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Comparison of obesity-related indices for identifying nonalcoholic fatty liver disease: a population-based cross-sectional study in China

Fangfei Xie*†, Yuyu Pei†, Quan Zhou, Deli Cao and Yun Wang

Abstract

Background: The relationship between nonalcoholic fatty liver disease (NAFLD) and obesity-related indices has been analyzed separately thus far, and evidence comparing these indices together is still lacking, especially in China. This study aimed to comprehensively evaluate the predictive performance of anthropometric and metabolic indices to identify NAFLD in Chinese adults.

Methods: This study recruited a total of 1748 participants who were 18 years or older in southeastern China. The systolic blood pressure (SBP), diastolic blood pressure (DBP), fasting blood glucose (FBG), total cholesterol (TC), triglycerides (TGs), low-density lipoprotein (LDL), waist circumference (WC), a body shape index (ABSI), atherogenic index of plasma (AIP), abdominal volume index (AVI), body adiposity index (BAI), body mass index (BMI), body roundness index (BRI), conicity index (CI), triglyceride glucose (TyG), waist hip ratio (WHR), and waist height ratio (WHtR) were measured. The association between these indices and NAFLD was analyzed via logistic analyses with odds ratios (ORs). Receiver operating characteristic (ROC) curves and areas under the curve (AUCs) were used to compare the predictive performance of these indices to identify NAFLD.

Results: BMI had the greatest total AUC (AUC = 0.841) in the ROC curve analysis. However, BRI and BMI both had the best diagnostic ability in males (AUC = 0.812), and BRI had the best diagnostic ability in females (AUC = 0.849). Furthermore, AVI had the greatest AUC for patients who were ~ 20 (AUC = 0.892) and ~ 40 years old (AUC = 0.831), while TyG showed a higher predictive ability than AVI in those who were ~ 60 years old (AUC = 0.766).

Conclusion: This study identified sex- and age-specific indices for predicting NAFLD in Chinese subjects. Compared with indices for all age groups, sex- and age-specific indices can provide more accurate assistance for clinical diagnosis and treatment.

Keywords: Nonalcoholic fatty liver disease, Obesity, Indices, Anthropometric, Metabolic, Prediction, Diagnostic ability

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Background

It is well established that nonalcoholic fatty liver disease (NAFLD) has become a major public health problem over the past few decades, with incidences of approximately 30 and 25% in Western and Asian countries, respectively. NAFLD has also caused large medical and economic burdens for both developed and developing countries [1–5]. NAFLD is also characterized by complex pathogenesis and is difficult to diagnose [6, 7]. Thus, it is of great necessity to further explore the pathogenesis of NAFLD to determine effective predictive indicators for the diagnosis of NAFLD, which is critical for the prevention and treatment of NAFLD.

Oxidative stress and inflammation can promote NAFL D to nonalcoholic steatohepatitis (NASH) or even hepatic cirrhosis in the progression of NAFLD [8]. Although the pathogenesis of NAFLD is still not fully understood, obesity has been demonstrated to play a major role in most of the pathogenic pathways involved in NAFLD. Dietary nutrients have played an increasingly important role in the progression of NAFLD in recent years by affecting lipid and carbohydrate metabolism. For example, an obesogenic diet is associated with hepatic oxidative stress and inflammation, which might be due to the activation of anabolic pathways and can eventually lead to abdominal obesity [9]. In contrast, the intake of polyunsaturated fatty acids (n-3 polyunsaturated fatty acids) can reduce nutritional hepatic steatosis in adults, which favors fatty acid and TG production over fatty acid oxidation [10].

NAFLD is commonly associated with visceral adiposity, type II diabetes, dyslipidemia, and metabolic disorders [11–15]. The relationship between NAFLD and type II diabetes is complex and bidirectional and occurs in the context of a broader association between NAFLD and metabolic syndrome [16, 17]. In recent decades, the prevalence of NAFLD has increased alarmingly, along with increasing rates of obesity [18]. Some studies found that the development of NAFLD may be influenced by the regional distribution of lean and fat mass and suggested that abdominal fat is a risk factor for both fatty liver and fatty liver fibrosis [7, 14]. Therefore, obesity-associated factors might be utilized for predicting NAFLD.

As expected, several anthropometric or metabolic indices, such as the atherogenic index [19, 20], body mass index (BMI) [21], triglycerides (TGs)/high-density lipoprotein cholesterol [22], visceral adipose tissue [23], total cholesterol (TC)/high-density lipoprotein cholesterol [24], triglyceride glucose index (TyG) [25, 26], and blood pressure [27] have been reported to be associated with NAFLD in both cross-sectional and cohort studies. However, most existing studies mainly focused on only one or two indices, which might have limitations for predicting NAFLD considering the high complexity of the pathogenesis of NAFLD. Meanwhile, it remains unclear which indices might be even more advantageous than others for predicting NAFLD. This is especially true for Chinese subjects since the prevalence of overweight and obesity has increased considerably in China [28]. This study aimed to evaluate the performance of obesity-related indices, including the systolic blood pressure (SBP), diastolic blood pressure (DBP), fasting blood glucose (FBG), TC, TGs, low-density lipoprotein (LDL), waist circumference (WC), body shape index (ABSI), atherogenic index of plasma (AIP), abdominal volume index (AVI), body adiposity index (BAI), BMI, body roundness index (BRI), specificity index (CI), TyG, waist hip ratio (WHR) and waist height ratio (WHtR), in identifying NAFLD in Chinese adults. Hopefully, the result will provide a theoretical basis for utilizing anthropometric and metabolic indices to predict NAFLD in China.

Methods

Study population

Participants were recruited in the physical examination center of Suzhou in southeastern China from January 2020 to December 2020 cross-sectionally. Subjects included in this study were of Chinese Han ethnicity and were over 18 years old. A total of 1748 subjects were finally included in the analysis after excluding those with alcohol abuse, other known causes of chronic liver disease and missing or invalid data (Fig. 1). The ethical committee of the Affiliated Suzhou Hospital of Nanjing Medical University approved this study (approval no. KL9011 Study 12), and the study also obtained approval from all subjects who had agreed to participate in the present study.

Data collection

The morning health examination was performed by expert medical staff. Health checkups and blood markers were measured as described previously by Xie et al. [19]. In brief, weight and height were measured in light indoor clothing without shoes and heavy clothes using a calibrated measuring apparatus. WC and hip circumference (HC) were measured as the horizontal circumference that passes through the navel position and the bulge at the hip, respectively. SBP and DBP were measured by sphygmomanometer. Metabolic markers, including TC, TG, LDL, HDL and FBG, were measured biochemically within 3 h after the peripheral blood draw.

The obesity-related indices, including ABSI, AIP, AVI, BAI, BMI, BRI, CI, TyG, WHR, and WHtR, were calculated using the equations shown in Fig. 2 [20, 21, 25, 29].

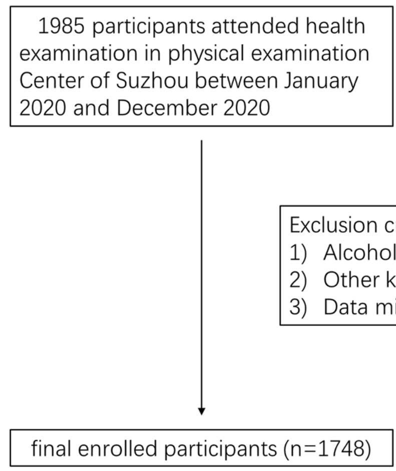

Fig. 1 Flow chat

Diagnoses of NAFLD were based on the "Chinese Guideline on Diagnosis and Treatment of NAFLD (2006)" by experienced radiologists with expertise in liver imaging. The NAFLD diagnosis met two of the three following items: diffuse hyperechoic liver relative to kidney, ultrasound beam attenuation, and weakening visualization of intrahepatic structures. In addition, patients with no history of drinking or an alcohol intake less than 40 g in males or 20 g in females per day over 5 years were included in this study [30].

Statistical analysis

Categorical variables are expressed as numbers (percentages). Continuous variables are expressed as medians and two specific percentiles (P_{25} and P_{75}) for nonnormally distributed data. All participants were divided into NAFLD and non-NAFLD groups. The baseline variables (sex, age, anthropometric and metabolic indices) were compared using the chi-square test and rank tests.

The values for SBP, DBP, FBG, TC, TG, LDL, WC, ABSI, AIP, AVI, BAI, BMI, BRI, CI, TyG, WHR and WHtR were divided into 4 quartiles according to their own changes. The first quartile was used as a reference. Logistic analyses were performed to determine the associations between these anthropometric and metabolic indices and NAFLD with odds ratios (ORs) and 95% confidence intervals (CIs).

Receiver operating characteristic (ROC) curves and areas under the curve (AUCs) were generated to compare the predictive ability of the various indices for identifying NAFLD.

All statistical analyses were performed with the Statistical Package for the Sciences software (SPSS, version 23.0). A value of $P < 0.05$ in the two-tailed test was considered significant.

Results

Characteristics of the study population

A total of 1748 subjects were included in this study, including 526 (30.09%) patients and 1222 (69.91%) control

$$ABSI=\frac{WC(cm)}{BMI^{\frac{2}{3}}(kg/m2)\times height^{\frac{1}{2}}(m)}$$

$$AIP=Lg\frac{TG(mmol/L)}{HDL(mmol/L)}$$

$$AVI=\frac{2\times WC^{2}(cm)+0.7\times(WC-HC)^{2}(cm)}{1000}$$

$$BAI=\frac{HC(m)}{height^{\frac{3}{2}}(m)}-18BMI$$

$$BMI=\frac{weight(kg)}{height^{2}(m)}$$

$$BRI=364.2-365.5\times\sqrt{1-\Pi-2\times WC^{2}(m)\times height^{-2}(m)}$$

$$CI=0.109^{-1}\times WC(m)\times\sqrt{\frac{weight(kg)}{height(m)}}$$

$$TyG=Ln[TG(mg/dL)\times\frac{FBG(mg/dL)}{2}]$$

$$WHtR=\frac{WC(cm)}{height(cm)}$$

$$WHR=\frac{WC(cm)}{HC(cm)}$$

Fig. 2 Equations of obesity-related indices subjects. The mean ages of the patients and control subjects were 48.55 ± 14.21 and 46.18 ± 14.74 years, respectively ($P < 0.01$). Among these subjects, 464 (26.54%) males and 62 (3.55%) females had NAFLD. Table 1 compares the demographic characteristics and anthropometric and metabolic indices of the individuals in both groups. The percentage of NAFLD in males was higher than that in females, and the age of female subjects with NAFLD was significantly older than that of female subjects without NAFLD. Subjects with NAFLD had significantly higher SBP, DBP, FBG TC, TG, LDL, WC, ABSI, AIP, AVI, BAI, BMI, BRI, CI, TyG, WHR and WHtR than those without NAFLD in both the male and female groups (all $P < 0.01$).

ORs for NAFLD risk across quartiles of each index

Table 2 demonstrates that the analyzed parameters were significantly associated with NAFLD ($P < 0.01$). The ORs for NAFLD still increased across the quartiles of each index in males and females after adjusting for sex and age. Among all subjects, the BMI showed the highest risk of NAFLD among all the indices, followed by WC and AVI.

ROC curves and AUC for indices in identifying NAFLD

Table 3 shows that BMI had the greatest AUC of 0.841. WC and AVI showed the same ability for predicting NAFLD and had the second highest AUC (0.836) among all the indices. The Youden index values of these indices were over 0.5.

As shown in Fig. 3, BMI and BRI had the same diagnostic ability for NAFLD in males (AUC = 0.812), and WHtR had the next best diagnostic ability (AUC = 0.810). In females, BRI also had the greatest predictive ability (AUC = 0.849), and WHtR (AUC = 0.846) had the second greatest predictive ability, followed by BMI (AUC = 0.844).

Figure 4 presents the ROC curves and AUCs of the indices for NAFLD in patients who were ~ 20, ~ 40 and ~ 60 years old. For all three age groups, BMI and WC were both in the top three indices for predictive ability. AVI had the greatest AUC in the ~ 20 years age group (AUC = 0.892) and the ~ 40 years age group (AUC = 0.831), while TyG had a higher AUC than AVI in the ~ 60 years age group (AUC = 0.757). In addition, DBP, TC, LDL and ABSI in subjects aged ~ 60 had no significant predictive ability ($P > 0.05$).

Discussion

This cross-sectional study comprehensively evaluated the predictive ability and cutoff value of obesity-related anthropometric and metabolic indices to identify NAFL D and found that BMI had the greatest AUC among all

Table 1 Demographic, anthropometric, and metabolic characteristics of the study participants

Characteristics	All (n = 1748)			Male (n = 1153)			Female (n = 595)		
	FL (+)	FL (−)	P-Value	FL (+)	FL (−)	P-Value	FL (+)	FL (−)	P-Value
n (%)	526 (30.09%)	1222 (69.91%)	< 0.01	464 (26.54%)	689 (39.42%)	< 0.01	62 (3.55%)	533 (30.49%)	< 0.01
Age (years)	46 (38, 57)	43 (34, 55)	< 0.01	45 (38, 56)	46 (36, 58)	0.368	55 (42, 65)	40 (33, 51)	< 0.01
SBP (mmHg)	130 (119, 144)	120 (108, 133)	< 0.01	130 (119, 143)	124 (114, 137)	< 0.01	132 (118, 151)	113 (104, 127)	< 0.01
DBP (mmHg)	80 (72, 87)	73 (65, 81)	< 0.01	80 (72, 88)	76 (68, 83)	< 0.01	77 (71, 84)	69 (62, 77)	< 0.01
FBG (mmol/l)	5.47 (5.07, 6.33)	5.10 (4.81, 5.46)	< 0.01	5.47 (5.07, 6.36)	5.17 (4.86, 5.58)	< 0.01	5.49 (5.15, 6.18)	5.02 (4.76, 5.33)	< 0.01
TC (mmol/l)	5.17 (4.54, 5.82)	4.89 (4.30, 5.54)	< 0.01	5.13 (4.53, 5.79)	4.90 (4.34, 5.62)	< 0.01	5.41 (4.61, 6.14)	4.89 (4.25, 5.47)	< 0.01
TG (mmol/l)	2.03 (1.41, 2.79)	1.11 (0.82, 1.57)	< 0.01	2.08 (1.46, 2.82)	1.21 (0.92, 1.74)	< 0.01	1.68 (1.35, 2.54)	0.96 (0.73, 1.33)	< 0.01
LDL (mmol/l)	3.26 (2.87, 3.75)	3.00 (2.54, 3.46)	< 0.01	3.24 (2.86, 3.67)	3.05 (2.63, 3.55)	< 0.01	3.43 (2.88, 3.92)	2.94 (2.47, 3.36)	< 0.01
WC (cm)	92.9 (88.0, 99.1)	82.0 (76.5, 87.8)	< 0.01	94.0 (88.6, 99.7)	84.2 (78.8, 90.1)	< 0.01	88.9 (85.6, 93.4)	78.8 (74.1, 84.0)	< 0.01
ABSI	0.081 (0.079, 0.083)	0.080 (0.078, 0.082)	< 0.01	0.081 (0.079, 0.083)	0.080 (0.077, 0.082)	< 0.01	0.081 (0.079, 0.083)	0.081 (0.079, 0.082)	0.334
AIP	0.59 (0.13, 0.98)	−0.18 (−0.56, 0.22)	< 0.01	0.63 (0.16, 0.99)	−0.03 (−0.037, 0.039)	< 0.01	0.33 (− 0.01, 0.72)	− 0.42 (− 0.76, 0)	< 0.01
AVI	17.3 (15.5, 19.7)	13.5 (11.8, 15.5)	< 0.01	17.7 (15.8, 19.9)	14.3 (12.5, 16.3)	< 0.01	15.8 (14.7, 17.4)	12.5 (11.1, 14.2)	< 0.01
BAI	27.3 (25.5, 20.3)	25.5 (23.8, 27.3)	< 0.01	27.0 (25.3, 28.9)	24.6 (22.9, 26.3)	< 0.01	29.8 (27.9, 31.9)	26.7 (24.8, 28.5)	< 0.01
BMI	26.5 (24.6, 28.5)	22.7 (20.5, 24.5)	< 0.01	26.7 (24.7, 28.6)	23.4 (21.5, 24.9)	< 0.01	25.5 (23.9, 26.9)	21.6 (19.9, 23.5)	< 0.01
BRI	4.36 (3.77, 5.00)	3.22 (2.72, 3.84)	< 0.01	4.32 (3.73, 5.00)	3.24 (2.75, 3.84)	< 0.01	4.52 (4.11, 5.01)	21.6 (19.9, 23.5)	< 0.01
CI	1.28 (1.25, 1.31)	1.23 (1.20, 1.27)	< 0.01	1.27 (1.24, 1.32)	1.23 (1.20, 1.27)	< 0.01	1.28 (1.25, 1.31)	1.23 (1.21, 1.26)	< 0.01
TyG	4.90 (4.71, 5.10)	4.56 (4.40, 4.75)	< 0.01	4.92 (4.72, 5.11)	4.62 (4.47, 4.81)	< 0.01	4.83 (4.66, 5.09)	4.47 (4.32, 4.67)	< 0.01
WHR	0.93 (0.90, 0.96)	0.88 (0.85, 0.91)	< 0.01	0.93 (0.90, 0.96)	0.88 (0.85, 0.92)	< 0.01	0.93 (0.90, 0.95)	0.87 (0.84, 0.90)	< 0.01
WHtR	0.55 (0.52, 0.58)	0.49 (0.46, 0.53)	< 0.01	0.55 (0.52, 0.58)	0.49 (0.47, 0.53)	< 0.01	0.56 (0.54, 0.58)	0.49 (0.46, 0.53)	< 0.01

Table 2 ORs for NAFLD stratified by quartiles of each index

Variables	Constant	Q1	Q2		Q3		Q4		*P*
	B	OR (CI)	B	OR (CI)	B	OR (CI)	B	OR (CI)	
Crude model									
SBP (mmHg)	−1.91	1	0.99	2.69 (1.91, 3.79) **	1.33	3.79 (2.71, 5.29) **	1.68	5.38 (3.86, 7.50) **	< 0.01
DBP (mmHg)	−1.75	1	0.79	2.21 (1.59, 3.08) **	1.06	2.90 (2.09, 4.01) **	1.60	4.97 (3.61, 6.85) **	< 0.01
FBG (mmol/l)	−1.55	1	0.29	1.34 (0.96, 1.86)	0.66	1.92 (1.40, 2.66) **	1.64	5.12 (3.77, 6.98) **	< 0.01
TC (mmol/l)	−1.23	1	0.28	1.32 (0.97, 1.79)	0.54	1.71 (1.27, 2.31) **	0.70	2.01 (1.50, 2.71) **	< 0.01
TG (mmol/l)	−2.66	1	1.15	3.15 (2.01, 4.94) **	2.04	7.68 (5.02, 11.74) **	3.13	22.94 (15.02, 35.02) **	< 0.01
LDL (mmol/l)	−1.49	1	0.61	1.84 (1.34, 2.52) **	0.80	2.22 (1.62, 3.03) **	1.07	2.92 (2.15, 3.98) **	< 0.01
WC (cm)	−3.67	1	1.74	5.71 (2.95, 11.08) **	3.26	25.92 (13.83, 18.58) **	4.31	74.21 (39.52, 139.35) **	< 0.01
ABSI	−1.24	1	0.36	1.43 (1.06, 1.94) *	0.46	1.58 (1.17, 2.14) **	0.71	2.03 (1.51, 2.74) **	< 0.01
AIP	−3.12	1	1.61	5.00 (2.97, 8.41) **	2.56	12.87 (7.81, 21.21) **	3.64	38.23 (23.21, 62.96) **	< 0.01
AVI	−3.66	1	1.76	5.82 (3.00, 11.27) **	3.25	25.68 (13.70, 48.14) **	4.28	72.53 (38.63, 136.19) **	< 0.01
BAI	−2.02	1	0.97	2.64 (1.84, 3.79) **	1.40	4.04 (2.84, 5.74) **	1.95	7.00 (4.95, 9.91) **	< 0.01
BMI	−4.12	1	2.55	12.79 (5.82, 28.09) **	3.45	31.50 (14.55, 68.20) **	4.89	132.37 (61.07, 286.93) **	< 0.01
BRI	−3.34	1	1.78	5.92 (3.35, 10.49) **	2.75	15.62 (9.00, 27.10) **	3.91	49.68 (28.64, 86.17) **	< 0.01
CI	−2.22	1	0.69	1.98 (1.30, 3.03) **	1.67	5.30 (3.52, 7.98) **	2.40	11.02 (7.34, 16.53) **	< 0.01
TyG	−2.85	1	1.32	3.72 (2.34, 6.00) **	2.30	9.97 (6.37, 15.62) **	3.38	29.45 (18.81, 46.14) **	< 0.01
WHR	−2.54	1	1.20	3.31 (2.23, 4.95) **	2.37	10.66 (7.17, 15.86) **	2.81	16.55 (11.29, 24.24) **	< 0.01
WHtR	−3.82	1	1.81	6.12 (3.54, 10.56) **	2.90	18.17 (10.64, 31.02) **	3.95	51.95 (30.14, 89.54) **	< 0.01
After adjusting gender and age									
SBP (mmHg)	−2.55	1	0.72	2.06 (1.44, 2.94) **	1.03	2.80 (1.97, 3.97) **	1.42	4.14 (2.85, 6.00) **	< 0.01
DBP (mmHg)	−2.70	1	0.61	1.85 (1.31, 2.60) **	0.77	2.16 (1.53, 3.04) **	3.36	2.39 (2.39, 4.72) **	< 0.01
FBG (mmol/l)	−2.26	1	0.30	1.35 (0.95, 1.91)	0.63	1.88 (1.34, 2.64) **	1.62	5.04 (3.56, 7.13) **	< 0.01
TC (mmol/l)	−2.80	1	0.22	1.24 (0.90, 1.71)	0.58	1.79 (1.31, 2.46) **	0.65	1.92 (1.40, 2.62) **	< 0.01
TG (mmol/l)	−3.60	1	0.92	2.52 (1.59, 3.98) **	1.77	5.89 (3.82, 9.09) **	2.79	16.32 (10.59, 25.15) **	< 0.01
LDL (mmol/l)	−3.01	1	0.52	1.68 (1.21, 2.35) **	0.75	2.11 (1.52, 2.92) **	0.93	2.53 (1.84, 3.50) **	< 0.01
WC (cm)	−5.15	1	1.62	5.01 (2.57, 9.78) **	3.05	21.17 (11.20, 40.01) **	4.06	58.17 (30.57, 110.66) **	< 0.01
ABSI	−3.27	1	0.64	1.89 (1.37, 2.62) **	0.76	2.13 (1.54, 2.95) **	1.01	2.74 (1.99, 3.76) **	< 0.01
AIP	−3.90	1	1.37	3.92 (2.31, 6.64) **	2.24	9.41 (5.66, 15.63) **	3.24	25.45 (15.32, 42.29) **	< 0.01
AVI	−5.16	1	1.63	5.09 (2.61, 9.91) **	3.04	20.93 (11.07, 39.58) **	4.04	57.04 (29.97, 108.56) **	< 0.01
BAI	−4.06	1	1.18	3.26 (2.25, 4.74) **	1.86	6.40 (4.41, 9.28) **	2.77	15.97 (10.80, 23.62) **	< 0.01
BMI	−5.28	1	2.33	10.23 (4.64, 22.58) **	3.12	22.74 (10.45, 49.49) **	4.56	95.98 (44.06, 209.10) **	< 0.01
BRI	−4.93	1	1.70	5.49 (3.08, 9.80) **	2.64	14.00 (8.00, 24.47) **	3.92	50.41 (28.71, 88.53) **	< 0.01
CI	−4.21	1	0.90	2.47 (1.59, 3.83) **	1.83	6.25 (4.08, 9.57) **	2.50	12.21 (7.99, 18.67) **	< 0.01
TyG	−3.39	1	1.09	2.97 (1.84, 4.80) **	2.06	7.83 (4.95, 12.39) **	3.05	21.07 (13.27, 33.46) **	< 0.01
WHR	−4.03	1	1.14	3.13 (2.08, 4.71) **	2.27	9.66 (6.41, 14.55) **	2.64	14.07 (9.50, 20.84)	< 0.01
WHtR	−4.84	1	1.73	5.88 (3.26, 9.85) **	2.83	16.88 (9.80, 29.07) **	3.95	51.69 (29.60, 60.25)	< 0.01

* *P*-value < 0.05. ** *P*-value < 0.01

participants. Additionally, sex- and age-specific indices for predicting NAFLD existed.

Age and sex might be critical factors affecting the prevalence of NAFLD [3, 4, 11]. This study found that men had a similar prevalence of NAFLD regardless of age, whereas it increased steadily with age in women. This is also consistent with a previous finding that aging is a risk factor for NAFLD in Japanese women, independent of weight gain or the influence of metabolic syndrome [31]. The increased prevalence of NAFLD with age for females might be associated with alterations in sex hormones postmenopause. Visceral adiposity may be caused by the loss of estrogen after menopause, which may lead to extensive changes in the metabolic

Table 3 AUC, Youden index, sensitivity, specificity and cut-off point of clinical parameters and obesity-related indices for predicting NAFLD

	AUC (95% CI)	Sensitivity (%)	Specificity (%)	Youden Index	Cut-off point
SBP	0.660 (0.634, 0.687) **	68.3	56.5	0.247	122.5
DBP	0.663 (0.636, 0.690) **	81.4	57.0	0.243	70.5
FBG	0.682 (0.654, 0.710) **	59.7	67.7	0.274	5.32
TC	0.581 (0.552, 0.610) **	65.6	47.7	0.132	4.82
TG	0.785 (0.762, 0.808) **	73.0	71.5	0.445	1.48
LDL	0.610 (0.582, 0.638) **	76.4	42.0	0.184	2.86
WC	0.836 (0.816, 0.855) **	87.5	66.1	0.536	85.3
ABSI	0.578 (0.549, 0.607) **	63.7	48.9	0.125	0.0799
AIP	0.804 (0.783, 0.825) **	80.8	65.4	0.462	0.045
AVI	0.836 (0.817, 0.855) **	87.5	66.0	0.535	14.6
BAI	0.691 (0.665, 0.717) **	64.8	64.0	0.288	26.4
BMI	0.841 (0.822, 0.860) **	71.3	80.1	0.521	24.9
BRI	0.817 (0.796, 0.837) **	78.3	70.1	0.485	3.67
CI	0.740 (0.715, 0.765) **	68.6	70.1	0.388	1.26
TyG	0.807 (0.785, 0.828) **	72.1	74.5	0.466	4.75
WHR	0.776 (0.754, 0.799) **	73.6	70.8	0.444	0.905
WHtR	0.815 (0.794, 0.836) **	78.7	69.1	0.478	0.515

* *P*-value < 0.05. ** *P*-value < 0.01

system. Generally, NAFLD is primarily considered a male disease; however, the alteration in sex hormone levels, specifically reduced estrogens and increased androgens during and after menopause, might play an important role in the emergence of NAFLD in female subjects [32, 33]. Investigators should also pay attention to NAFLD with increased age in Chinese females.

Epidemiological studies propose a causative link between obesity and progressive liver disease in individuals, and this association was observed at both the initial stages and severe stages of the disease [18, 34]. Pathophysiological and clinical studies have shown that an imbalance between lipid uptake and lipid utilization may eventually cause oxidative stress and hepatocyte injury

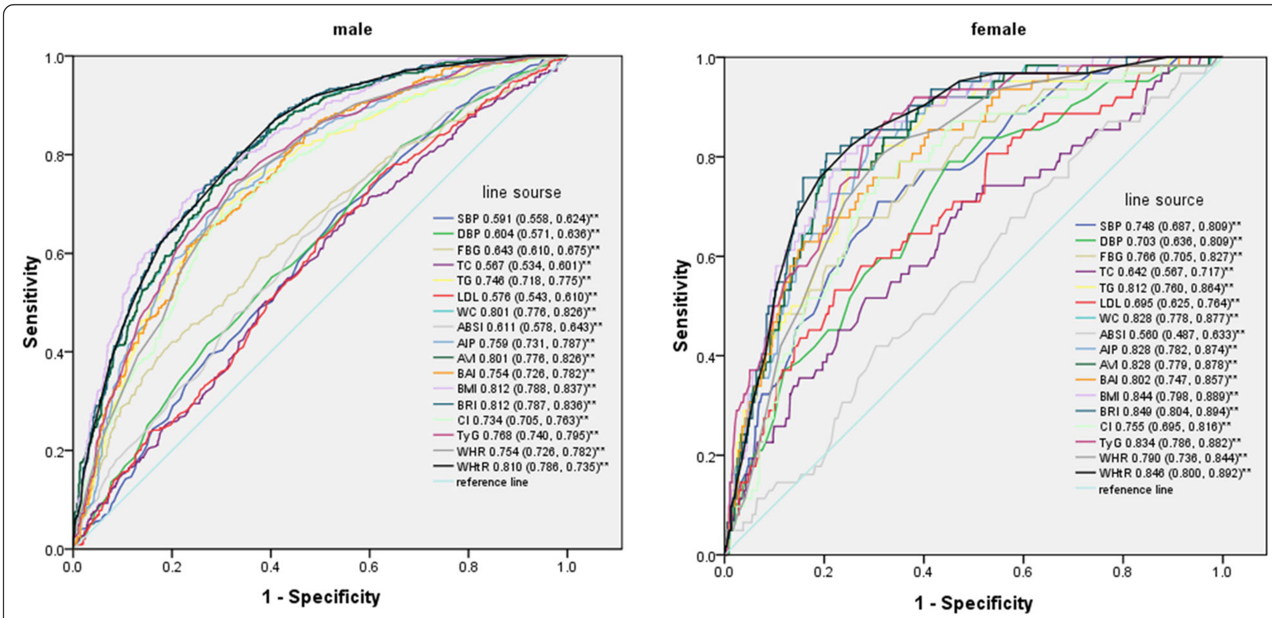

Fig. 3 Comparison of the predictive value of NAFLD-related parameters for diagnosis of NAFLD among males and females

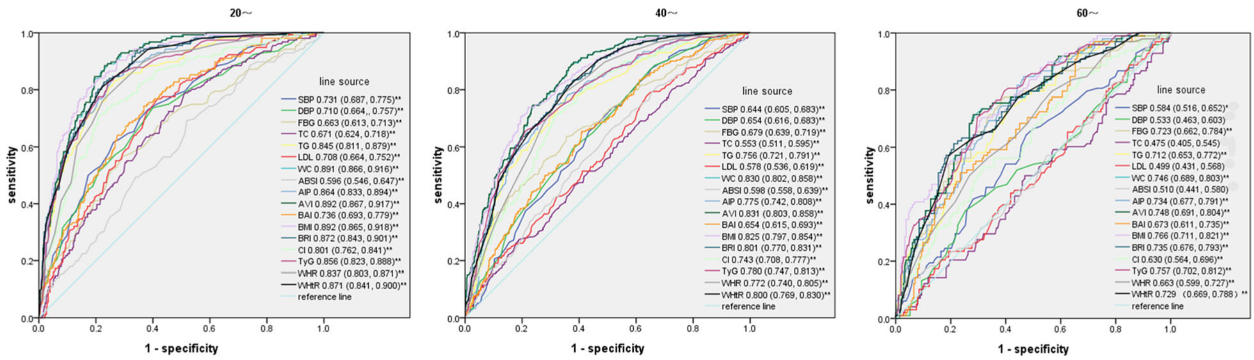

Fig. 4 Comparison of the predictive value of NAFLD-related parameters for diagnosis of FL among ~ 20, ~ 40 and ~ 60 years old

[35]. Some studies have suggested that visceral adiposity is the main adipose depot responsible for NAFLD, and visceral adiposity was associated with NAFLD in a dose-dependent manner in a cohort study [36]. WC, WHR, WHtR and BMI have been used in many clinical trials as indicators of the severity of fatty liver disease [21, 24]. The calculation of the ABSI considers the adjustment for height and WC compared with BMI [37]. AVI is used to assess general volume, and it has been highly associated with the dysfunction of glucose metabolism [38]. Increased AIP might be concordantly associated with the incidence of NAFLD [19, 20]. BAI is a better and more easily applicable measure for the determination of body fat than BMI, WHR, WHtR and WC in Turkish adults [39]. BRI was used to predict body fat and the percentage of visceral adipose tissue by Thomas et al. [40]. TyG is often used to explore the relationship between insulin resistance and excessive visceral fat accumulation [41, 42]. Additionally, accumulating evidence strongly suggests that advanced blood lipids, blood pressure and blood sugar could also lead to more severe histological changes and poorer clinical outcomes [17, 24, 43]. Furthermore, insulin resistance can promote the progression of NAFLD to a more severe state of liver endangerment, such as nonalcoholic steatohepatitis.

This study also revealed that BMI and BRI had a relatively high association with NAFLD and high diagnostic ability (0.812 in men and 0.849 in women) for NAFLD after considering the influence of sex. These results are also supported by research by Nima Motamed et al., which reported high AUCs for BRI and WHtR (0.85 in men and 0.86 in women) [44]. The subtle differences between the two studies may be due to the differences between Chinese and Iranian populations. The findings that AVI had the greatest AUC in the ~ 20 and ~ 40 age groups are concurrent with the study by Filippo Procino et al. They reported that AVI had a low false negative rate and high ability to identify NAFLD, and it should be mentioned that their research may be more helpful in NAFLD prediction for people in the 20–59 age range [45]. Diabetes is one of the strongest risk factors for NAFLD, and the increasing prevalence of diabetes with age, especially in female subjects [15, 46]. These findings may explain the result that AVI had the greatest AUC in the ~ 20 and ~ 40 years old age groups, while TyG had a higher AUC than AVI in the ~ 60 years old age group.

Strengths and limitations of the study

One of the biggest strengths of this study is that almost all obesity-related anthropometric and metabolic indices were included in this study to be comprehensively evaluated by sex and age. Although the association between these obesity-related indices and NAFLD has been analyzed separately in many articles, few articles have combined them for evaluation, especially in a Chinese population.

However, there are still some limitations. First, this is a cross-sectional study. Second, the data of other confounders, such as smoking and drinking status and exercise, were not included in the analysis because this information was not available. Third, ultrasonography diagnosis is a fast, reliable, reproducible and invasive method compared with liver biopsy, but it is unable to adequately determine the levels of steatosis and fibrosis.

Conclusion

This study found sex- and age-specific indices for predicting NAFLD in Chinese subjects. For the population as a whole, BMI might be the best predictor for NAFLD, followed by WC and AVI. When stratified by sex, BRI and BMI might both be the best predictors for NAFLD in males, and BRI was suitable for predicting NAFLD in females. Considering age, AVI had the greatest AUC for those aged 20–60 years, while TyG had the higher predictive ability in those ~ 60 years old. Compared with indices for all age groups, sex- and age-specific indices can provide more accurate assistance for clinical diagnosis and treatment. In addition, clues of disease cause can be found by comparing sex- and age-specific indices.

Abbreviations

NAFLD: Non-alcoholic Fatty Liver Disease; SBP: Systolic Blood Pressure; DBP: Diastolic Blood Pressure; FBG: Fasting Blood Glucose; TC: Total Cholesterol; TG: Triglyceride; LDL: Low Density Lipoprotein; WC: Waist Circumference; ABSI: A Body Shape Index; AIP: Atherogenic Index of Plasma; AVI: Abdominal Volume Index; BAI: Body Adiposity Index; BMI: Body Mass Index; BRI: Body Roundness Index; CI: Conicity Index; TyG: Triglyceride Glucose; WHR: Waist–hip Ratio; WHtR: Waist-to-Height Ratio; OR: Odds Ratio; ROC: Receiver Operating Characteristic; AUC: Areas Under Curve

Supplementary Information

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Additional file 1.

Additional file 2.

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Not applicable.

Authors' contributions

XFF contributed to the study planning and design, data collection and manuscript writing and revision. PYY contributed to the study planning and design, data collection, analysis and interpretation. ZQ contributed to data collection, analysis and interpretation. WY and CDL contributed to ethics applications and organisational collaborations. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets generated and analysed during the current study are not publicly available due personal privacy but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The was approved by the ethical committee of the Affiliated Suzhou Hospital of Nanjing Medical University (KL9011 study 12). Subjects agreed to participate into the present study and had provided a written informed consent.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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