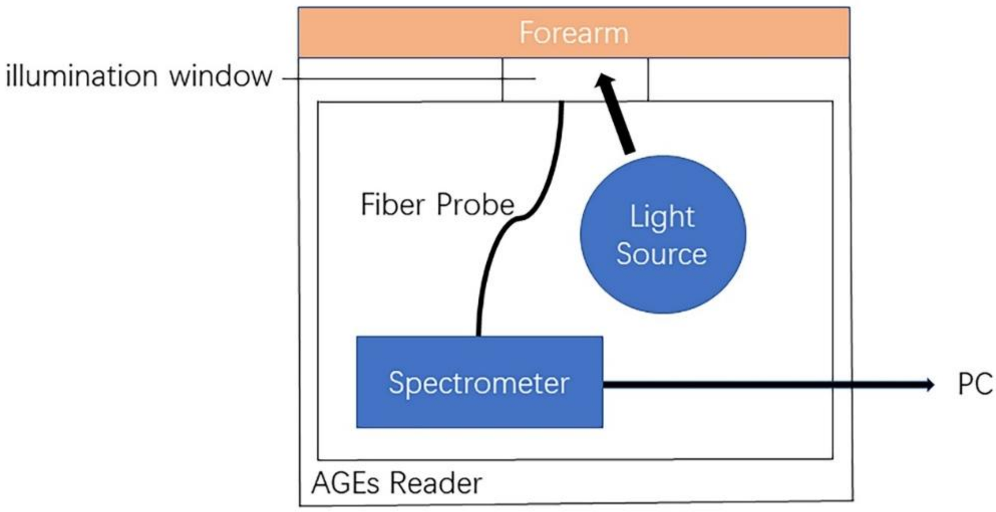

Figure 2. The AGEs Reader has an ultraviolet (UV) tube. It can emit UV light with a peak intensity of 370 nm and excite AGEs in the skin, which have unique spontaneous fluorescence properties in the frequency range of 300–420 nm. Using this property, skin autofluorescence is transmitted to the instrument through a fiber-optic probe. After analysis, the results are transmitted to a personal computer.

2.3.2. Measurement of PWV

The carotid-femoral and carotid-radial pulse wave velocities (CFPWV, CRPWV) were detected by a Complior SP device (Complior SP, ALAM Medical, Saint-Quentin-Fallavier, France). During the measurement, the subject relaxed and rested for 5 min. The participants maintained normal breathing in a supine position with their head to the left at a 45° tilt (Figure 3). The carotid-femoral and carotid-radial distances were measured with a measuring tape, and the data were input into a computer. The pressure sensors were placed in the carotid artery, radial artery, and femoral artery so that the heartbeats were obvious. The computer automatically recorded the conduction time and measured the pulse wave velocity. The applicability of PWV in this experiment is demonstrated by several factors. Firstly, its non-invasive nature ensures that it can be safely used among the undergraduate participants without causing any discomfort or harm. Secondly, the simplicity of the measurement process allows for efficient data collection within the context of the study. Given the need to assess cardiovascular-related parameters in a relatively large group of young adults, PWV provides a practical and effective means to evaluate arterial stiffness and related cardiovascular health indicators. However, considering the potential influences on its accuracy and the technical demands on operators, it is crucial to ensure that the measurements are conducted under controlled conditions and by well-trained personnel to obtain reliable results.

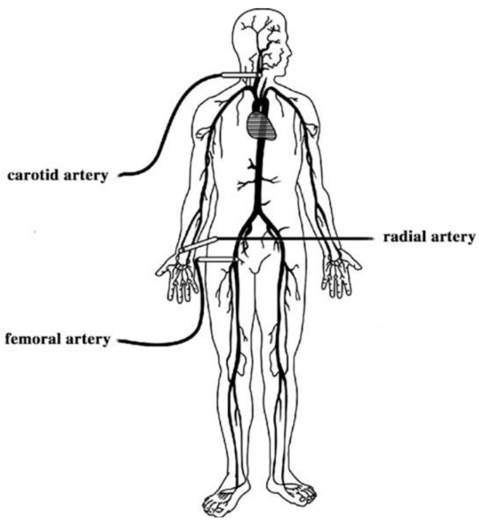

Figure 3. The participants keep breathing normally in a supine position with their head to the left at 45° tilt. The pressure sensors were placed in the carotid artery, radial artery, and femoral artery so that the heartbeats were obvious.

2.3.3. Measurement of HPF

The indicators related to HPF included body mass index (BMI), skeletal muscle mass (SMM), body fat (BF), body water (BW), grip strength (GS), vertical jump (VJ), vital capacity (VC), sit-and-reach (SR), and cardiorespiratory endurance index (CEI). According to the standards of the National Physical Fitness Test Standard Manual, an All-in-One Fitness Test Machine (iDong, Taishan Sport, Dezhou, Shandong, China) was used to measure the HPF indicators.

Height and weight were tested using the all-in-one machine. During the test, the participants stood naturally with their hands down at their sides and their eyes looking straight ahead, and the results were automatically saved and recorded. Body composition was measured using a bioelectrical impedance method. During the test, participants were asked to stand naturally, keeping the spine in a neutral position. Participants gripped the electrode surface with their hands, placing their bare feet on metal electrodes to ensure direct contact between the skin and the metal electrodes. BMI, SMM, BF, and BW were automatically saved and recorded.

The GS, VJ, VC, SR, and CEI were measured on the corresponding instrument in an all-in-one machine. In the GS test, the participants stood naturally and held the GS dynamometer in the right hand, with the arm down and the palm facing inwards. Participants were not allowed to swing their arms or hold the dynamometer near their bodies during the test. In the VJ test, participants were asked to jump vertically upwards with their hands naturally down and knees slightly bent. In VC tests, participants held a test instrument, took a deep breath, and exhaled completely. In the SR tests, the participants were asked to sit with their knees straight, upper limbs extended and arms straight, with the entire upper body bent forward so that the fingers reached the furthest point on the device scale to obtain the best result. The GS, VJ, VC, and SR tests were performed twice, and the highest measurements were recorded. The CEI was calculated based on the recovery heart rate after exercise in the 3-min step test. The 3-min step test was adapted from the Harvard Step Test, which assesses the cardiorespiratory fitness of individuals. The 3-min step test is performed on a step (30 cm for men and 25 cm for women). The subject goes up and down the step at a frequency of 120 times per minute. The test lasted for three minutes. After three minutes of continuous repetition, the subject immediately sat in a chair, and the heart rate was recorded between 60 and 90 s, 120 and 150 s, and 180 and 210 s after sitting. The CEI is equal to the exercise time in seconds multiplied by 100, divided by 2 times the sum of the heart rates of the three measurements [22]. The participants were asked not to engage in vigorous exercise within 12 h before the tests or drink within 30 min before the tests, and they were asked to fast for 4 h before the tests.

2.4. Statistical Analysis

SPSS 26.0 software (IBM, Chicago, IL, USA) was used for the statistical analyses. The participants were grouped according to sex. The missing data were deleted because some participants failed to complete the experimental test. All variables were checked for normality using the Kolmogorov–Smirnov test. Continuous variables with a normal distribution are presented as the mean ± standard deviation (SD), and continuous variables with a nonnormal distribution are presented as the median (interquartile range (IQR)). When the assumption of a normal distribution was not met, the Mann–Whitney U test was used to compare the differences between groups. Spearman correlation was used to analyse the correlations of HPF indicators with PWV and AF, and the variables that were correlated with PWV and AF were screened out. Multiple linear regression analysis was used to determine the independent relationships between AF, PWV and related variables, controlling for age as a confounding factor. Age is a classical parameter known to affect the primary outcome. It was selected as a predefined confounder and has been demonstrated in previous studies [21]. In the multivariate linear regression analysis, the enter method was used for analysis. The linear relationship between independent variables and dependent variables was determined by constructing scatter plots. The Durbin-Watson test was used to judge the mutual independence of the data. Cook distance analysis was used to judge whether the data had outliers that needed to be deleted. The correlation coefficient, variance inflation factor, and tolerance are used to determine that there is no serious multicollinearity among the independent variables. Standardized residual histograms and residual P-P graphs were drawn to determine whether the residuals followed a normal distribution. The homogeneity of variance of the residuals was judged by drawing residuals. Ninety-five percent confidence intervals were calculated for measures of effect to indicate the amount of uncertainty, and a two-sided level of significance of 0.05 was used to indicate statistical significance.

A post hoc power analysis was calculated using G*power software (latest ver. 3.1.9.7; Heinrich Heine University, Düsseldorf, Germany) because sample size calculation was not conducted before recruitment. The statistical test is set to linear multiple regression: random model, the type of power analysis is Post hoc. This manuscript adheres to STROBE guidelines on reporting [23].

3. Results

3.1. Baseline Characteristics of the Participants

A total of 132 young adults (male 73, female 59) were recruited from a university in Shaanxi Province. Fifteen young adults did not complete all the tests, and 6 young adults were fitness enthusiasts. Ultimately, 111 young adults (male 65, female 46) were included in this study. Table 1 illustrates the baseline characteristics of the participants. There were 65 males with an average age of 24.12 ± 2.16 years and 46 females with an average age of 23.48 ± 2.19 years. The CFPWV, BMI, SMM, BW, GS, VJ, and VC of male young adults were significantly greater than those of female young adults ($p = 0.004$, $p = 0.019$, $p < 0.001$, $p < 0.001$, $p < 0.001$, $p < 0.001$, $p < 0.001$). The AF, BF, and SR were significantly lower than those of female young adults ($p = 0.002$, $p = 0.004$, $p = 0.003$). There was no significant difference in the CRPWV or CEI between male and female young adults ($p = 0.592$, $p = 0.351$).

Table 1. Comparison of various indicators among young adults.

	Male (n = 65)	**Female (n = 46)**
Age (yr)	24.12 ± 2.16	23.48 ± 2.19
Height (cm)	175.91 ± 5.18	161.28 ± 5.24
Weight (kg)	71.88 ± 12.44	56.08 ± 8.56
AF	1.67 ± 0.09 *	1.72 ± 0.08

CFPWV (m/s)	6.70 (5.90, 7.50) *	5.90 (3.18, 6.72)
CRPWV (m/s)	7.90 (3.90, 10.00)	7.64 ± 2.45
Body composition		
BMI (kg/m^2)	23.18 ± 3.57*	21.60 ± 3.38
SMM (kg)	30.30 (28.30, 34.65) *	21.12 ± 2.52
BF (kg)	15.90 ± 6.78 *	16.89 ± 5.93
BW (kg)	39.70 (37.25, 44.75) *	28.54 ± 3.02
Muscular fitness		
GS (kg)	43.33 ± 5.91 *	26.96 ± 4.31
VJ (cm)	35.15 ± 6.59 *	22.68 ± 3.89
Cardiorespiratory fitness		
VC (mL)	4611.12 ± 763.34 *	2968.26 ± 484.77
CEI	48.26 ± 5.95	46.75(43.28, 49.70)
Flexibility		
SR (cm)	9.49 ± 7.32 *	13.62 ± 6.68

Note: * indicates that there were significant differences between male and female young adults, $p < 0.05$. AF: autofluorescence; CFPWV: carotid-femoral pulse wave velocity; CRPWV: carotid-radial pulse wave velocity; BMI: body mass index; SMM: skeletal muscle mass; BF: body fat; BW: body water; GS: grip strength; VJ: vertical jump; VC: vital capacity; CEI: cardiorespiratory endurance index; SR: sit-and-reach.

3.2. Correlation Analysis of AF, PWV, and HPF Indicators

Table 2 shows the correlations of AF and PWV with HPF indicators in male young adults. AF was positively correlated with BMI and BF ($p = 0.013$, $p = 0.0004$). AF was negatively correlated with the CEI ($p = 0.046$). AF was not significantly correlated with SMM, BW, GS, VJ, VC, or SR ($p = 0.669$, $p = 0.684$, $p = 0.651$, $p = 0.902$, $p = 0.223$, $p = 0.934$). There was no significant correlation between the CFPWV or CRPWV and any HPF indicator ($p > 0.05$).

Table 2. Correlation analysis of AF, PWV, and HPF indicators in male young adults.

	AF (n = 65)		**CFPWV (n = 65)**		**CRPWV (n = 65)**	
	r	***p***	**r**	***p***	**r**	***p***
Body composition						
BMI	0.309 *	0.013	−0.125	0.330	0.039	0.760
SMM	0.054	0.669	0.022	0.866	0.030	0.817
BF	0.427 *	<0.001	−0.136	0.287	−0.053	0.678
BW	0.052	0.684	0.024	0.853	0.043	0.735
Muscular fitness						
GS	0.058	0.651	0.150	0.241	−0.146	0.252
VJ	0.016	0.902	−0.026	0.842	−0.226	0.074
Cardiorespiratory fitness						
VC	0.155	0.223	0.025	0.848	0.114	0.375
CEI	−0.251 *	0.046	0.239	0.059	0.065	0.611
Flexibility						
SR	−0.011	0.934	−0.241	0.057	−0.179	0.160

Note: * indicates that AF and PWV were significantly correlated with HPF indicators ($p < 0.05$). AF: autofluorescence; CFPWV: carotid-femoral pulse wave velocity; CRPWV: carotid-radial pulse wave velocity; BMI: body mass index; SMM: skeletal muscle mass; BF: body fat; BW: body water; GS: grip strength; VJ: vertical jump; VC: vital capacity; CEI: cardiorespiratory endurance index; SR: sit-and-reach.

Table 3 shows the correlations between AF, PWV, and HPF indicators in female young adults. AF was positively correlated with BMI and BF ($p = 0.049$, $p = 0.015$). AF was not significantly correlated with SMM, BW, GS, VJ, VC, CEI, or SR ($p = 0.411$, $p = 0.398$, $p = 0.807$, $p = 0.079$, $p = 0.690$, $p = 0.216$, $p = 0.994$). There was no significant correlation between the CFPWV or CRPWV and any HPF indicator ($p > 0.05$).

Table 3. Correlation analysis of AF, PWV, and HPF indicators in female young adults.

	AF (n = 46)		**CFPWV (n = 46)**		**CRPWV (n = 46)**	
	r	***p***	**r**	***p***	**r**	***p***
Body composition						
BMI	0.292 *	0.049	0.126	0.403	0.005	0.971

SMM	0.124	0.411	0.047	0.759	−0.054	0.724
BF	0.355 *	0.015	0.167	0.267	0.084	0.579
BW	0.128	0.398	0.067	0.660	−0.046	0.762
Muscular fitness						
GS	0.037	0.807	−0.140	0.354	0.086	0.568
VJ	−0.262	0.079	−0.051	0.737	0.107	0.481
Cardiorespiratory fitness						
VC	0.060	0.690	0.084	0.580	0.056	0.713
CEI	0.186	0.216	0.081	0.590	−0.118	0.434
Flexibility						
SR	0.001	0.994	−0.205	0.171	0.283	0.057

Note: * indicates that AF and PWV were significantly correlated with HPF indicators ($p < 0.05$). AF: autofluorescence; CFPWV: carotid-femoral pulse wave velocity; CRPWV: carotid-radial pulse wave velocity; BMI: body mass index; SMM: skeletal muscle mass; BF: body fat; BW: body water; GS: grip strength; VJ: vertical jump; VC: vital capacity; CEI: cardiorespiratory endurance index; SR: sit-and-reach.

3.3. Correlation Analysis of AF and PWV

Table 4 shows the correlation between AF and PWV in young adults. There was no significant correlation between AF and CFPWV or CRPWV (Male: $p = 0.305$, $p = 0.318$, Female: $p = 0.411$, $p = 0.071$).

Table 4. Correlation analysis of AF and PWV in young adults.

	CFPWV		CRPWV	
	r	***p***	**r**	***p***
Male				
AF	−0.132	0.305	−0.129	0.318
Female				
AF	−0.124	0.411	−0.071	0.071

Note: AF: autofluorescence; CFPWV: carotid-femoral pulse wave velocity; CRPWV: carotid-radial pulse wave velocity.

3.4. Multivariate Linear Analysis of AF and HPF Indicators

The results of multiple linear regression analysis are shown in Table 5, and the changes in each indicator are shown in Figure 4. AF was positively correlated with BMI and BF (male: $p = 0.020$, $p = 0.0003$, female: $p = 0.044$, $p = 0.017$) young adults whether male or female and was negatively correlated with CEI ($p = 0.043$) in male young adults. After controlling for age, AF was positively correlated with BF ($p = 0.032$) and was not significantly correlated with BMI or CEI in male young adults ($p = 0.143$, $p = 0.608$). There was no significant correlation between AF and BMI or BF in female young adults ($p = 0.449$, $p = 0.107$). The mean of the residuals for all the models is less than 0.001, which indicates that the models do not have systematic bias.

Table 5. Multiple linear regression analysis of the effects of HPF indicators on AF in young adults.

	Model 1 (Unadjusted)			Model 2 (Adjusted)		
	β	**SE**	**Adjusted-R^2**	**β**	**SE**	**Adjusted-R^2**
Male						
BF	0.800 *	0.012	0.096	0.792 *	0.005	0.087
BMI	0.554 *	0.002		−0.513	0.009	
CEI	−0.067 *	0.001		−0.046	0.002	
Female						
BF	0.637 *	0.023	0.097	0.663	0.006	0.088
BMI	0.298 *	0.011		−0.338	0.010	

Note: The multiple linear regression models adjusted for age. * indicates that AF was significantly correlated with HPF indicators ($p < 0.05$). AF: autofluorescence; BMI: body mass index; BF: body fat; CEI: cardiorespiratory endurance index.

In post hoc analysis, there were 65 samples and 3 regression indicators in males. There were 46 samples and 2 regression indicators in females. Upon performing the calculations based on the R^2 values, the H1 ρ^2 was determined to be 0.14 for the male young adults and $\rho^2 = 0.15$ for the female young adults. H0 ρ^2 is set to 0, and α is set to 0.05. Subsequent calculations revealed that the statistical power was 0.66 for the male and 0.59 for the female. This indicates that the research had a 66% chance of detecting a true effect in the male young adults and a 59% chance in the female young adults, given that the effects exist.

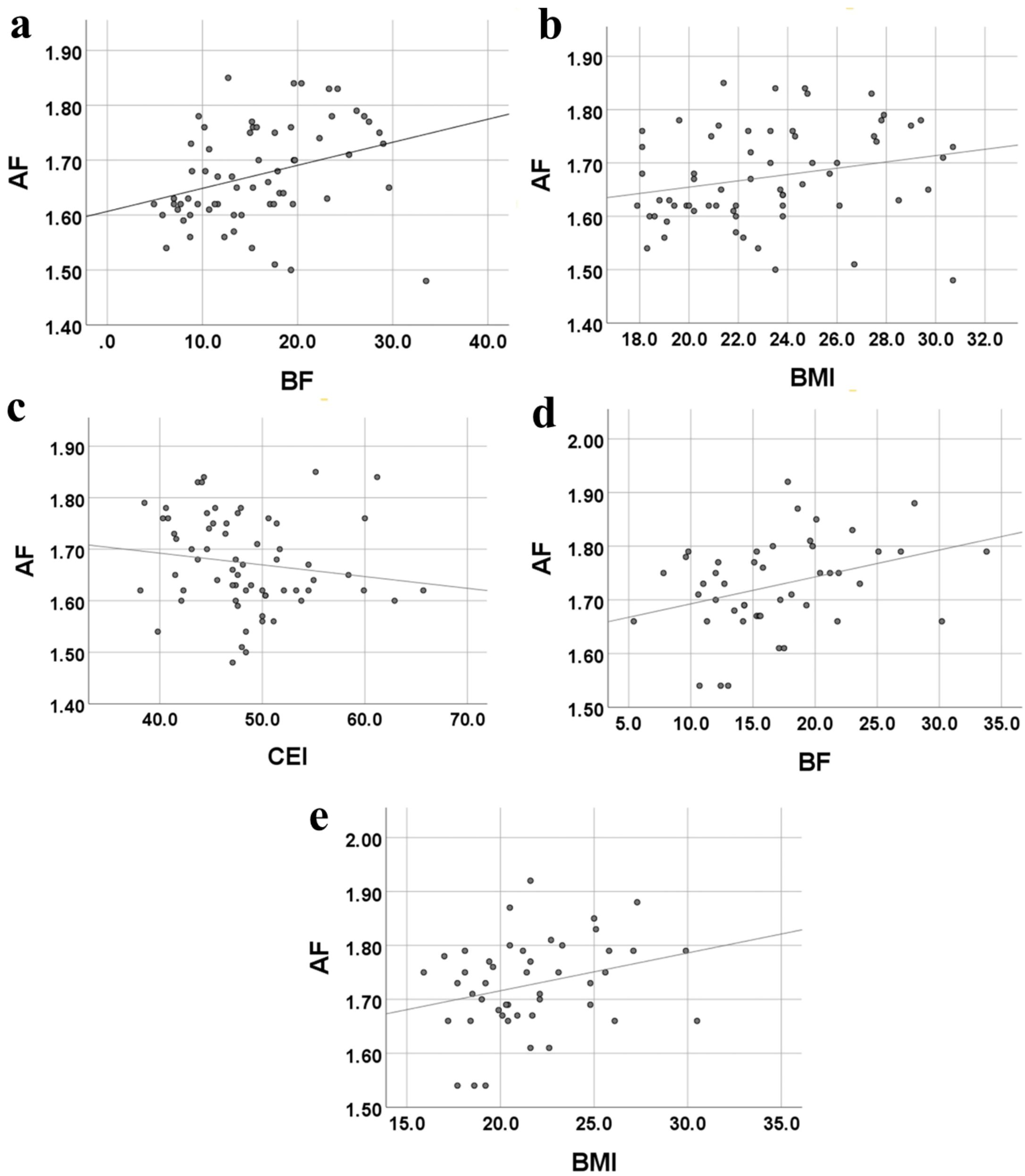

Figure 4. The relationship between HPF indicators and AF for young adults whether male or female. (**a**): BF in men; (**b**): BMI in men; (**c**): CEI in men; (**d**): BF in women; (**e**): BMI in women.

4. Discussion

In this study, the relationship between HPF and arterial stiffness was investigated. PWV, which is closely related to the risk of atherosclerosis, and skin fluorescence, which reflects the accumulation of AGEs, were measured separately. The results were found that AF has a significant positive correlation with BMI and body fat, which was particularly pronounced among male college students, suggesting that higher BMI and body fat levels may be associated with increased arterial stiffness in this specific population. Furthermore, AF was negatively correlated with CEI in male college students, suggesting that higher levels of CEI may be related to lower arterial stiffness, and may contribute to a reduced risk of chronic diseases. There was no significant correlation between AGEs and muscle strength or flexibility, suggesting that AGEs may not be the main a primary factor affecting muscle function and flexibility. At the same time, it is found that there is no significant correlation between PWV and HPF. The reasons were that younger people's blood vessels are more elastic and less rigid, which may reduce the likelihood that PWV is significantly associated with HPF. Therefore, while PWV is an important cardiovascular disease risk indicator, its association with other health indicators may not be significant in the younger population.

4.1. Associations between AGEs and HPF

In this study, AGEs are associated with body fat and increase with age. AGEs are polymers formed by nonenzymatic reactions and can be divided into endogenous AGEs and exogenous AGEs. Endogenous AGEs are synthesized by excessive sugar and protein in the body, while exogenous AGEs are ingested from food. Foods riching in fats and proteins contained higher levels of AGEs compared to sugary foods. Excessive consumption of high-fat and -protein foods could increase AGE levels in the body. Consequently, a higher body fat content is associated with greater AGE concentrations [24]. 24Previous research has demonstrated a significant association between central obesity and AGEs; those with central obesity had greater AF than did those without central obesity and that waist circumference was positively correlated with AGE levels [25].26 In another study, the relationship between skin autofluorescence and clinical variables, including micro- and macrovascular complications, was investigated in a type 2 diabetes primary care population, including 973 patients and 231 participants without type 2 diabetes mellitus. The results showed that AF was positively correlated with BMI. Multiple linear regression analysis after controlling for age, sex, and smoking status revealed significant correlations between AF and BMI ($R^2 = 46\%$, $\beta = 0.71$, $p < 0.001$) [26]. In our study, AF was also positively correlated with BMI and body fat (male: $p = 0.013$, $p = 0.0004$, female: $p = 0.049$, $p = 0.015$) in young adults, but multiple linear regression analysis after controlling for age showed that AF was positively correlated with body fat only among male young adults ($p = 0.032$). This indicates that age is an important influencing factor on the correlation between AF and BMI. A study was conducted to evaluate the correlation between BMI, BF, blood pressure (BP), cardiorespiratory fitness and AGEs in children aged 6–8 years. Multiple linear regression models were used to compare changes in the SAF score with changes in BMI, BF, BP, and CRF. BMI, BF, and BP were not significantly correlated with AF [27]. The finding is inconsistent with the results of this study. The possible reason may be attributed to the different ages of the participants. In this study, the participants were approximately 24 years old, while those in the cited studies were 6–8 years old. AGEs more easily accumulate in adults than in children, likely due to children having a higher metabolism. It is well known that males are more prone to accumulate fat in the abdominal and other visceral areas, which is closely related to the generation and accumulation of AGEs. The metabolic activities of visceral fat cells are relatively active, which could produce more AGEs, which can bind to their receptor RAGE, thereby affecting adipose tissue homeostasis and leading to adipocyte hypertrophy and lipid accumulation [28].

The CEI may be a risk indicator for arterial stiffness in young male adults. At present, there are few studies on the correlation between AGEs and cardiorespiratory fitness. There was a study on the correlations of AF with BMI, BF, BP, and cardiorespiratory fitness in children aged 6–8 years [27]. That study used 20-metre shuttle running to evaluate children's cardiopulmonary endurance. The results showed that cardiorespiratory fitness was significantly negatively correlated with AF. AGEs may interact with receptors for advanced glycation end products (RAGE) to trigger a series of reactions in the lung, resulting in pulmonary endothelial cell dysfunction, inflammation and apoptosis, and further impaired lung function 2830. Decreased lung function can affect cardiorespiratory fitness. Previous studies have shown that long-term aerobic exercise can not only improve cardiorespiratory fitness but also reduce AGEs in the body [31]. In this study, vital capacity and 3-min step tests were used to measure cardiorespiratory fitness. The 3-min step test was adapted from the Harvard Step Test, which assesses cardiorespiratory fitness based on recovery heart rate after exercise in the 3-min step test. It reflects the body's cardiopulmonary endurance. During the 3-min recovery period after exercise, the lower the heart rate was, the greater the cardiopulmonary endurance. There have been many variations of the Harvard Step Test, and it has been adapted for China [32,33]. Therefore, this method is suitable for real-life situations and can replace the Harvard step test. The results of this study show that AF and the CEI are significantly negatively correlated with each other but not significantly correlated with vital capacity. In addition, further research is needed for the complex correlation between AGEs and cardiopulmonary fitness in young adults. Therefore, we could only deduce that the CEI may be a risk indicator for chronic diseases in young male adults.

Muscle strength and flexibility are not associated with AGEs in this study. Research has shown an inverse association between AGEs and muscle strength in older adults, independent of confounding factors such as age, sex, smoking status, body fat percentage, and diabetes status [34]. A study on the relationship between AGEs and muscle strength for 518 adult men in Japan showed that AF was negatively correlated with grip strength according to the Spearman rank correlation test [35]. 36Another study found that AF was associated with low skeletal muscle mass and weak muscle strength among 1,934 residents aged 30–74 years. After further controlling for skeletal muscle mass, the correlation between AF and muscle strength decreased [36]. These results suggested that the negative correlation between AGEs and muscle strength can be attributed to decreased muscle mass. The possible mechanism is that the accumulation of AGEs in the body leads to a reduction in muscle mass. The combination of AGEs and RAGE can cause an inflammatory response, promote an increase in inflammatory factors, and activate

NADPH oxidase to increase the amount of reactive oxygen species (ROS). An increase in inflammatory factors and ROS activates the ubiquitin–proteasome system and accelerates the degradation of muscle proteins [37]. The combination of AGEs and RAGE can mediate the downregulation of the AKT signalling pathway by AMPK and inhibit myotube formation in myoblasts [38]. The combination of AGEs and RAGE can also lead to impaired repair of the myocyte membrane, which leads to muscle atrophy [39]. In this study, there was no significant correlation between AGEs and skeletal muscle mass or muscle strength, which is inconsistent with the results of previous studies. This may be caused by the age of the participants. In previous studies, the age of participants was over 30. Skeletal muscle mass and muscle strength gradually decline from the age of 30 [40]. With increasing age, AGEs accumulate substantially in the body [41]. The participants in this study were 20–30 years old and had relatively strong skeletal muscle mass and muscle strength. Therefore, studies on the relationship between AGEs and muscle strength need to control for age. In addition, there are no other studies on the relationship between AGEs and flexibility. In this study, it was found that AGEs in the skin of young adults were not significantly correlated with flexibility.

These studies all emphasized the impact of AGEs on health, suggesting that reducing high-fat and high-protein intake and increasing cardiorespiratory endurance can help lower AGEs, thereby potentially decreasing the risk of obesity and illness-related metabolism.

4.2. Associations between PWV and HPF Indicators

This study shows no significant correlation between PWV and HPF indicators. PWV is the propagation speed of the pulse wave generated in the arterial blood vessels when the heart contracts and is an index reflecting the health of blood vessels.42 A study investigating the relationship between PWV and body composition demonstrated strong correlations between PWV and BMI, waist circumference, visceral fat, and body fat, even after adjusting for various confounders, highlighting the impact of obesity on arterial stiffness [42]. This suggests that obese people can prevent cardiovascular and cerebrovascular diseases early by controlling their body fat percentage. Studies have shown that obese people exhibit greater PWV than normal-weight people at the age of 20–30 years [43], and the age-related PWV growth rate is much greater in individuals with obesity than in those without obesity [44]. The possible reason is that increased body fat leads to increased inflammation in the body and changes in vascular endothelial function, further leading to an increase in PWV [15,45]15. In a cross-sectional study of the relationships among cardiorespiratory fitness, muscle strength, and arterial stiffness, it was noted that in elderly individuals, the higher the levels of cardiorespiratory fitness and muscle strength, the lower the PWV.46 Another study investigating the relationship between flexibility and arterial stiffness in 526 middle-aged and elderly participants found that after multiple regression analysis, there was a negative correlation between sit-and-reach performance ($\beta = -0.14$) and PWV in those individuals but not in young participants [46]. This is because oxidative stress reduces NO bioavailability and stimulates changes in the extracellular matrix, leading to vascular ageing with increasing age. Exercise intervention studies have shown that improvements in cardiorespiratory fitness, muscle strength, and flexibility are accompanied by beneficial changes in PWV, as exercise improves oxidative stress, inflammation, and sympathetic nerve activity, contributing to lower PWV [47,48]48. A cross-sectional study revealed a stronger correlation between advanced glycation end-products and pulse wave velocity in men and individuals under 67 years old. In men, each unit increase in skin AF led to a 0.63 m/s increase in CFPWV, with a 95% confidence interval of 0.38 to 0.89 [49]. 50In a study of nondiabetic individuals, AGEs were positively correlated with CFPWV in the middle-aged group under 65 years old ($r = 0.51$; $p < 0.0001$) but not in the elderly group over 65 years old. After adjusting for age and blood pressure, there was no significant correlation between AGEs and CFPWV in the middle-aged group ($r = 0.098$; $p = 0.454$) [50]. This suggests that the relationship between AGEs and PWV in middle-aged adults is influenced by age or blood pressure. Studies have shown that blood pressure is one of the largest influencing factors of PWV [51,52]52. In this study, the results reveal no significant correlation between young adults' CFPWV or CRPWV and HPF indicators or AF, which is consistent with the results of previous studies [46].

Research on PWV has revealed its value as a predictor of cardiovascular health. However, a significant relationship between PWV and HPF indicators in young adults was not observed in this study, possibly because young adults have better vascular elasticity. Interestingly, AF was significantly correlated with obesity-related indicators, including BMI and BF, especially in men. This suggests that optimizing body composition is particularly important in the process of preventing chronic diseases.

There are shortcomings in this study. First, this study is only a cross-sectional study and cannot prove cause and effect, and our study population mainly consists of young adults from a specific university, which may restrict the generalizability of our findings. Second, muscle endurance and shoulder flexibility-related HPF indicators were not tested. Third, there was a varying proportion of male and female participants in each group, which may raise concerns about potential bias due to different group sizes. Finally, our study revealed that the statistical power was 0.66 for the male and 0.59 for the female, falling short of the recommended 0.8 threshold. To mitigate the heightened risk of Type II errors, future investigations should prioritize larger sample sizes and categories.

5. Conclusions

BMI and body fat are the main factors affecting the risk of arterial stiffness in young adults, whether male or female, which were not significantly affected by age in male young adults, but were more significantly affected by age in female young adults. Therefore, this study shows that young adults should appropriately control their weight and body fat. In addition, cardiorespiratory fitness is also the main factor for the risk of chronic disease in young male adults. These risks may be closely related to the sedentary lifestyle of young adults. Therefore, it is recommended that health education for young adults should be strengthened.

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