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Triglyceride-glucose index is independently associated with fatty pancreas disease in Chinese elderly

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Abstract

Objective To determine the prevalence of fatty pancreas disease (FPD) diagnosed by transabdominal ultrasound in Chinese elderly aged 65 years and above to explore the correlation between triglyceride glucose index (TyG index) and FPD and its severity, and to evaluate the ability of TyG index to identify FPD and its severity.

Methods The study population was derived from the Thyroid Diseases in Older Population: Screening, Surveillance, and Intervention (TOPS) study conducted in the iodine-adapted areas of Jiangsu Province from May to July 2021. A total of 567 participants aged 65 years and above in rural areas were included in the final analysis. TyG index was calculated by the established formula: Ln [TG (mg/dL) × FBG (mg/dL)/2]. FPD and the degree of intra-pancreatic fat deposition (IPFD) were diagnosed by abdominal ultrasound. The logistic regression model was performed to determine the correlation between clinical parameters, including TyG index, and FPD and its severity. The diagnostic power of TyG index was assessed by receiver operating characteristic curve (ROC).

Results Overall, 72.66% (412/567) of subjects had FPD, of which over half had moderate to severe FPD. The proportions of overweight, obesity, NAFLD, and dyslipidemia were significantly higher in the moderate-to-severe FPD group than in the mild FPD group. Multivariate logistic regression showed that TyG index was independently associated with FPD in the elderly population, but was not significantly associated with the severity of IPFD. As the level of TyG index increased, the metabolic disorders in the population worsened and the prevalence of FPD increased significantly. TyG index had a good diagnostic performance for FPD. The combination of BMI or NAFLD and TyG index improved the diagnostic ability for FPD.

Conclusion The prevalence of FPD diagnosed by abdominal ultrasound is high in the elderly aged 65 years and above in rural areas in China. TyG index has good identification of FPD but poor recognition of the severity of IPFD. TyG index, when combined with other clinical parameters, may have more diagnostic advantages.

Keywords Triglyceride-glucose index, Elderly, Fatty pancreas disease

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Introduction

As the world's population ages, a variety of chronic diseases are gradually becoming the leading cause of disability and mortality in the elderly [1]. Aging increases the risk of many chronic diseases, including diabetes, cardiovascular disease, and metabolic syndrome [2]. Non-alcoholic fatty liver disease (NAFLD) is considered as a hepatic manifestation of metabolic syndrome, and its prevalence rises among the old population. Because of the close histological and embryological relationship between the liver and the pancreas, fat deposition in the pancreas has become a focus of research. The pancreas can contain small amounts of fat in healthy people, and the deposition of fat in the pancreas has recently been described as intrapancreatic fat deposition (IPFD). When IPFD exceeds the upper normal limit, the condition is known as fatty pancreas disease (FPD) [3].

The prevalence of FPD in adults usually ranges from 16 to 35%, with significant variations between age groups and comorbidities [4]. Previous studies have shown that patients with FPD have a significantly increased risk of metabolic diseases such as diabetes mellitus and metabolic syndrome, and are closely associated with the development and progression of cardiovascular diseases such as atherosclerosis. Furthermore, FPD may be associated with an increased risk of pancreatic cancer [5, 6]. Therefore, early identification and diagnosis of FPD in the elderly is of particular importance. Currently, transabdominal ultrasound (US), computer tomography (CT), magnetic resonance imaging (MRI), or endoscopic ultrasound (EUS) are the most common methods for diagnosing FPD in the clinic. These methods have certain limitations as well as variations in diagnostic sensitivity and accuracy [7]. Currently, MRI has good performance as a non-invasive tool for assessing IPFD [6, 8, 9], but the relatively high cost and the need for experienced operators make it less widely used than transabdominal ultrasound in primary care. Therefore, a reliable and cost-effective biomarker to diagnose FPD is still needed.

Fat deposition in the pancreas may be associated with β-cell dysfunction and insulin resistance. Previous population-based studies have found that pancreatic fat content is inversely related to insulin sensitivity. Among these, the index of insulin resistance (homeostasis model assessment-insulin resistance, HOMA-IR) was independently associated with FPD and tended to increase with the severity of FPD [10, 11]. However, assessment tools such as HOMA-IR are based on fasting plasma insulin and have some limitations in clinical practice. Recent studies have highlighted the triglyceride-glucose (TyG) index as a reliable alternative tool for assessing insulin resistance [12]. Several small studies have shown that TyG index has a good diagnostic performance for the prevalence of NAFLD and non-alcoholic steatohepatitis (NASH) in the general population and is positively correlated with the severity of hepatic steatosis and liver fibrosis in patients with NAFLD [13–15]. Therefore, we hypothesized that TyG index is related to the prevalence of FPD and has certain diagnostic performance for FPD. Thus, our study aimed to clarify the prevalence of FPD diagnosed by transabdominal ultrasound in the Chinese elderly population by conducting a cross-sectional study in two rural areas in China. We also aimed to investigate the correlation between TyG index and the prevalence and severity of FPD in the elderly population and to evaluate the diagnostic value of TyG index in identifying FPD and its severity.

Materials and methods

Study population

The participants of this cross-sectional study were selected from the Thyroid Diseases in Older Population: Screening, Surveillance, and Intervention (TOPS) study, a population-based study of thyroid disorders in the elderly population in iodine-adapted areas of Jiangsu Province, which aimed to establish age-specific thyroid-stimulating hormone (TSH) reference ranges among people aged ≥ 65 years and observe the natural history of subclinical hypothyroidism (SCH) [16–18]. It was approved by the Ethics Committee of Affiliated Hospital of Integrated Traditional Chinese and Western Medicine, Nanjing University of Chinese Medicine. A total of 2460 participants aged ≥ 65 years were recruited using cluster sampling. Exclusion criteria included severe organic diseases, psychiatric disorders, and impaired cognition and communication. The baseline assessment was conducted from May 2021 to July 2021. All procedures were performed under the relevant guidelines and regulations. An informed consent was also required from the participants.

An adequate sample size of 299 was calculated by Epi Info (the software was developed by the Centers for Disease Control and Prevention, available via the link https://www.cdc.gov/epiinfo/index.html.), based on the estimates of the target population ($n = 2460$), expected prevalence (33%), statistic corresponding to confidence level (95% CI) and allowable absolute deviation (5%) [19, 20]. Finally, we used cluster-stratified random sampling from July 2022 to September 2023 in both Suqian and Xuzhou. We selected the top 4 communities based on the population size of the residents and stratified by age and sex to select 1000 older adults to participate in the FPD assessment. A total of 881 older adults aged ≥ 65 years finally agreed to participate in this study, with a response rate of 88.10%. The study was approved by the Ethics Committee of Affiliated Hospital of Integrated Traditional Chinese and Western Medicine, Nanjing University of Chinese Medicine. All methods were performed in accordance

with the relevant guidelines and regulations. All participants signed the informed consent.

Participants were excluded if they had cardiac, pulmonary, and renal insufficiency; had infections or malignant tumors; consumed excessive alcohol (>210 g of alcohol per week for men and >140 g per week for women) [21]; had chronic pancreatic or hepatic disease; had undergone liver or pancreatic partial resection; had language, cognitive, hearing impairments, or psychiatric disorders. Finally, 567 eligible participants were enrolled in our study (Fig. 1).

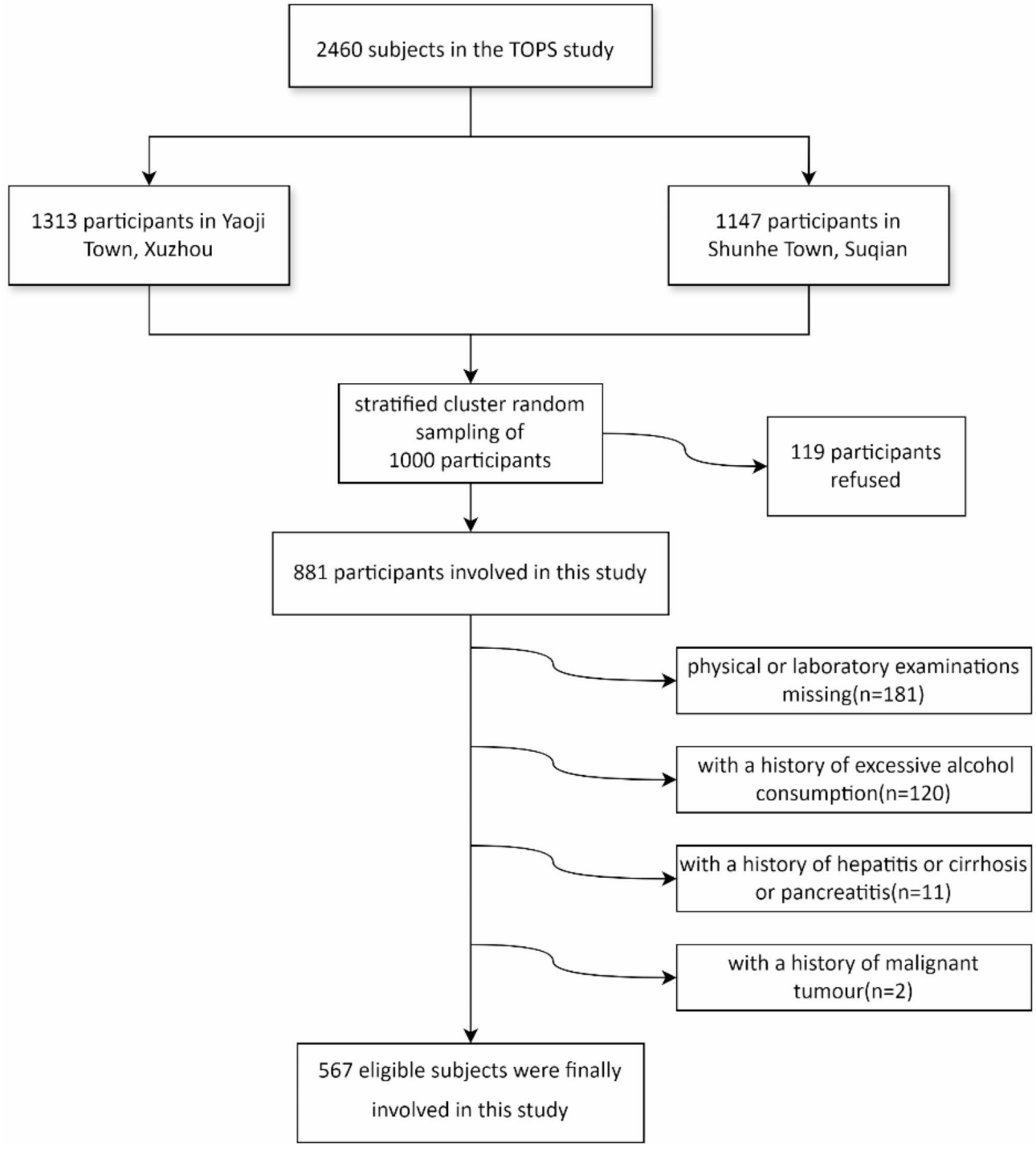

Fig. 1 Flow chart of the study

Data collection and measurement of biochemical and metabolic index

All participants were given a questionnaire and physical examinations. Clinical data including age, gender, height, weight, blood pressure, medical history (thyroid, diabetes, hypertension, dyslipidemia, etc.) and medication history were recorded.

After an overnight fasting, 10 ml of venous blood of each participant was collected between 8 a.m. and 10 a.m. The supernatant serum sample obtained by a 15-minute centrifugation at 1500×g was stored at -80 °C and sent for testing in the Laboratory of the Affiliated Hospital of Integrated Traditional Chinese and Western Medicine, Nanjing University of Chinese Medicine. Total cholesterol (TC), triglyceride (TG), high-density lipoprotein cholesterol (HDL-C), low-density lipoprotein cholesterol (LDL-C) and fasting blood glucose (FBG) were measured by Swiss Roche Cobas 702 biochemical analyzer via colorimetric method. Serum free triiodothyronine (FT3), free thyroxine (FT4), and TSH were measured by Swiss Roche Cobas 601 biochemical analyzer via electrochemiluminescence method.

NAFLD and FPD were evaluated using the Hivision Preirus color Doppler ultrasound diagnostic device manufactured by Hitachi, Japan. During the abdominal examination, a convex array probe with a frequency of 1–5 MHz was used, and the preset abdominal mode of the device was selected to comprehensively scan the liver and pancreas, and ultrasound images were recorded. Participants were in the supine position with the abdomen fully exposed for the examination. Echo intensity, edges, and posterior echogenic changes of the pancreas and liver were assessed and recorded by two experienced sonographers. The decision was made after discussion in case of disagreement.

Diagnostic criteria

NAFLD was defined as abnormal accumulation of hepatic fat on ultrasound images after excluding excessive alcohol consumption (≤ 210 g per week for men and ≤ 140 g per week for women), chronic liver disease, drug use, or hereditary disorders. The degree of hepatic steatosis was graded as mild, moderate, or severe based on liver echogenicity and the visualization of the diaphragm and intrahepatic vessels [22, 23]. Similarly, FPD was graded by comparing pancreatic echogenicity to renal and retroperitoneal fat echogenicity, with mild, moderate, and severe levels corresponding to progressively higher pancreatic echogenicity based on the literature [24].

TyG index = Ln [TG (mg/dL) × FBG (mg/dL)/2] [25]. The formula used for converting mmol/L to mg/dL is as follows: for FBG, 1 mmol/L = 18 mg/dL; for TG, 1 mmol/L = 88.5 mg/dL [26].

Other clinical parameters

In our center, the laboratory reference ranges for TSH, FT3 and FT4 are 0.27–4.20 mIU/mL, 3.1–6.8 pmol/L and 12.0–22.0 pmol/L, respectively. Subclinical hypothyroidism was defined as TSH > 4.2 mIU/mL with FT4 levels within the normal range, whereas overt hypothyroidism was defined as TSH > 4.2 mIU/mL with FT4 levels below the lower limit of the normal range. Both conditions were termed as hypothyroidism in the present study. Hyperthyroidism was defined as TSH < 0.27mIU/mL with both FT3 and FT4 levels above the upper limit of the normal range.

Dyslipidemia was defined according to the Chinese guideline for the management of dyslipidemia in adults [27]: TC ≥ 5.2 mmol/L and/or TG ≥ 1.7 mmol/L and/or LDL-c ≥ 3.4 mmol/L and/or HDL-c < 1.0 mmol/L and/or use of lipid-lowering medication.

Body mass index (BMI) = weight (kg)/height2 (m2). Participants were categorized according to BMI into underweight (BMI < 18.5 kg/m2), normal weight (BMI: 18.5–23.9 kg/m2), overweight (BMI: 24.0–27.9 kg/m2), and obesity ranges (BMI ≥ 28.0 kg/m2) [28].

Hypertension was defined as systolic blood pressure (SBP) ≥ 140 mmHg and/or diastolic blood pressure (DBP) ≥ 90 mmHg and/or use of antihypertensive medication [29].

Statistical analysis

Statistical processing was performed using SPSS 26.0 (IBM Corporation, Armonk, NY, USA) and R 4.3.2 software. The Kolmogorov-Smirnov test was applied to examine the normality. Normally distributed measurement data were expressed as mean ± standard deviation ($\bar{x}$ ± SD), and differences were analyzed by the Student's *t*-test or ANOVA; otherwise, they were expressed as the median (interquartile range [IQR]), and differences were analyzed by the Mann-Whitney U test or Kruskal-Wallis.

Binary logistic regression models were constructed to examine the association of demographic and clinical parameters, including TyG index, with the presence and severity of FPD. To determine which factors were independently associated with FPD, in addition to potential confounders selected based on clinical applicability, non-collinear factors associated at $P < 0.05$ in univariate analysis were proposed in the multivariable logistic regression model. (VIF ≤ 10 as a non-collinear diagnostic criterion for the variables). The conditional (ENTER method) logistic regression models were used to improve the accuracy of the analysis. Receiver operating characteristic (ROC) curve analysis and area under the curve (AUC) were used to evaluate the diagnostic performance of TyG index for.

FPD and its severity. To further compare the diagnostic performance of different parameters, the area under the curve was compared using the DeLong method to determine whether the combination of other parameters provided a more significant diagnostic advantage than TyG index alone. We further performed sensitivity analyses. With the collection of the subjects' medication by questionnaire, we repeated the analyses after excluding individuals taking either glucose-lowering or lipid-lowering medication. All statistical tests were two-tailed and statistically significant at $P<0.05$.

Results

Baseline characteristics of participants

The mean age of 567 analyzed participants was 73.39 ± 5.14 years and 54.85% (311/567) were female. Among them, 25.75% (146/567) of subjects had NAFLD and 72.66% (412/567) had FPD. Participants were divided into two groups according to whether they had FPD or not. Those with FPD had significantly higher body weight, BMI, SBP, DBP, FBG, TG, and TyG index, and lower HDL-C than those without FPD (all $P<0.05$) (Table 1). Furthermore, the proportion of subjects with NAFLD, hypertension, and dyslipidemia was significantly higher in the FPD group than in the non-FPD group (all $P<0.05$). The majority of participants in two groups had normal thyroid function, with no significant differences in FT3, FT4 and TSH levels or in the proportion of abnormal thyroid function. Smoking and alcohol consumption were similar as well.

Table 1 Demographic and clinical characteristics of the study participants

	Overall (567)	FPD (*n* = 412)	Non-FPD (*n* = 155)	*P* value
Age(yr)	73.39 ± 5.14	73.48 ± 5.13	73.17 ± 5.17	0.487
Female(%)	311(54.85)	235(57.03)	76(49.03)	0.088
Height(kg)	156.26 ± 8.85	156.38 ± 8.56	155.95 ± 9.61	0.758
Weigth(cm)	61.37 ± 10.61	63.31 ± 10.68	56.21 ± 8.53	<0.001
BMI(kg/m^2)	25.11 ± 3.71	25.86 ± 3.65	23.14 ± 3.09	<0.001
Normal weight(%)	194(34.21)	111(26.94)	83(53.55)	<0.001
Over weight(%)	250(44.09)	195(47.33)	55(35.48)	
Obesity(%)	108(19.05)	99(24.03)	9(5.81)	
SBP(mmHg)	145.40 ± 23.31	146.85 ± 23.59	141.53 ± 22.15	0.029
DBP(mmHg)	83.37 ± 11.48	83.97 ± 11.62	81.75 ± 10.99	0.040
FT3(pmol/L)	5.06 ± 0.90	5.02 ± 0.63	5.17 ± 1.37	0.548
FT4 pmol/L	17.58 ± 2.45	17.59 ± 2.45	17.55 ± 2.46	0.616
TSH(mIU/ml)	2.62(1.76–3.84)	2.59(1.78–3.84)	2.66(1.61–3.86)	0.897
Hypothyroidism(%)	106(18.69)	79(19.17)	27(17.42)	0.464
Hyperthyroidism(%)	2(0.35)	2(0.49)	0(0)	
Euthyroid(%)	459(80.95)	331(80.33)	128(82.58)	
FBG(mmol/L)	5.25(4.77–5.90)	5.37(4.89–6.13)	4.99(4.52–5.44)	<0.001
TC(mmol/L)	4.72(4.06–5.39)	4.75(4.05–5.43)	4.69(4.09–5.32)	0.477
TG(mmol/L)	1.20(0.87–1.66)	1.33(0.97–1.75)	0.95(0.76–1.30)	<0.001
HDL-C(mmol/L)	1.28(1.08–1.51)	1.26(1.04–1.45)	1.36(1.18–1.66)	<0.001
LDL-C(mmol/L)	2.72(2.10–3.25)	2.75(2.08–3.29)	2.61(2.17–3.16)	0.434
TyG index	6.98 ± 0.61	7.09 ± 0.61	6.68 ± 0.49	<0.001
NAFLD(%)	146(25.75)	139(33.74)	7(4.52)	<0.001
Hypertension(%)	382(67.37)	289(70.15)	93(60.00)	0.022
Dyslipidemia(%)	334(58.91)	257(62.37)	77(49.68)	0.006
Non-smokers(%)	451(79.54)	332(80.58)	119(76.77)	0.603
Current smokers(%)	78(13.76)	54(13.11)	24(15.48)	
Ex-smokers(%)	38(6.70)	26(6.31)	12(7.74)	
Non-drinkers(%)	503(88.71)	371(90.05)	132(85.16)	0.151
Occasional drinkers(%)	33(5.82)	23(5.58)	10(6.45)	
Ex-drinkers(%)	31(5.47)	18(4.37)	13(8.39)	

BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; TSH, thyroid-stimulating hormone; FT3, free triiodothyronine; FT4, free thyroxine; SCH, subclinical hypothyroidism; FBG, fasting blood glucose; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; TC, total cholesterol; TG, triglyceride; TyG, triglyceride-glucose; FPD, fatty pancreas disease; NAFLD, non-alcoholic fatty liver disease

Clinical characteristics of participants with different degrees of IPFD

To further compare clinical characteristics, participants with fatty pancreas were divided into mild FPD group ($n = 180$) and moderate-to-severe FPD group ($n = 232$). As shown in Table 2, participants in the moderate-to-severe FPD group had significantly higher weight, BMI, SBP, DBP, TG, TyG index, and lower HDL-C compared with those in the mild FPD group (all $P < 0.05$). The proportions of overweight, obesity ($P < 0.001$), and hypertension ($P = 0.044$) were significantly higher in the moderate-to-severe FPD group than in the mild FPD group. However, there was no significant difference in the proportion of dyslipidemia between the two groups.

Correlation of TyG index with FPD and its severity

Binary logistic regression analysis was performed to determine the association between clinical parameters, including TyG index, and FPD (Table 3). Univariate analysis showed that BMI, SBP, DBP, FBG, TG, HDL-C, TyG index and NAFLD were significantly associated with FPD (all $P < 0.05$). After adjustment for potential confounders, TyG index remained independently associated with FPD (OR 2.096, 95%CI 1.403–3.134, $P < 0.001$).

The correlation between TyG index and FPD severity was further analyzed (Table 4). In the univariate model, TyG index was significantly correlated with the degree of IPFD ($P = 0.023$). The association was no longer found in the multivariate model ($P = 0.652$). In contrast, age (OR 1.075, 95% CI 1.030–1.122, $P = 0.001$), BMI (OR 1.213, 95% CI 1.126–1.307, $P < 0.001$), DBP (OR 1.027, 95% CI 1.008–1.047, $P = 0.006$) and NAFLD (OR 1.637, 95% CI 1.004–2.672, $P = 0.001$) were still positively associated with IPFD.

To further verify whether there was a threshold effect for the association of TyG index with FPD and its severity, multivariate logistic regression was performed after grouping participants according to TyG index tertiles. Compared with the lowest TyG index tertile group, higher levels of TyG index tertiles were significantly associated with FPD after adjustment for relevant confounders (tertile 2: OR 1.993, 95%CI 1.247–3.186, $P = 0.004$;

Table 2 Demographic and clinical characteristics of participants with mild FPD and moderate to severe FPD

	Mild FPD ($n = 180$)	Moderate to severe FPD ($n = 232$)	*P* value
Age(yr)	72.92 ± 4.82	73.91 ± 5.34	0.076
Female(%)	105(58.33)	130(56.03)	0.640
Height(kg)	155.83 ± 8.47	156.80 ± 8.62	0.185
Weigth(cm)	59.62 ± 9.66	66.18 ± 10.56	<0.001
BMI(kg/m^2)	24.57 ± 3.77	26.85 ± 3.24	<0.001
Normal weight(%)	74(41.11)	38(16.38)	<0.001
Over weight(%)	77(42.78)	118(50.86)	
Obesity(%)	24(13.33)	75(32.33)	
SBP(mmHg)	143.95 ± 24.84	149.11 ± 22.36	0.047
DBP(mmHg)	81.77 ± 11.19	85.68 ± 11.68	0.003
FBG(mmol/L)	5.33(4.79–6.09)	5.43(4.95–6.23)	0.360
TC(mmol/L)	4.81(4.04–5.43)	4.72(4.05–5.43)	0.597
TG(mmol/L)	1.26(0.89–1.61)	1.39(1.07–1.86)	0.003
HDL-C(mmol/L)	1.30(1.11–1.53)	1.20(0.99–1.40)	<0.001
LDL-C(mmol/L)	2.84(2.11–3.33)	2.66(2.06–3.25)	0.204
TyG index	7.02 ± 0.58	7.15 ± 0.62	0.013
Hypertension(%)	117(65.00)	172(74.14)	0.044
Non-NAFLD(%)	139(77.22)	134(57.76)	<0.001
Mild NAFLD(%)	36(20.00)	57(24.57)	
Moderate to severe NAFLD(%)	5(2.78)	41(17.67)	
Dyslipidemia(%)	104(57.78)	153(65.95)	0.090
Non-smokers(%)	145(80.56)	187(80.60)	0.267
Current smokers(%)	27(15.00)	27(11.64)	
Ex-smokers(%)	8(4.44)	18(7.76)	
Non-drinkers(%)	164(91.11)	207(89.22)	0.138
Occasional drinkers(%)	6(3.33)	17(7.33)	
Ex-drinkers(%)	10(5.56)	8(3.45)	

BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; FBG, fasting blood glucose; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; TC, total cholesterol; TG, triglyceride; TyG index, triglyceride-glucose index; FPD, fatty pancreas disease; NAFLD, non-alcoholic fatty liver disease

Table 3 Univariate and multivariate analyses of factors associated with FPD

	Univariate model		Multivariable model	
	OR(95%CI)	***P* value**	**OR(95%CI)**	***P* value**
Age	1.012(0.976–1.049)	0.522	1.042(0.998–1.087)	0.061
Female	Reference			
Male	0.725(0.50-1.049)	0.088	0.925(0.599–1.430)	0.727
BMI	1.285(1.204–1.373)	<0.001	1.188(1.108–1.273)	<0.001
SBP	1.010(1.002–1.018)	0.016	1.004(0.992–1.016)	0.496
DBP	1.017(1.001–1.034)	0.041	0.999(0.976–1.022)	0.928
FBG	1.487(1.259–1.756)	<0.001	1.387(0.974–1.974)	0.069
TC	1.095(0.926–1.296)	0.288		
TG	3.351(2.225-5. 047)	<0.001	2.166(0.575–8.157)	0.253
HDL-C	0.290(0.175–0.481)	<0.001	0.532(0.290–0.976)	0.042
LDL-C	1.074(0.873–1.320)	0.501	1.083(0.837–1.402)	0.545
TyG index	3.591(2.484–5.190)	<0.001	2.096(1.403–3.134)	<0.001
NAFLD	10.765(4.909–23.605)	<0.001	4.148(1.794–9.588)	0.001
Non-smokers	Reference			
Current smoker	0.806(0.477–1.363)	0.422		
Ex-smokers	0.777(0.380–1.588)	0.488		
Non-drinkers	Reference			
Occasional drinkers	0.818(0.379–1.765)	0.609		
Ex-drinkers	0.493(0.235–1.033)	0.061		

Variables included in the multivariate model were non-collinear factors (VIF ≤ 10) associated in univariate analysis at $P < 0.05$, that was age, sex, BMI, SBP, DBP, TG, HDL-C, LDL-C, FBG, TyG index and NAFLD

OR, odds ratio; CI, confidence interval; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; FBG, fasting blood glucose; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; TC, total cholesterol; TG, triglyceride; TyG index, triglyceride-glucose index; FPD, fatty pancreas disease; NAFLD, non-alcoholic fatty liver disease

Table 4 Univariate and multivariate analyses of factors associated with the severity of FPD patients

	Univariate model		Multivariable model	
	OR(95%CI)	***P* value**	**OR(95%CI)**	***P* value**
Age	1.039(1.00-1.080)	0.051	1.075(1.030–1.122)	0.001
Female	Reference			
Male	1.098(0.741–1.628)	0.640	1.262(0.799–1.993)	0.318
BMI	1.231(1.151–1.317)	<0.001	1.213(1.126–1.307)	<0.001
SBP	1.010(1.001–1.018)	0.029	1.000(0.988–1.011)	0.963
DBP	1.031(1.013–1.049)	0.001	1.027(1.008–1.047)	0.006
FBG	0.965(0.879–1.060)	0.459	0.912(0.745–1.118)	0.376
TC	0.948(0.798–1.125)	0.541		
TG	1.564(1.178–2.076)	0.002	1.028(0.475–2.222)	0.944
HDL-C	0.317(0.172–0.582)	<0.001	0.666(0.318–1.392)	0.279
LDL-C	0.857(0.693–1.059)	0.153	0.936(0.728–1.202)	0.603
TyG index	1.464(1.053–2.035)	0.023	1.306(0.409–4.174)	0.652
NAFLD	2.479(1.605–3.831)	<0.001	1.637(1.004–2.672)	0.048
Non-smokers	Reference			
Current smoker	0.775(0.436–1.379)	0.387		
Ex-smokers	1.745(0.738–4.125)	0.205		
Non-drinkers	Reference			
Occasional drinkers	2.245(0.866–5.822)	0.096		
Ex-drinkers	0.634(0.245–1.642)	0.348		

Variables included in the multivariate model were non-collinear factors (VIF ≤ 10) associated in univariate analysis at $P < 0.05$, that was age, sex, BMI, SBP, DBP, TG, HDL-C, LDL-C, FBG, TyG index and NAFLD

OR, odds ratio; CI, confidence interval; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; FBG, fasting blood glucose; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; TC, total cholesterol; TG, triglyceride; TyG index, triglyceride-glucose index; FPD, fatty pancreas disease; NAFLD, non-alcoholic fatty liver disease

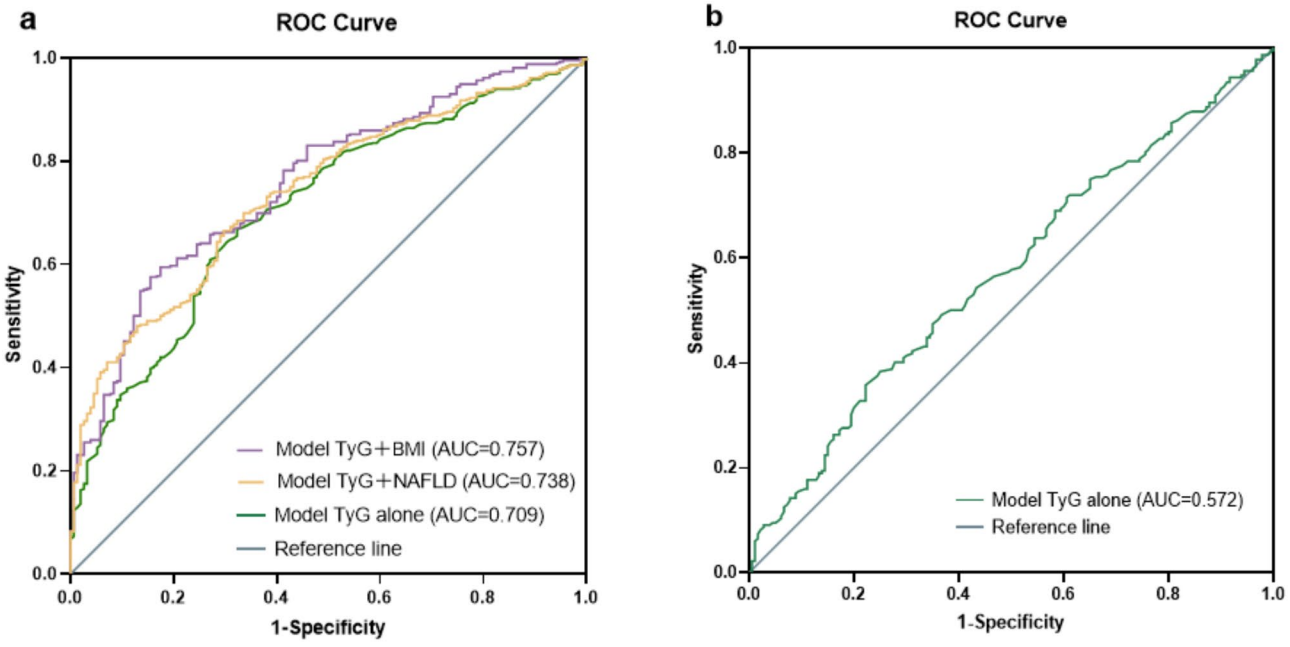

Fig. 2 ROC curve analyses of FPD and its severity. (**a**) ROC curve analysis of TyG index for FPD; (**b**) ROC curve analysis of TyG index for the severity of FPD. AUC, area under the curve; BMI, body mass index; TyG, triglyceride-glucose; NAFLD, non-alcoholic fatty liver disease; FPD, fatty pancreas disease

tertile 3: OR 2.668, 95%CI 1.514-4.700, $P = 0.001$), while no association was found with the degree of IPFD (tertile 2: OR 0.820, 95%CI 0.436–1.543, $P = 0.539$; tertile 3: OR 0.823, 95%CI 0.328–2.067, $P = 0.679$; Supplementary Tables 1–2).

Characteristics of participants in different TyG index tertiles

The study participants were divided into three groups according to TyG index tertiles and whether they had FPD (tertile 1: $n = 195$, TyG index ≤ 6.74; tertile 2: $n = 184$, $6.74 <$ TyG index ≤ 7.22; tertile 3: $n = 188$, TyG index > 7.22). Participants with FPD at different TyG index levels had higher body weight, BMI, and proportion of NAFLD than those without FPD. However, differences in lipids between FPD participants and non-FPD participants were found only in the lowest tertile group (Supplementary Table 5, all $P < 0.05$).

ROC curve analysis of TyG index for FPD and its severity

According to ROC curve analysis, TyG index had a good diagnostic performance for FPD with AUC value of 0.709 (95% CI, 0.662 to 0.755, $P < 0.001$). The critical value of TyG index was calculated based on the maximum value of the Yoden index as 6.84, with a sensitivity of 67.2% and a specificity of 67.7% (Fig. 2a). Nevertheless, TyG index may not be reliable in identifying the severity of IPFD (AUC = 0.572, 95% CI, 0.516–0.627, $P = 0.013$, Fig. 2b).

ROC curves were constructed for the combined variables as only BMI, NAFLD and TyG index were significantly associated with FPD in the multivariate model. The results showed that combining TyG index with BMI or NAFLD had higher sensitivity and specificity than TyG index alone (Fig. 2a). The AUC of BMI combined with TyG index was 0.757 (95% CI, 0.715-0.800, $P < 0.001$), and that of NAFLD combined with TyG index was 0.738 (95% CI, 0.695–0.781, $P < 0.001$). There was no significant difference between the two AUCs ($P = 0.260$), but both were significantly higher than that of TyG index alone (BMI + TyG index vs. TyG index, $P = 0.008$; NAFLD + TyG index vs. TyG index, $P = 0.022$).

Sensitivity analysis

A questionnaire on current medication use was administered to the study participants and of the 567 individuals who were finally included in the analysis, a total of 86 were recorded as using either glucose-lowering or lipid-lowering medication. Correlation analysis between TyG index and FPD was performed again on the remaining 481 individuals and found that the main results remained similar when individuals using medication were excluded from the dataset. In other words, TyG index was independently associated with FPD but was not significantly associated with the severity of IPFD (Supplementary Tables 3–4).

Discussion

In this cross-sectional study of rural elderly aged 65 years and above, the prevalence of FPD diagnosed by transabdominal ultrasound was as high as 72.66%, of which more than half were classified as moderate to severe FPD. With the onset and progression of IPFD, the population

suffered from aggravated glucose and lipid metabolism disorders, with progressively higher rates of overweight, obesity and comorbidities such as NAFLD. TyG index was independently associated with the development of FPD in the elderly population but had no significant association with the severity of IPFD. TyG index has a good ability to detect FPD and its diagnostic performance for the disease can be improved in combination with BMI or NAFLD.

The clinical diagnosis of FPD has gradually advanced with the maturation of diagnostic imaging techniques. Clinicians commonly assess pancreatic fat accumulation using non-invasive imaging tools. Transabdominal ultrasound, which has been used repeatedly in large population-based cohort studies [30, 31], is one of the most common diagnostic tools. Meta-analysis has shown that the prevalence of FPD in the general adult population is approximately 33% (95% confidence interval 24-41%), and the prevalence of IPFD varies widely by race, age group, and comorbidities [32]. Previous population studies have shown that high BMI, insulin resistance, metabolic syndrome, and hepatic steatosis are all associated with increased pancreatic adiposity [4]. Wu and Wang et al. have also reported that FPD is more likely to occur in older populations with higher BMI and more severe glucose and lipid disorders [33]. More than 70% of the participants in our study were diagnosed with FPD by abdominal ultrasound, which is significantly higher than in previous studies. The characteristics of our study population may explain this. The overall BMI of the participants in our study was high (mean 25.11 ± 3.71 kg/m^2). More than half of these older adults had overweight, obesity, or dyslipidemia. Furthermore, Saisho et al. assessed pancreatic volume by CT in humans from birth to 100 years and found that total and parenchymal pancreatic volume gradually decreases with age in adults over 60, whereas pancreatic fat gradually increases [34]. The participants in our study were older (73.39 ± 5.14 years), which may also explain the high prevalence of FPD in our study.

Insulin resistance is thought to be involved in the pathogenesis of many metabolic and cardiovascular diseases, including diabetes, coronary heart disease and heart failure [35]. The hyperinsulinemic-euglycemic clamp (HIEC) test is the gold standard for measuring IR, but the method is expensive and time-consuming, so it is not widely used in clinical practice. TyG index, based on fasting glucose and triglycerides, serves as a comprehensive assessment that is inexpensive, easy to popularize, and unaffected by statin lipid-lowering medications [15]. Guerrero-Romero et al. first demonstrated that TyG index strongly correlates with HIEC and can be used to identify insulin resistance in subjects with varying degrees of glucose tolerance and body weight [36]. TyG index also performs well in predicting metabolic diseases in the general adult population. Meta-analysis studies have found a positive correlation between TyG index and an increased risk of hypertension, atherosclerotic heart disease, and coronary heart disease in the population [37, 38]. In addition, TyG index is an important indicator for assessing the risk and prognosis of diabetes, heart failure and stroke in different populations [39, 40]. FPD is considered potentially associated with diabetes and insulin resistance. In the present study, TyG index was independently and positively correlated with FPD, and the prevalence of FPD increased significantly as TyG index level increased. ROC curve analysis further confirmed the good ability of TyG index to identify patients with FPD.

Although studies on TyG index and FPD are limited, Xiao et al. confirmed the high diagnostic value of TyG for the identification of FPD through a cross-sectional study. They pointed out that the combination of multiple parameters has a better predictive effect than a single parameter [41], which is consistent with the results of this study. Our study showed a significant increase in the diagnostic performance of TyG index in combination with BMI or NAFLD. Multivariate logistic regression also showed that in addition to TyG, BMI and NAFLD were positively correlated with FPD. Previous studies in large-sample populations have found that NAFLD is closely associated with the development of IPFD and is an independent risk factor for the deterioration of FPD [31, 42]. Therefore, this also suggests the need for early screening for FPD in the clinic for those who are obese or have NAFLD.

However, our study failed to find a correlation between TyG index and the degree of IPFD. This is similar to the findings of Fedchuk et al., who found that TyG index had poor specificity as a predictive marker of hepatic steatosis and was unable to differentiate between mild, moderate, and severe steatosis. The association of TyG index with hepatic steatosis was weakened by the significant effect of hepatic inflammation and fibrosis [43]. Whether this effect also weakened the ability of TyG index to recognize the degree of IPFD is currently unknown, and further studies are needed.

Our study showed no significant differences in gender between FPD and non-FPD groups. This was consistent with previous studies showing that there is a significant gender difference in adults with FPD younger than 55 years, which disappears with increasing age [31].In addition, the prevalence of NAFLD in our study was 25.75%, which was similar to the same type of study [44]. Approximately 90% of patients with NAFLD had FPD, and the percentage was significantly lower in participants without NAFLD ($P < 0.001$). This finding is similar to previous studies and suggests that individuals with NAFLD should be screened for fatty pancreas [45]. However,

a lower proportion of FPD patients in our study were found to have NAFLD, which may be due to the difference in fatty infiltration in different organs. The previous study showed that triglycerides in the liver are mainly deposited intracellularly, whereas the pancreas is directly infiltrated by adipocytes. Triglycerides accounted for 47% of total lipids in the normal human pancreas, making the pancreas more susceptible to fat deposition than the liver [46, 47]. In addition, dietary structure plays an important role in the pathogenesis of FPD, and a chronic high-fat diet results in fat accumulation in pancreatic acinar cells, which in turn triggers pancreatic fat deposition [48]. The sources of pancreatic fat are also more diverse, with circulating free fatty acids, dietary fat and de novo fat all contributing to fat deposition [49]. Therefore, the heterogeneity of fat sources and deposition may explain the lower proportion of NAFLD in patients with FPD in our study, although we did not record the dietary composition of our population.

Strengths and limitations

The strength of our study was that we selected rural Chinese elderly aged 65 years and above to assess the spectrum of FPD at this particular physiological stage. TyG index, which is easily accessible in primary care settings, was also chosen as a marker. In addition, to improve diagnostic accuracy and reduce internal heterogeneity, imaging examinations of FPD were performed by two experienced specialists and decisions were made after discussion when opinions differed. Although TyG index was not associated with the severity of FPD in this study, it was independently associated with FPD, which may be useful to help primary care physicians with limited resources to screen high-risk older adults for FPD as early as possible and provide the necessary early intervention. Meanwhile, the devices and indicators we used are relatively inexpensive, which is more conducive to promoting early screening for FPD at the primary health center and reducing the healthcare burden.

Several limitations in our study should be admitted. First, a cross-sectional study is not sufficient to clarify the causal relationship between TyG index and FPD. Second, the diagnosis of FPD was made by transabdominal ultrasound, which is widely used in clinical practice and is quick to perform. However, ultrasound is not sensitive enough compared to MRI, the non-invasive gold standard for quantifying IPFD, the objective criteria for quantifying images have not yet been standardized, and the sensitivity and specificity are largely dependent on the operator and participants which will somewhat limit the extrapolability of our findings. Third, the sample size of our study was relatively small, which affected and limited the validity of our statistical analyses and analytical methods. Fourth, we didn't evaluate the glycemic and insulin resistance of the population in the region and the association between FPD and insulin and diabetes because the glycated hemoglobin and fasting insulin levels were not measured. Also, other confounders such as diet and physical activity on the correlation between TyG index and FPD were not evaluated in this study. The results of the study were also limited by age and geography. Finally, we could not deny any possibility of selective bias although we used the cluster-stratified random sampling method in our study population. In the future, we will try to recruit a more diverse population to minimize study bias and increase the reliability and extrapolation of the results.

Conclusions

In conclusion, the prevalence of FPD diagnosed by abdominal ultrasound was high among Chinese elderly aged 65 years and above in rural areas. TyG index was significantly positively associated with FPD, but not significantly related to the progression of IPFD. Moreover, TyG index has good diagnostic performance for FPD and may have more diagnostic advantages when combined with other clinical parameters.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12902-025-01900-9.

Supplementary Material 1

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Author contributions

Weinuo Mi, Xingjia Li, Chao Liu and Shuhang Xu were responsible for the overall design; Yuzhi Zhang and Wenbo Ding performed ultrasound examination and analyzed related data; Weinuo Mi, Xingjia Li, Qifeng Wang, Xiaodong Mao, Shuhang Xu were responsible for field investigation; Xingjia Li and Yu Sun were responsible for data collection; Weinuo Mi was responsible for statistical analysis and manuscript drafting; Xingjia Li and Shuhang Xu revised the manuscript.

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Data availability

The datasets generated and analyzed in the present study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of Affiliated Hospital of Integrated Traditional Chinese and Western Medicine, Nanjing University of Chinese Medicine (2023-LWKYZ-027). Written informed consent was obtained from parents of the participants.

Consent for publication
Not applicable.

Clinical trial number
Not applicable.

Competing interests
The authors declare no competing interests.

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